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**CLINICAL AND IMAGING FEATURES OF THE LUMBAR SPINE IN ELITE  
MALE SCHOOLBOY CRICKETERS: THE EFFECT OF A PRE-SEASON  
LUMBAR STABILISATION INTERVENTION**

BY

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**DECLARATION**

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## **TERMS AND DEFINITIONS**

The following list contains useful terms and definitions for concepts presented in this thesis.

### **Fast bowler:**

*Bowler who either opens the bowling or bowls first change and delivers the ball at a fast velocity*

### **Spin bowler:**

*A bowler who bowls off only a few steps and delivers the ball at a slower speed and spins the ball in the air and on the ground*

### **Batsman:**

*A cricketer who is a specialised batsman either opening the batting for his team or batting up until number 5 in the batting order.*

### **Cricketing discipline:**

*Fast bowler, spin bowler or batsman*

### **Front foot impact:**

*When the fast bowler's front foot impacts the ground during delivery of the ball*

### **Back foot impact:**

*When the fast bowler's back foot impacts the ground during delivery of the ball*

### **Delivery stride:**

*From back foot to front foot impact when delivering the ball*

### **Run-up:**

*The number of steps the fast or spin bowler takes to reach back foot impact and the start of the delivery stride*

### **Overs:**

*Six consecutive ball deliveries make up one over in cricket. During a match a bowler will bowl a number of overs.*

**Shoulder counter-rotation:**

*The realignment of the shoulders in the transverse plane during the delivery stride in fast bowling. Initially the fast bowler rotates his shoulders towards the facing batsmen (maximum shoulder angle) and then subsequently rotates his shoulders away from the facing batsman (minimum shoulder angle). The difference (in degrees) between the maximum and minimum shoulder angles is known as shoulder counter-rotation.*

**Pre-season:**

*The few months preceding the cricket season, usually from July to October in the Southern Hemisphere*

**In-season:**

*The summer months in which cricket is played, this is usually from October to April in the Southern Hemisphere*

**Post-season:**

*The winter months following the cricket season. This is usually from April to July in the Southern Hemisphere and is known also as the off-season when cricket is not played.*

**Dominant :**

*The side of the body with which the bowler or batsman 'favours' to bowl or to bat with. In other words, if a bowler or batsman bowls or bats right-handed, their right side will be their dominant side.*

**Non-dominant:**

*The limb that is not the dominant side. In other words, if the bowler or batsman is right dominant then the left side will be the non-dominant side.*

**Muscle asymmetry:**

*When there are differences between the dominant and non-dominant sides in the specific abdominal and lumbar muscles*

**Morphometry:**

*Measurement of resting and change in thickness of the abdominal musculature and resting cross-sectional area of the lumbar musculature*

**Occurrence:**

*The number of times or percentage that something occurs*

**Anthropometry:**

*Body composition measurements, such as, height, weight, body fat percentage, muscle mass, fat mass.*

**Current pain:**

*The pain reported by the players on commencement of the study*

**Previous pain:**

*The pain reported by the players that was experienced in the 2 years preceding the study.*

**Injury:**

*Perceived pain reported by the cricketers*

**Total abdominal wall muscle thickness:**

*Combined muscle thickness measurements of the three abdominal muscles (external and internal oblique and transverse abdominis)*

**Absolute muscle thickness:**

*Resting 'raw' measurements (mm)*

**Relative muscle thickness:**

*Individual muscle thickness as a percentage of the total muscle thickness (%)*

**Percentage difference:**

*Difference between the dominant and non-dominant sides, with the non-dominant side expressed as a percentage of the dominant side*

**Abdominal hollowing:**

*Contraction of the lower abdominal wall to isolate the contraction of the transverse abdominis muscle from the internal and external oblique muscles*

**Muscle function:**

*Change in muscle thickness from rest to contraction during abdominal hollowing*

**Muscle hypertrophy:**

*Increase in muscle size due to the accumulation of muscle protein from either protein synthesis or a reduction in protein degradation*

**T1- & T2-weighted sequence:**

*The net magnetization vector on MRI has two components. The longitudinal magnetization is due to an excess of protons in the lower energy state. This gives the net polarization parallel to the external field. The transverse magnetization is due to coherences forming between the two proton energy states. This gives a net polarization perpendicular to external field in the transverse plane. The recovery of longitudinal magnetization is called T1 relaxation and the loss of phase coherence in the transverse plane is called T2 relaxation.*

**Sagittal:**

*Posterior image of the lumbar spine taken in the vertical plane*

**Axial:**

*Image of the lumbar spine taken in the horizontal plane in order to view the nerve root compressions in cross-section and measure the cross-sectional area of the lumbar muscles*

**Score:**

*Grade of severity of pathology: for example normal = a score of 0, grade I = a score of 1, grade II = a score of 2, grade III = a score of 3*

**Positive clinical test:**

*Pain experienced by the subject during clinical examination*

**Inter-observer:**

*Analysis between different observers performed once*

**Intra-observer:**

*Analysis performed more than once, on separated occasions, by the same observer*

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**LIST OF ABBREVIATIONS**

<b>CSA</b>	Cross-sectional area (cm <sup>2</sup> )
<b>TrA</b>	Transverse abdominis
<b>OI</b>	Internal oblique
<b>OE</b>	External oblique
<b>QL</b>	Quadratus lumborum
<b>DOM</b>	Dominant
<b>ND</b>	Non-dominant
<b>LBP</b>	Lower back pain
<b>NLBP</b>	No lower back pain
<b>MRI</b>	Magnetic resonance imaging
<b>SCR</b>	Shoulder counter-rotation (°)
<b>EMG</b>	Electromyographic
<b>MVC</b>	Maximal voluntary contraction
<b>ANOVA</b>	Analysis of variance
<b>PRE-INT</b>	Pre-intervention
<b>POST-INT</b>	Post-intervention
<b>POST-SEAS</b>	Post-season
<b>BFI</b>	Back foot impact
<b>FFI</b>	Front foot impact
<b>BR</b>	Ball release
<b>BMI</b>	Body mass index
<b>DESS</b>	Dual echo steady state
<b>STIR</b>	Short tau inversion recovery
<b>T<sub>12</sub></b>	The 12 <sup>th</sup> thoracic vertebral level
<b>L<sub>1</sub></b>	The 1 <sup>st</sup> lumbar vertebral level
<b>L<sub>2</sub></b>	The 2 <sup>nd</sup> lumbar vertebral level
<b>L<sub>3</sub></b>	The 3 <sup>rd</sup> lumbar vertebral level
<b>L<sub>4</sub></b>	The 4 <sup>th</sup> lumbar vertebral level
<b>L<sub>5</sub></b>	The 5 <sup>th</sup> lumbar vertebral level
<b>SLHR</b>	Single leg hyperextension rotation test

**ABSTRACT****OBJECTIVES**

Current evidence indicates that schoolboy cricketers are at a high risk of injury to the lumbar spine. This is particularly relevant in the case of fast bowlers who bowl with a high degree of shoulder counter-rotation. There, however, is a lack of evidence in the literature with respect to injury research of all cricketing disciplines, as fast bowlers receive the most attention. After reviewing the literature it was evident that the effect of a cricket-specific lumbar stabilisation exercise intervention in an attempt to reduce lower back pain and alter other physiological variables, had never been studied. Previous interventions in cricketers have focused only on fast bowlers in an attempt to decrease the degree of shoulder counter-rotation. However, these studies either took two years to observe a decrease or were unsuccessful.

Therefore, the primary objective of this thesis, using a randomized controlled trial design, was to investigate the effect of a pre-season cricket specific progressive lumbar stabilisation intervention and its subsequent in-season maintenance on morphometric changes to the abdominal and lumbar musculature, clinical findings, imaging features as determined using MRI in a group of male schoolboy cricketers, and changes in shoulder counter-rotation in schoolboy fast bowlers.

**Chapter 3**

The aim of Chapter 3 was to assess the occurrence of self-reported lower back pain that was both present on entering the study and experienced in the years preceding the study, in a group of male schoolboy cricketers. In this chapter the researchers also investigated the effect of a pre-season cricket-specific progressive lumbar stabilisation intervention on the subsequent occurrence or resolution of lower back pain in this group of cricketers. Furthermore, the access to medical care within this group of cricketers was also assessed in this chapter.

**Chapter 4**

The aim of Chapter 4 was to assess the morphometry of the lateral abdominal and posterior lumbar musculature in elite schoolboy cricketers with and without lower back

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pain. This chapter was structured to provide insight into the thickness of the abdominal musculature and cross-sectional area of the posterior musculature across all the cricketing disciplines. Furthermore, the relationship between abdominal and lumbar morphometry and lower back pain was investigated.

### **Chapter 5**

The aim of Chapter 5 was to assess the effect of the pre-season cricket-specific progressive lumbar stabilisation intervention on changes in lateral abdominal muscle thickness and posterior lumbar muscle cross-sectional area. Changes in muscle morphometry were assessed in the combined group of cricketers, by cricketing discipline and with respect to change in lower back pain status during the intervention, in both the intervention and control groups,.

### **Chapter 6**

In Chapter 6 the development of a new MRI scoring system for disc and bony pathology of the lumbar spine was described. The aim of this chapter was also to assess the inter- and intra-observer reliability of this new classification system with respect to disc and bony pathology at the individual intervertebral levels. Furthermore this chapter laid the foundation for the calculation of a total pathology score to determine the overall severity of the pathology of the lumbar spine on MRI assessment of these cricketers. The scoring system was to be subsequently used in the latter chapters.

### **Chapter 7**

The aim of Chapter 7 was to assess baseline clinical signs and symptoms and MRI features of lumbar pathology in a group of elite male schoolboy cricketers. The baseline results were also used to determine whether the clinical and imaging features were specific to cricketing disciplines and to relate these changes to the presence or absence of lower back pain.

### **Chapter 8**

The aim of Chapter 8 was to investigate whether the cricket-specific lumbar stabilisation intervention had any influence on specific positive signs during clinical examination and lumbar pathology as assessed by MR imaging.

**Chapter 9**

The aim of Chapter 9 was to investigate the degree of shoulder counter-rotation in the group of elite schoolboy fast bowlers. The relationship between degree of shoulder counter-rotation and lateral abdominal and posterior lumbar muscle morphometry, clinical and imaging features of lumbar spine injury was also investigated. The degree of shoulder counter-rotation which is harmful, either being 20-40° or greater than 40° was further investigated.

**Chapter 10**

The aim of Chapter 10 was to assess the effect of the pre-season cricket-specific progressive lumbar stabilisation intervention on change in degree of shoulder counter-rotation and the subsequent maintenance thereof in these young fast bowlers.

**METHODS****Chapter 3**

This was a descriptive study of the occurrence of self-reported lower back pain and injury in elite male schoolboy cricketers. Forty-six cricketers, including fast bowlers, spin bowlers and batsmen who participated at either under 17 or under 19 levels with a mean age of  $16.6 \pm 0.8$  years were studied. Anthropometry, history of previous medical conditions and episodes of lower back pain as well as access to treatment was assessed by means of a questionnaire. This chapter also included a randomized controlled trial whereby all cricketers were divided into experimental (n=21) and control (n=18) groups to determine the effect of a lumbar stabilisation intervention on change in lower back pain status.

**Chapter 4**

This was a descriptive study investigating the lateral abdominal and posterior lumbar musculature of elite male schoolboy cricketers. 46 cricketers with and without self-reported lower back pain from under 17 and 19 age group levels were assessed. Information regarding bowling or batting dominance was obtained in order to assess symmetry. Cricketers were divided into cricketing disciplines and according to the lower back pain status. Lateral abdominal muscle thickness was measured using high resolution soft tissue ultrasound imaging to assess the resting thickness of the internal oblique, external oblique and transverse abdominis muscles. This technique was also

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used to assess change in muscle thickness of transverse abdominis and internal oblique during abdominal hollowing. This change in muscle thickness provides insight into the function of the transverse abdominis muscle which is suggested to be impaired in the presence of lower back pain. Posterior lumbar muscle cross-sectional area of psoas, quadratus lumborum, multifidus, longissimus and iliocostalis was measured at the 4<sup>th</sup> lumbar vertebral level using MR imaging.

### **Chapter 5**

This was a randomized controlled trial investigating the effect of a lumbar stabilisation intervention on the change in lateral abdominal and posterior lumbar morphometry in a group of elite male schoolboy cricketers. Thirty nine (39) cricketers from all disciplines with and without lower back pain were recruited from under 17 and 19 age group levels. Detail reporting on bowling or batting dominance was obtained in order to assess symmetry. Cricketers were randomized into intervention (n=21) and control (n=18) groups to assess the effect on the intervention program post-intervention and the effect of the maintenance program post-season. Change in absolute resting muscle thickness (mm), relative resting muscle thickness (%), percentage difference between dominant and non-dominant sides and change in lateral abdominal muscle thickness during abdominal hollowing were assessed over time. Furthermore change in individual lumbar muscle cross-sectional area was assessed following the intervention. The intervention and control groups were subdivided into cricketing disciplines and with respect to change in lower back pain status to assess the changes of the abovementioned variables during the intervention.

### **Chapter 6**

This part of the study involved the design of a semi-quantitative system for lumbar spinal segment pathology changes on MR imaging in elite, male, schoolboy cricketers. This new classification system of lumbar pathology seen on MR imaging studies was assessed to determine the reliability and repeatability of reporting pathology on MRI at specific intervertebral levels. Thirteen MRI scans were assessed by 5 radiologists to determine inter-observer reliability. One radiologist assessed the scans twice on different days to determine intra-observer reliability. Furthermore a total pathology score was calculated to indicate the overall severity of pathology in the lumbar spine.

**Chapter 7**

This was a descriptive study to assess the occurrence of pain during clinical examination and pathology on MR imaging of the lumbar spine in 45 male schoolboy cricketers with a mean age of  $16.7 \pm 0.8$  years. Baseline measures of these variables were determined to profile the total group of cricketers as well as by cricketing discipline and lower back pain status. Clinical examinations were performed by a medical professional. MRI scanning was performed to determine disc, bone, nerve and endplate pathology of the lumbar spine. The MRI scans were assessed by specialist radiologists, from the University of Stellenbosch, using the scoring system developed in Chapter 6.

**Chapter 8**

This was a randomized controlled trial to determine the effect of a lumbar stabilisation program on changes in clinical signs and symptoms and pathologic changes on MR imaging of the lumbar spine. Participants included 39 elite male schoolboy cricketers (mean age of  $16.7 \pm 0.8$  years) who were randomly divided into intervention ( $n=21$ ) and control ( $n=18$ ) groups. Cricketers were assessed to compare changes in the occurrence of positive clinical tests and pathology on MR imaging of the lumbar spine in the intervention and control groups during the intervention period. The intervention and control groups were subdivided into cricketing disciplines and with respect to change in lower back pain status to assess the changes of the abovementioned variables during the intervention.

**Chapter 9**

This was a descriptive study of 18 elite male schoolboy pace bowlers to assess their degree of shoulder counter-rotation. Shoulder counter-rotation was assessed by filming the fast bowlers from overhead and using SiliconCoach 2-dimensional analysis to analyse the maximum and minimum shoulder angles during the delivery stride (from back foot impact to front foot impact). The fast bowlers ( $n=17$ ) were then divided into bowlers who counter-rotated their shoulders between  $20^\circ$  and  $40^\circ$  ( $n=6$ ) and greater than  $40^\circ$  ( $n=11$ ). A bowler who counter-rotated his shoulders below  $20^\circ$  was not included in the analysis of the above two groups, hence only 17 fast bowlers were analysed. Self-reported lower back pain, abdominal muscle thickness both at rest and during abdominal hollowing, lumbar cross-sectional area, clinical signs and symptoms

and pathology seen on MR imaging of the lumbar spine was then assessed to determine differences in the two groups.

### **Chapter 10**

This was a randomized controlled trial to determine effect of a lumbar stabilisation program on change in shoulder counter-rotation of 15 elite, male, schoolboy fast bowlers. Fast bowlers were randomly divided into intervention (n=7) and control (n=8) groups to determine the effect of the intervention program. The fast bowlers were assessed at the end of the cricket season to determine whether any change occurred to shoulder counter-rotation during the 8-week intervention were maintained. The effect of the intervention was also assessed in these groups with respect to change in abdominal and lumbar muscle morphometry, occurrence of clinical signs and symptoms and lumbar pathology on MR imaging.

## **RESULTS AND DISCUSSION**

### **Chapter 3**

Adolescent schoolboy cricketers sustain a high occurrence of self-reported lower back pain. This finding was particularly demonstrated in the group of young fast bowlers. Spin bowlers and batsmen also sustain injuries resulting in lower back pain, however, the occurrence in these cricketing disciplines was less than in the fast bowlers. Furthermore, the majority of all injuries were sustained during cricket matches, particularly at the beginning and end of the cricket season. The implementation of a cricket-specific lumbar stabilisation program significantly decreased the occurrence of lower back pain. Importantly, the maintenance of the intervention program was shown to assist in preventing the recurrence of lower back pain when cricketers were tested at a 6-month follow-up. Compliance for both the 8-week intervention and maintenance periods was 71%. Two further findings of this chapter, were that the consensus definition of injury for cricketers needs to be redefined for this specific age group as schoolboy cricketers tend to play with pain and are unlikely to miss a match or practice session due to injury. Secondly, the failure to report and monitor their symptoms of pain or injury, as well as inadequate access to pain or injury management may increase the occurrence and progression of injury in this age group. Therefore, access to adequate injury management is important in reducing the occurrence and progression of injuries.

**Chapter 4**

Asymmetry in the lateral abdominal musculature indeed occurs in cricketers. This finding was demonstrated when combining all cricketing disciplines and found in the total abdominal wall muscle thickness and resting absolute internal oblique muscle thickness, with both being thicker on the non-dominant side. Furthermore, cricketers without lower back pain had asymmetry of the total abdominal wall muscle thickness and resting TrA muscle thickness with the non-dominant side being thicker. Cricketers without lower back pain also had less function of the OI and TrA muscles as measured by change in muscle thickness during abdominal hollowing, compared to those with lower back pain. Furthermore, fast bowlers specifically, demonstrated asymmetry of resting absolute internal oblique muscle thickness, with the non-dominant side being thicker than the dominant side. There was also asymmetry present in the posterior lumbar musculature in cricketers, specifically in the cross-sectional area of the longissimus muscle, where the dominant side was greater than the non-dominant side in the combined group of cricketers. However, there were no asymmetries demonstrated for the other lumbar muscles, which included psoas, quadratus lumborum, multifidus and iliocostalis. There were also no asymmetries in the lumbar muscles when separating the cricketers into cricketing discipline and with respect to the presence of absence of lower back pain. A further finding of this chapter was that, dominant quadratus lumborum was found to have a greater cross-sectional area in cricketers with lower back pain compared to those without lower back pain.

**Chapter 5**

A progressive, 8-week cricket-specific lumbar stabilisation intervention program is able to increase the total abdominal wall and internal oblique muscle thickness on the dominant side in combined cricketing disciplines. Furthermore, these increases in total wall and internal oblique muscle thickness on the dominant side assisted in decreasing the pre-intervention asymmetry in these muscles. Importantly, the 6-month in-season maintenance program was able to maintain these changes in muscle symmetry. The function of the TrA muscle did not appear to change with the implementation of a lumbar stabilisation intervention. There was also no change in abdominal muscle morphometry with respect to change in lower back pain status. Furthermore, there was no change in cross-sectional area of the individual lumbar musculature. This lack of change in lumbar muscle hypertrophy may require further research involving a

program of longer duration, more frequent exercise sessions with an increase in focus on sport-specific strengthening exercises.

### **Chapter 6**

The novel MRI scoring system was found to be reliable for both inter- and intra-observer agreement for pathology scored at various intervertebral disc levels and for different types of lumbar pathology. The small sample size, however, affected the ability to calculate the level of agreement for all types of pathology. Furthermore radiologists were able to reliably distinguish between severity of disc degeneration at the different lumbar intervertebral disc levels. A further finding of this chapter was that this new MRI scoring system is comprehensive since it assesses a variety of anatomical structures of the lumbar spine. Furthermore, it allows for the calculation of a total pathology score to assist in assessment of the overall severity of injury to the lumbar spine and evaluate the effects of an intervention on the pathological features described in the latter chapters of this thesis.

### **Chapter 7**

There is a high occurrence of positive clinical tests and pathology as seen on MRI of the lumbar spine. There were a high number of positive clinical tests demonstrated particularly among the fast bowlers and cricketers with lower back pain. The occurrence of disc degeneration in the lumbar spine of these cricketers is higher than reported in previous studies, with all cricketers in this study, independent of pain and cricketing discipline having a minimum of grade I disc degeneration. Fast bowlers, in particular, demonstrated the highest occurrence of more severe disc degeneration, whilst batsmen demonstrated the highest occurrence of endplate and nerve root pathology. Furthermore, there was no significant difference in total pathology score between cricketers with and without lower back pain. This finding indicates a dissociation between the occurrence of pathology in the lumbar spine and self-reported lower back pain in young cricketers. However, cricketers with a higher mean pathology score (> 10) appeared to have a greater occurrence of pain during clinical specific clinical tests.

### **Chapter 8**

There was little change in the frequency of pain elicited during clinical examination in the entire group of cricketers, when separated into cricketing disciplines or by change in lower back pain status as a result of the intervention program. Furthermore, there

was no change in total pathology score, change in percentage occurrence of disc, nerve and endplate pathology following the intervention period. Indeed, this was demonstrated in the entire group of cricketers, when separated into cricketing disciplines or by change in lower back pain status during the intervention period. Therefore, it is suggested that both the occurrence of positive clinical findings and pathology seen on MRI of the lumbar spine may take longer to regress following resolution of lower back pain with the aid of a lumbar stabilisation intervention. Furthermore, there is an apparent dissociation between self-reported lower back pain and pathological findings of an MRI of the lumbar spine. Even though symptoms of lower back pain resolve in some cricketers, there is still the presence of disc, nerve and endplate pathology detected on MR imaging.

### **Chapter 9**

The findings of this study are important, firstly as they show the high occurrence of shoulder counter-rotation above 40° in elite schoolboy fast bowlers. Secondly, fast bowlers with a shoulder counter-rotation above 40° also have a greater maximum shoulder angle at back foot impact compared to bowlers who counter-rotate their shoulders between 20° and 40°. Therefore, a greater maximum angle at back foot impact causes a high degree of shoulder counter-rotation during the delivery stride. There were no differences in resting abdominal muscle thickness and lumbar muscle cross-sectional area found between the fast bowlers with a shoulder counter-rotation greater than 40° and fast bowlers with a lower degree of shoulder counter-rotation. However, the fast bowlers with a shoulder counter-rotation of greater than 40° had lower transverse abdominis muscle function during abdominal hollowing compared to fast bowlers with a lower degree of shoulder counter-rotation. There also appears to be a possible relationship between a shoulder counter-rotation of greater than 40° and a greater frequency of pain during lumbar palpation and single leg hyperextension rotation tests. Importantly, there was no difference in total pathology score between bowlers who counter-rotated their shoulders above 40° or between 20° and 40°. The finding that young fast bowlers have a high occurrence of self-reported lower back pain and coupled with a high degree of shoulder counter-rotation indicates the need for the education and correction of their bowling technique and the implementation of successful injury prevention strategies for this age group.

**Chapter 10**

A cricket-specific progressive, lumbar stabilisation intervention program in schoolboy fast bowlers is effective in significantly decreasing the degree of shoulder counter-rotation. This decrease in shoulder counter-rotation appears to have occurred due to the significant decrease in the maximum shoulder angle at back foot impact. Importantly, the lumbar stabilisation intervention was successful in maintaining the decrease in the degree of shoulder counter-rotation in young fast bowlers at a 6-month follow-up. There was little change in abdominal and lumbar morphometry in the group of fast bowlers who decreased their shoulder counter-rotation. There was also little change in the occurrence of positive clinical tests following the intervention and subsequent decreased in shoulder counter-rotation. Furthermore, there was no change in the percentage occurrence of disc degeneration, disc tear, nerve root and endplate pathology as seen on MR imaging of the lumbar spine.

**CONCLUSION**

This thesis showed that there is a high occurrence of self-reported lower back pain in schoolboy cricketers across all cricketing disciplines, yet fast bowlers indeed had the highest occurrence of lower back pain. The occurrence of self-reported lower back pain decreased significantly following a lumbar stabilisation intervention. Furthermore, the decrease in the occurrence of self-reported lower back pain was maintained at a 6-month follow-up, indicating the importance of a maintenance phase during the intervention period. Importantly, the compliance for both the 8-week intervention and subsequent maintenance was 71%.

Cricketers had asymmetry of the total abdominal muscle wall and resting internal oblique muscle thickness with the non-dominant side being thicker, prior to the intervention. The intervention program increased the mean resting muscle thickness of the total abdominal wall and internal oblique muscle on the dominant side, thus these muscles appeared to become more symmetrical. The change in muscle thickness was maintained at a 6-month follow-up. Furthermore, the cricketers without lower back pain had asymmetry of the transverse abdominis muscle, with the non-dominant side being thicker. Thus there appears to be a pattern of abdominal muscle asymmetry in cricketers, with the non-dominant side being thicker than the dominant side.

There was a high occurrence of positive tests on clinical examination and pathology on MRI of the lumbar spine. An important pathological finding was that cricketers from all disciplines had disc degeneration at all lumbar intervertebral disc levels. However, the

intervention program had little effect on decreasing the occurrence of pain during clinical examination and pathology present on MR imaging of the lumbar spine.

Lastly, the assessment of the fast bowling technique indicated that the majority of the young fast bowlers bowled with greater than 40° shoulder counter-rotation. This appears to be due to the high degree of shoulder rotation demonstrated at back foot impact. There also appears to be a relationship between a shoulder counter-rotation of more than 40° and impaired transverse abdominis muscle function during abdominal hollowing. A further important finding was the successful reduction in the degree of shoulder counter-rotation during the 8-week intervention program and the subsequent maintenance thereof at a 6-month follow-up. Thus, a pre-season cricket-specific lumbar stabilisation intervention with subsequent maintenance appears to be beneficial for young adolescent cricketers.

University of Cape Town



## SECTION 1

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In this section I will introduce the study and focus specifically on a review of the literature and the methodology of the study.

Chapters in this section:

- Chapter 1: Literature review: Lower back pain in cricketers
- Chapter 2: Methodology

## CHAPTER 1

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### Literature Review: Lower Back Pain in Cricketers

#### 1.1 INTRODUCTION

The game of cricket has evolved from a fledgling sport in the 1600s to a formalized sport with the first international test match played between England and Australia in 1877 in Melbourne, Australia<sup>1</sup>. In South Africa, domestic cricket matches were first played in 1870 as four day events. One-day limited overs (45 or 50 overs) competitions were first introduced in 1972, and 2004 saw the start of the 20-over a-side competition. There was little financial incentive for cricketers prior to 1977, when businessman Kerry Packer introduced substantial salaries for players who joined his breakaway, limited overs World Series Cricket initiative<sup>2</sup>. Since then, players have come to be regarded as professionals who earn monthly salaries. With both changes in the way competitions are organized and players are incentivized, the demands placed on cricketers have increased significantly and players are expected to perform at an optimal level on an ongoing basis.

Traditionally, the cricket season is played over six months of the year from the start to the end of summer. The South African domestic season, defined as the period during which cricket competitions are played, runs from 1<sup>st</sup> October to 31<sup>st</sup> March. The period July to October is considered to be the pre-season period. However, some players play throughout the year as they have chosen to play for English county teams during the South African off-season. International players may also play throughout the year, depending on their international tour schedule. As a consequence, domestic and international players are expected to play at a high level for a longer period and with participation in a greater amount of cricket matches. Furthermore, the introduction of 50 over and 20 over matches, which has also accelerated the pace of the game, has placed considerable physical demands on cricketers' musculoskeletal systems.

The cricket team consists of eleven players, made up of batsmen, fast bowlers, spin bowlers and wicketkeepers. Bowlers are defined as players who bowled an average of

more than 5 overs a match in the previous season. All players are required to field for a certain amount of time when the opposing team is batting. During 4-day matches (two-innings matches), the fast and spin bowlers can bowl about 30-40 overs per innings. Furthermore, with the increased performance demands fast bowlers are now also required to bat more effectively. This is specifically the case in limited overs matches, should the specialist batsmen fail to score sufficient runs. Thus longer seasons, more matches, the faster pace of the game and financially driven performance requirements, together with the erosion of rest and recovery time, have all combined to increase the risk and occurrence of injuries in cricket players over the years.

It has been calculated that this increase in physical demand on cricketers has increased the rate of injury from 2.6 to 333 per 10 000 player hours. The majority of these injuries occur in the lower back and trunk<sup>3-6</sup>. This alarming situation has created an increased awareness of the need for injury prevention<sup>3-6</sup>.

Thus it is suggested that the high occurrence of lower back injury in cricketers is linked to the physical demands of the various cricketing disciplines. This appears to be particularly evident in the case of fast bowlers.

## 1.2 PHYSIOLOGICAL DEMANDS OF CRICKET WITH SPECIFIC REFERENCE TO THE FAST BOWLING TECHNIQUE

The fast bowling technique consists of different components comprising the run-up<sup>1</sup>, delivery stride<sup>11</sup>, ball release and the follow-through<sup>7</sup>. The execution of these components during fast bowling results in an asymmetrical, explosive movement, producing high amounts of stresses and strains on the body<sup>8;9</sup>. Furthermore, fast bowling involves the combination of compression and shear forces. These forces are transmitted during back foot and front foot landing during the delivery phase of the bowling action and increase the loading on the lumbar spine<sup>3;4;7;8;10-15</sup>. It has been postulated that increased spinal loading may lead to injury of the lower back among sportsmen who use running during their sporting activity<sup>15</sup>. The aetiology of spinal pathology has been attributed to a combination of poor physical preparation, bowling mechanics and overuse<sup>10</sup>. Overuse injuries are very common in fast bowlers<sup>16</sup>. These injuries generally result from the repetitive microtrauma caused by forces below the critical threshold limit for the specific bodily tissue that combine to produce a fatigue effect over time<sup>17</sup>.

At front-foot impact, the ground reaction forces transmitted through the bowler's body are about 5 times the body weight<sup>9</sup>. These forces pass through the bones, cartilage, tendons and muscles of the foot, leg, thigh and pelvis to the intervertebral discs and facet joints of the lumbar spine. Absorption by the body of these ground reaction forces creates a load which, if excessive, may cause pain and injury in the lumbar region<sup>8-11;18;19</sup>. Besides axial loading of the spine, during the phase of front foot impact the lumbar spine also undergoes hyperextension, lateral flexion, rotation and forward flexion in order for the fast bowler to achieve maximum power. The combination of these forces and movements predispose the fast bowler to injury of the lumbar spine.

Young fast bowlers are particularly prone to injury because their musculoskeletal systems are too immature to withstand this combination of force and movement<sup>20</sup>. Since complete ossification of the posterior elements does not occur until about the age of 25, these structures are unable to absorb the forces associated with fast bowling<sup>20</sup>. In addition, there is an increased elasticity of the intervertebral discs of

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<sup>1</sup> The run-up starts when the bowler begins to advance towards the batsmen and end as the bowler leaps to in preparation for back foot impact<sup>7</sup>.

<sup>11</sup> The delivery stride begins when the back foot impacts and ends at front foot impact.

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young fast bowlers which allows greater torsional forces to reach the vertebrae<sup>21;22</sup>. Young athletes are also vulnerable as the iliolumbar ligament, which assists with stabilisation of the lumbosacral junction, is only completely formed by the third decade of life<sup>23;24</sup>.

Since, particular fast bowling techniques are associated with an increased risk of injury, the specific technique used and the risks involved need to be described in more detail.

### 1.2.1 Bowling techniques

The fast bowling technique is characterised into three distinct actions, the side-on, front-on and mixed bowling actions<sup>14</sup>. Both the side-on and front-on actions are associated with the lowest incidence of injury, as both techniques are associated with less extension and lateral flexion of the lumbar spine compared to the mixed bowling action<sup>10;14;16;25-27</sup>.

#### 1.2.1.1 Side-on technique

The side-on technique has been suggested to be the most effective bowling technique to use<sup>7</sup>. This technique involves a relatively low run-up pace. At the start of the delivery stride at back foot impact, the foot is positioned perpendicular to the pitch. The line through the shoulders points down the wicket (parallel) at about 180° (see Figure 1.1)<sup>7;10</sup>.

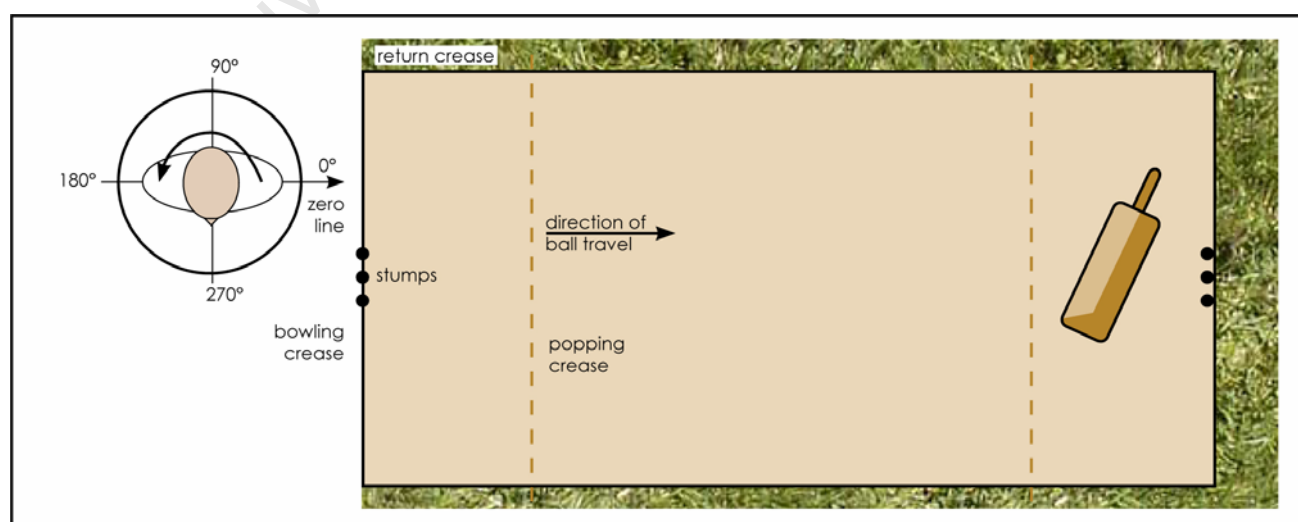


Figure 1.1: Transverse view of shoulder alignment for the side-on technique (shoulder angle = 180°) for a right-arm fast bowler bowling [Figure adapted from Bartlett et. al., (1996)<sup>7</sup>]

### 1.2.1.2 Front-on technique

The front-on technique is a more open-chested action at back foot impact compared to the side-on technique<sup>7</sup>. The run-up speed is also higher and the bowler's back foot points in the direction of delivery of the ball at back foot impact<sup>7;10</sup>. At this point the line of the shoulder angle relative to the pitch is greater than 180° (see Figure 1.2).

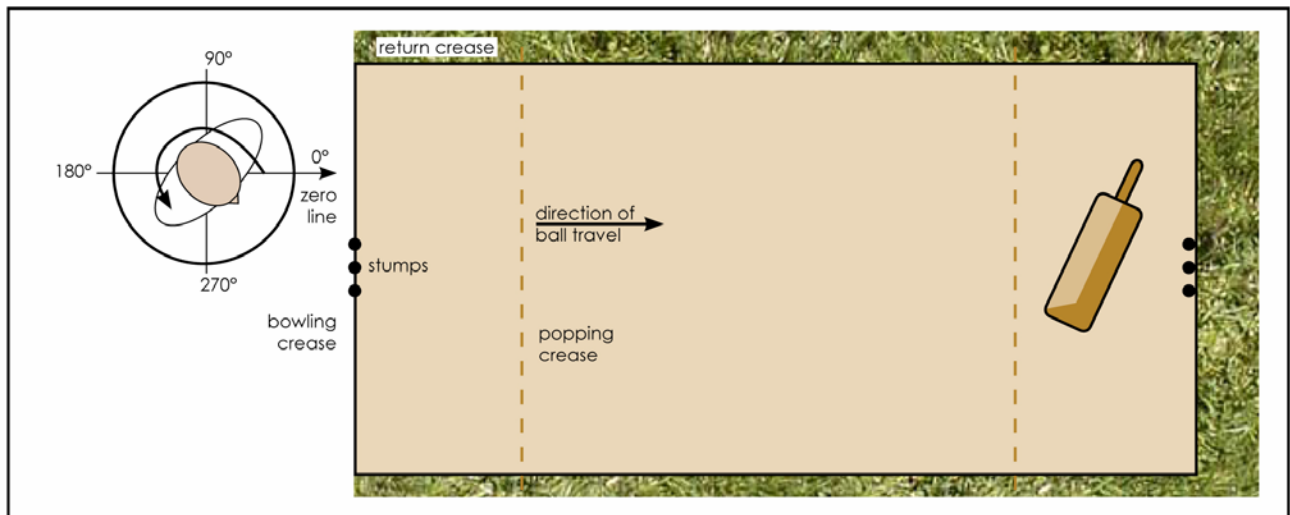


Figure 1.2: Transverse view of shoulder alignment for the front-on bowling technique (shoulder angle = approximately 240°) for a right-arm fast bowler bowling [Figure adapted from Bartlett et. al., (1996)<sup>7</sup>]

In both of the above techniques the bowler adopts a body position where the hip and shoulders are in alignment at back foot impact, therefore there is no major deviation between these segments<sup>10</sup>. Furthermore the peak ground reaction forces of these two bowling techniques are not different<sup>10</sup>.

### 1.2.1.3 Mixed technique

The mixed technique is a combination of both the side-on and front-on bowling techniques. The bowler adopts a front-on position at back foot impact followed by the realignment of the shoulders to a more side-on action during the delivery stride<sup>10;25</sup>. This mixed fast bowling technique involves a greater degree of lumbar axial rotation, trunk extension and forward and lateral trunk flexion compared to the side-on and front-on techniques. The increased degree of trunk rotation in the three anatomical planes (transverse plane, sagittal plane and frontal plane) during the mixed technique could possibly subject the spinal structures to greater mechanical loading compared to the side-on and front-on bowling techniques<sup>16</sup>. This type of bowling action is therefore

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associated with a higher incidence of lower back injuries. This is probably due to the hyperextension and rotational nature of the delivery action combined with the high ground reaction forces at front foot impact<sup>10;25;27;28</sup>. Furthermore, the mixed bowling technique has been linked to abnormal radiological features of the lumbar spine in fast bowlers<sup>10;14;20;25</sup>.

Since the mixed action involves realignment of the shoulders during delivery, it produces a movement known as shoulder counter-rotation<sup>10;25</sup>. Shoulder alignment is viewed in the transverse plane (overhead) and describes the line joining the left and right acromion processes<sup>28</sup>. The shoulder angle, being the line of best fit between the acromion processes, is calculated in an anti-clockwise direction from the zero line. The zero line is defined as the straight line running down the pitch from the bowlers end to the batsman's end. Shoulder counter-rotation is calculated as the difference between the maximum and minimum shoulder angles. Maximum shoulder counter-rotation generally occurs after the hips have initiated rotation towards the batsmen and therefore, direct movement for rotation, flexion and lateral rotation of the spine. Shoulder counter-rotation and the measurement thereof will be fully explained in Chapter 2. Fast bowlers have been found to increase their shoulder counter-rotation later in their bowling spell, resulting in the bowlers adopting a more mixed bowling technique<sup>29</sup>.

A mixed bowling technique was initially defined as an action in which the bowler counter-rotates the shoulders 40° between back foot and front foot impact<sup>10</sup>. Foster et al., (1989) were the first to link the increased incidence of injury with the mixed bowling technique<sup>10</sup>. The authors showed that the greater the degree of shoulder counter-rotation the greater the occurrence of bony and discal pathology of the lumbar vertebrae. Fast bowlers with counter-rotation greater than 40° had more injuries of the lumbar spine, with 6 out of 17 bowlers having stress fractures and 7 out of 17 bowlers other soft tissue lumbar injuries. However, more recent studies have described a mixed bowling action as a shoulder counter-rotation above 30°. Indeed one study has used 20° of shoulder counter-rotation as the limit indicating a mixed bowling action and therefore a predisposition for lower back injuries<sup>14;30</sup>. Further studies also used 20° of counter-rotation to define the mixed bowling action<sup>16;25;28</sup>. Therefore, there appears to be a lack of consensus regarding the degree of shoulder counter-rotation that defines the mixed bowling technique and this requires further investigation. This finding will be

part of the focus of research conducted in this thesis and described in Chapters 9 and 10.

#### 1.2.1.4 Arm and trunk movements during fast bowling

The non-bowling arm and trunk play an important role during the fast bowling action, specifically during the delivery stride and ball release<sup>7</sup>. The rapid adduction and extension of the non-bowling arm before and during trunk rotation aids in the summation of forces, especially during the side-on action. This movement also aids lateral trunk flexion and hyperextension during back foot impact, and assists with the natural positioning of the bowler to lean back at the start of the delivery stride. At which point, the trunk flexes from its extended position to prepare the bowler for rotation of the bowling arm. At front foot impact the non-bowling arm and front leg must be thrust down simultaneously to bring about flexion and rotation of the trunk and bowling arm<sup>10</sup>. Furthermore, trunk rotation is important for the generation of ball speed<sup>18</sup>.

The internal oblique muscle on the non-bowling arm side of the trunk plays an important role in shoulder counter-rotation<sup>10;25;29</sup>. During shoulder counter-rotation it assists in rotating the shoulders away from the batsman between back foot and front foot impact. This occurs prior to further forward rotation of the shoulders and hips at front foot impact and ball release. The mixed bowling technique has a greater amount of lateral flexion to the non-dominant side specifically at front foot impact, compared to the side-on and front-on bowling techniques<sup>31</sup>. Therefore, these asymmetrical movements of the trunk may cause asymmetry of the trunk musculature. Possible asymmetry of the abdominal muscles as a result of the mixed bowling technique therefore needs to be investigated with respect to the development of lower back pain and degree of shoulder counter-rotation. This type of investigation has not previously been done with respect to fast bowlers. The role of the internal obliques and the other muscles of the abdominal wall will be discussed later in this chapter (1.3.4).

In summary, existing evidence links the risk of developing lower back injury to bowling technique, especially in fast bowlers who use the mixed bowling technique. It is therefore important to explore the occurrence of lower back injuries and morphometry of the trunk muscles and their possible role in injury development, prevention and rehabilitation.

## 1.3 INJURY TO THE LUMBAR SPINE IN CRICKETERS

### 1.3.1 Definition of injury

The prevailing consensus with respect to definition of an injury is; “a medical condition that causes a player to not be fully available for selection in a match”<sup>32</sup>. The recovery of an injury is described as “when a player is able to return to full participation in at least one match”<sup>32</sup>.

### 1.3.2 Overview of cricket injuries

Cricket, specifically fast bowling, requires a high level of fitness, technical skill and involves repetitive training which makes the fast bowlers susceptible to injuries due to overuse<sup>33</sup>. Fast bowling is a major cause of injury to schoolboy cricketers with seasonal injury occurrence of 38% to 47% compared to 17% in batsmen and 33 – 66% for provincial players<sup>5;6;10</sup>. The lower back and trunk regions are found to be injured most frequently<sup>5;6</sup>. It is for this reason that studies have focused on fast bowlers with little research being done on spin bowlers and batsmen.

Furthermore, international and provincial cricketers are reported to sustain a higher occurrence of injuries (33 - 74%) compared to schoolboy cricketers<sup>6;34</sup>. Lumbar and abdominal muscle injuries account for 48% and 19% respectively. Of all cricketing disciplines, fast bowlers at higher levels of the game have the highest incidence (70 injuries per 1000 hours) and occurrence of injury (65%). Fast bowlers are followed by all-rounders (bowler and batsmen: 55 injuries per 1000 hours), batsmen (49 injuries per 1000 hours and 4%) and wicketkeepers (47 injuries per 1000 hours: 2%)<sup>3;6;33</sup>. Fast bowlers also have the highest incidence of lumbar injury (8 bowlers injured per 10 000 player hours) compared to batsmen (2 batsmen injured per 10 000 player hours)<sup>4</sup>.

A study on the occurrence of lower back pain in cricketers from schools and clubs (mean age 20.2 years) in the Western Cape area reported a 61% occurrence of lower back pain, with 79% of lower back pain being linked to cricketing activities<sup>35</sup>. The study found that fast bowlers incurred the most lower back pain (76%) followed by spin bowlers (48%). Of the players with lower back pain, only 56% had knowledge of injury prevention strategies. These findings compare with research by Gregory et al., (2002) who found that fast bowlers had a higher rate of lower back injury (0.029/1000 balls – 6%) compared to spin bowlers (0.011/1000 balls – 2%)<sup>36</sup>.

### **1.3.2.1 Seasonal occurrence of cricketing injuries**

Cricketing injuries are reported to peak at the end of the pre-season and the beginning of the season (September/October) and then again towards the end of the season (February/March)<sup>37</sup>. The most likely time to sustain an injury is during cricket matches<sup>37</sup>. Forty-six percent of injuries to schoolboy cricketers and 20 – 29% of injuries to senior cricketers are sustained during cricket practice<sup>33;34</sup>. The high occurrence of injuries in schoolboy practice sessions could be due to insufficient practice sessions, limited, incorrect or absent application of appropriate training principles and the lack of specialised coaching at this level. Young fast bowlers also tend to bowl excessively throughout their growth period when their spine is still immature, making them more vulnerable to injury<sup>12</sup>. Like schoolboy cricketers, provincial and club cricketers incur the majority of cricket injuries at the beginning and end of the season<sup>3;6</sup>. While cricket preparation takes place mostly pre-season and competition occurs in season, it has been found that players who do off-season training are better able to adapt to early pre- and in-season demands and are at lower risk of injury<sup>5;34</sup>.

In summary, the available evidence points to a high occurrence of lumbar injuries specifically in fast bowlers. These injuries have increased in frequency over time due to the increased physical demands of the game of cricket. Furthermore cricketers appear to be unaware of injury prevention strategies.

### **1.3.3 Diagnosis of injury**

#### **1.3.3.1 Lumbar clinical assessment in fast bowlers**

Elliott et al., (1986) have described the findings of clinical assessment of fast bowlers<sup>18</sup>. Forward trunk flexion, extension and lateral flexion were measured from the upright position using a lumbo-sarcal goniometer. Trunk flexion was measured as the displacement of the distal aspect of the third digit from the starting upright position. Mean trunk flexion was recorded as  $39 \pm 7^\circ$ , mean trunk extension was recorded as  $7 \pm 3^\circ$ . Trunk rotation was measured with the subject starting in the upright position with the upper limbs abducted. Trunk rotation was recorded as  $34 \pm 5^\circ$  and lateral flexion as  $79 \pm 13^\circ$ .

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Beyond this single study, there are no data obtained through clinical assessment specifically related to injured cricketers. However, the physical examination of the lumbar-sacral spine in other athletes, however, has been well documented<sup>38</sup>.

### 1.3.3.2 Imaging of the lumbar spine

There are a number of available methods of imaging to assist in the diagnosis of lumbar injuries<sup>38;39</sup>. These include plain film x-ray, radioisotopic bone scanning, computerized tomography (CT) and magnetic resonance imaging (MRI). Plain film x-ray is the initial imaging investigation of choice and provides information with respect to bony abnormalities indicating fractures, calcification and dislocations. Correct positioning of the patient and a minimum of two views of the bone is essential for accurate diagnosis with this technique<sup>38</sup>. Furthermore plain film x-ray involves a degree of radiation emission.

Radioisotopic bone imaging provides the clinician with a functional image of skeletal osteoblastic activity to confirm a bone or joint abnormality<sup>38;39</sup>. This method involves the detection of gamma ray photon emission from a patient following an intravenous administration of a radioactive isotope. This method is invasive and lacks specificity for certain conditions, including certain lumbar spine abnormalities<sup>38;39</sup>.

CT scans are a sensitive method for the diagnosis of lumbar pathology and is specifically useful to assess the healing of bone stress fractures of the lumbar spine<sup>40</sup>. However, this method requires the emission of radiation to produce an image<sup>38;39</sup>.

MR imaging is based on the amount of free water protons within a sample of tissue and their ability to align with an external magnetic field<sup>38</sup>. During this form of imaging the subject is placed in a strong magnetic field and radiofrequency pulses are then applied to the tissue sample. This causes the protons to change their alignment relative to the external magnetic field. This realignment releases energy which is used to create the image produced. This method of diagnosis is therefore non-invasive and does not involve the use of radiation<sup>41</sup>. Furthermore, magnetic resonance imaging has been shown to be a reliable method of assessing intervertebral disc pathology and pars interarticularis, vertebral endplate and soft tissue abnormalities<sup>42;43</sup>.

Studies of radiological abnormalities in fast bowlers have utilized various imaging techniques to diagnose lumbar pathology<sup>25;26</sup>. The results of these studies indicated that all players who experienced lower back pain showed some evidence of radiological abnormality. Furthermore, no players with normal imaging complained of pain. This finding, confirmed in research by Payne et al., (1987) and Annear et al., (1992), suggests that pain is a useful predictor of potentially serious lumbar spine pathology which can be visualized using certain imaging techniques<sup>7;19;27;44</sup>.

Quantification of the extent of spinal pathology as seen on imaging can be achieved by using a classification system. There are no published grading classification systems specifically for use in the cricketing population. However, previous MRI classifications have focused on intervertebral disc degeneration and abnormalities of the pars interarticularis in the general population<sup>41;43;45</sup>. Pfirrmann et al., (2001) developed a classification system to quantify intervertebral disc degeneration (see Table 1.4 below). Inter-observer (0.69-0.81; substantial – excellent) and intra-observer (0.84-0.90; excellent) agreement was found to be reliable in the assessment of the extent of total intervertebral disc pathology<sup>42</sup>.

**Table 1.4: Classification of intervertebral disc degeneration by Pfirrmann et al., (2001)<sup>42</sup>**

Grade	Structure	Distinction of Nucleus and Anulus	Signal Intensity	Height of Intervertebral Disc
I	Homogeneous, bright white	Clear	Hyperintense, isointense to cerebrospinal fluid	Normal
II	Inhomogeneous with or without horizontal bands	Clear	Hyperintense, isointense to cerebrospinal fluid	Normal
III	Inhomogeneous, gray	Unclear	Intermediate	Normal to slightly decreased
IV	Inhomogeneous, gray to black	Lost	Intermediate to hypointense	Normal to moderately decreased
V	Inhomogeneous, black	Lost	Hypointense	Collapsed disc space

Other studies have assessed the reliability of graded classification systems for nerve root pathology (Intra-observer agreement: 0.72-0.77; inter-observer agreement: 0.62-0.67), endplate pathology (3-type Modic system assessing signal intensity) and lumbar

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spondylolysis<sup>46-48</sup>. Firstly, these classification systems assessed individual pathologies and no one system has investigated multiple pathologies thus giving an overall scoring of total pathology of the lumbar spine. Secondly, these studies assessed the reliability of combined intervertebral disc levels that had pathology and not the reliability of the specific intervertebral disc level. Therefore, there is a need to further investigate the reliability of these lumbar pathologies at specific intervertebral disc levels.

The more common pathological conditions prevalent in fast bowlers include lumbar disc degeneration and spondylolysis. However, there is a lack of evidence of other radiological abnormalities in cricketers. Therefore, this area requires further investigation. The specific injuries common to fast bowlers will be described in more detail below.

#### 1.3.3.3 Composition of uninjured vertebrae and intervertebral discs

In order to understand the various injuries sustained by cricketers, it is important to briefly describe the normal anatomy of the vertebrae and intervertebral disc of the lumbar spine. The vertebrae of the lumbar spine are composed of an anterior vertebral body and a posterior vertebral or neural arch that protects the spinal cord and spinal nerve roots from injury<sup>49</sup>. The lumbar vertebrae articulate with each other via an anterior intervertebral disc and two posterior apophyseal or facet joints. The intervertebral discs are classified as fibrocartilaginous symphyses interposed between adjacent surfaces of the vertebral bodies providing a strong attachment between these vertebral bodies<sup>49</sup>. The intervertebral disc is metabolically active and metabolism is dependant on diffusion of fluid either from the marrow of the vertebral bodies across the subchondral bone and cartilaginous endplate or through the anulus fibrosus from the surrounding blood vessels<sup>50;51</sup>. The anulus fibrosus is supplied by adjacent blood vessels and is composed of lamellae of fibrocartilage which assists in providing a strong bond between adjacent vertebrae<sup>49</sup>. The nucleus pulposus of the intervertebral disc acts as a shock absorber to disseminate axial forces. The facet joints are formed by the opposing articular processes of adjacent vertebral arches and help control flexion, extension and rotation of the adjacent lumbar vertebrae<sup>49</sup>.

### 1.3.3.4 Specific injuries to fast bowlers

#### 1.3.3.4.1 Intervertebral disc degeneration

##### 1.3.3.4.1.1 Aetiology of disc degeneration

Disc degeneration is characterized by the conversion of the normal hydrated intervertebral disc to an anhydrous intervertebral disc. Disc degeneration may cause decreased capability of the disc to attenuate shock and effectively distribute the load uniformly over the cartilaginous endplate with resultant pain<sup>14</sup>. Changes in the morphology of the vertebral bone and cartilaginous endplate, which occur with advancing age or degeneration interfere with the normal disc nutrition and advance the degenerative process<sup>50;51</sup>. The disruption of the normal endplate results in deformation under loading. This allows nuclear material to pass through the endplate with subsequent bulging and loss of disc height. This adds more stress to the surrounding annulus. Compressive damage to the vertebral body endplate alters the distribution of stresses in the adjacent disc<sup>50;51</sup>. Continual cyclic loading makes these changes worse. Diminished blood flow in the endplate initiates tissue breakdown, first in the endplate and then in the nucleus. These altered stress distribution adversely affects the metabolism of the cells within the disc affecting the integrity of the proteoglycans and water concentration, reducing the number of viable cells with subsequent alteration in the movement of solutes into and out of the disc<sup>50;51</sup>.

##### 1.3.3.4.1.2 The prevalence of disc degeneration in cricketers

Disc degeneration in the general population increases in the second decade of life and increases further with age<sup>10;16;18;19;29</sup>. A previous study has reported an occurrence of disc degeneration in 10% of non-cricketing 12 year olds and 26% in non-cricketing 15 year olds<sup>20</sup>. Other studies of the non-sporting population reported the occurrence of disc degeneration in 17% and 35% of 18-32 year olds and 20-39 year old respectively<sup>52;53</sup>. However, the occurrence of disc degeneration is much higher in cricket fast bowlers<sup>25;27</sup>. Approximately 65% of 17-18 year old cricketers have at least one abnormal intervertebral disc and up to 70% of retired fast bowlers have at least one degenerative disc. Elliott et al., (1993), found that 21% of fast bowlers who had an MRI scan had disc degeneration at L<sub>1</sub>-L<sub>2</sub> to L<sub>5</sub>-S<sub>1</sub> and demonstrated an increased shoulder counter-rotation<sup>14</sup>.

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Walker et. al., (1996) studied the occurrence of disc degeneration in 13 to 17 year old fast bowlers<sup>13</sup>. The authors found that disc degeneration in fast bowlers increased with age. The under 13 bowlers had 15%, under 15 bowlers had 30% and under 17 group had 40% disc degeneration in the respective groups. The lumbosacral disc was the region most frequently affected.

Studies of imaging of the lumbar spine have found that between 34% and 58% of fast bowlers have at least one degenerative disc<sup>13;54</sup>. In one study, 25% of the fast bowlers had at least three degenerative intervertebral discs<sup>54</sup>. This research also showed a close association between disc degeneration and bowling technique. Indeed 69% of all fast bowlers with disc degeneration employed a mixed bowling technique. Similarly, a study of young fast bowlers (mean age of 13.7 years) found that 21% of bowlers had disc degeneration. All of the bowlers with disc degeneration used a mixed bowling technique<sup>14</sup>. The bowlers who counter-rotated their shoulders by at least 30° were found to be more likely to have a radiological abnormality compared to those who showed less counter-rotation. A further study assessing 16 to 18 year old fast bowlers (n=20) found that only two bowlers had normal imaging studies and were without lower back pain<sup>26</sup>. Sixty-three percent of this group showed features of disc degeneration on imaging studies. Seventy-eight percent of this group reported the presence of lower back pain. It is of interest to note that in this study the bowlers who counter-rotated their shoulders greater than 10° had a higher occurrence of disc degeneration.

Burnett et. al., (1996) assessed fast bowlers (mean age of 13.6 ± 0.6 years) to determine the prevalence and progression of disc degeneration over a 2.7 years period<sup>16</sup>. They found that there was a significant increase (21% to 58%) in the prevalence of disc degeneration over time. At the first assessment, 4 bowlers had 5 degenerative discs between them, compared to session 2, where 11 bowlers had 19 degenerative discs in total. There was also an increase in the occurrence of lower back pain from 5% to 53% at the second testing session. However, the authors found no association between the symptom of lower back pain and disc degeneration. Thus the causal link between disc degeneration and LBP is controversial. Burnett et. al., (1996) also found that bowlers with a mixed bowling technique as witnessed at both testing sessions were more likely to show the progression of disc degeneration, compared to those who bowled with a mixed technique at session one and then altered their technique<sup>16</sup>.

Elliott and Khangure (2002), assessed a group of young fast bowlers (mean age 13.2 years) over a 4 year period<sup>55</sup>. Those who bowled with a front-on or side-on technique had very few lumbar disc abnormalities on imaging, compared to the 20 mixed action bowlers who were found to have significantly more lumbar disc degeneration seen on imaging studies. Furthermore, these bowlers who changed from a mixed to either side-on or front-on bowling action showed no progression of lumbar disc pathology over a 4 year period. Those who continued to bowl with a mixed bowling technique had progressive lumbar disc pathology seen on imaging studies.

This evidence clearly indicates that the prevalence of disc degeneration in fast bowlers who bowl with a mixed technique is high. Furthermore, those who bowl with a poor technique over a longer period predisposes fast bowlers to accelerated disc degeneration.

#### *1.3.3.4.2 Lumbar spondylolysis*

##### *1.3.3.4.2.1 Aetiology of spondylolysis*

Spondylolysis has been defined as a stress fracture occurring at the pars interarticularis<sup>8;56</sup>. The pars interarticularis is a narrow strip of bone lying between the lamina and inferior articular process (below) and the pedicle and superior articular process (above). The pars interarticularis is the vulnerable pivot between the vertebral body and the posterior apophyseal joints. L<sub>5</sub> is the vertebral level most affected in this injury<sup>8</sup>. The mechanism of injury involves repetitive loading of the neural arch in the region of the pars interarticularis<sup>57</sup>. In fast bowling this repetitive loading is combined with multiplanar movement of the trunk<sup>19;56</sup>. Furthermore, young cricketers are more vulnerable in this region because complete ossification of the neural arch may not have yet occurred<sup>27;57;58</sup>. This makes the growth cartilage less resistant to repetitive stress.

##### *1.3.3.4.2.2 The prevalence of spondylolysis in cricketers*

The occurrence of spondylolysis in the general population is only 5-10%. However, the occurrence in fast bowlers in cricket ranges from 11% to 55%<sup>3;10;14;25;27;44</sup>. Further studies found an occurrence of spondylolysis in 19% to 83% of fast bowlers and have

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described an association between this pathology and increased shoulder counter-rotation in these athletes<sup>10;25;29;54</sup>.

A study of bowlers who bowl with their right arm (right arm dominant bowlers) showed that they are more likely to develop spondylolysis of the non-dominant pars interarticularis as this side is associated with rotation and extension of the lumbar spine<sup>8;56</sup>. These unilateral pars interarticularis defects on the opposite side to the bowling arm have been reported in greater than 80% of bowlers with spondylolysis and are closely linked to increased shoulder counter-rotation<sup>54</sup>. Whilst bilateral pars interarticularis defects are mainly caused by lumbar hyperextension<sup>8;56</sup>.

Millson et. al., (2004) found a dissociation between pain and the presence of spondylolysis in cricketers<sup>40</sup>. However, Hardcastle (1991) found that stress fractures of the pars interarticularis were the most common cause of lower back pain in a group of fast bowlers under 20 years of age<sup>54</sup>. Therefore, it appears that pars interarticularis defects may or may not be symptomatic. Some bowlers with this injury complain of pain after long bowling spells while others are unable to bowl due to pain<sup>54;56</sup>.

Specific studies show the prevalence of pars interarticularis stress lesions in fast bowlers. Engstrom et al., (2007) found a 22% and 20% occurrence in 13 to 17 year olds with all lesions being symptomatic. Lesions were at L<sub>4</sub> and L<sub>5</sub> respectively on the non-bowling side<sup>59</sup>. A study by Hardcastle et al., (1992) of 16-18 year olds found an occurrence of 55% pars interarticularis defects, with half being bilateral and the other half being unilateral on the contralateral side. Nearly all of these bowlers reported LBP during bowling, however, only 42% had to stop bowling due to pain<sup>26</sup>. A further study by Ranawat and Heywood-Waddington (2004) of 21 year old cricketers found a high occurrence of stress fractures<sup>60</sup>. Forty-seven percent of these players had bilateral stress fractures of which over three quarter were on the contralateral side. Thirty-nine percent of the cricketers were fast bowlers who had 20 lesions between them, of which 25% of these were multiple level stress fractures. Of the cricketers who had no stress lesions, 33% were medium pace bowlers and 6% spin bowlers. However, 22% of the cricketers assessed were batsmen who reported 4 stress lesions. Therefore, this injury is more prevalent in fast bowlers, however, it also can occur in other cricketing disciplines.

Clinical signs of spondylolysis show great variation in severity, but the symptom of pain is evident with the repetitive motion of bowling<sup>61</sup>. As the reported pain is normally localized and aggravated by lumbar extension and lateral rotation to one or both sides, spondylolysis is most commonly diagnosed in the clinical assessment by performing a single leg hyperextension test<sup>8;54;56</sup>.

#### *1.3.3.4.3 Endplate pathology*

Vertebral endplate changes are bone marrow lesions visible on an MRI and are assumed to be associated with degenerative disc disease. Attempts to correlate Modic changes with clinical symptoms have produced controversial results. In Kjaer et. al's., (2005) study, Modic changes showed significant association with the history of low back pain<sup>62</sup>. Kuisma et al., (2007) investigated the association between pain and Modic changes (type I or II) by disc level<sup>63</sup>. The authors found that Modic changes at the upper lumbar levels were not associated with pain whereas Modic type I changes at L<sub>5</sub>-S<sub>1</sub> were more likely to be associated with symptoms of pain.

#### **1.3.4 The role of the abdominal and spinal muscles in injury**

The coordinated co-contraction of the lumbar paraspinal muscles with the lateral abdominal wall muscles is thought to have a stabilising effect on the lumbar spinal segments, thus providing a safe platform for trunk movement<sup>64-66</sup>. Therefore, the roles of the abdominal and posterior muscle groups in stabilising the lumbar spine are described in this section.

During maximal isometric trunk extension, TrA is the only abdominal muscle showing heightened activity, as well as consistently being related to intra-abdominal pressure (IAP)<sup>67</sup>. TrA, along with multifidus are known as the stability synergists as they are more deeply placed, contain a greater amount of type I fibres and are able to control low force levels over a long period. These muscles are also important due to their involvement in the thoracolumbar fascia (TLF) mechanism and because they enhance intra-abdominal pressure<sup>67</sup>.

### 1.3.4.1 Lateral abdominal musculature

The lateral abdominal muscles include external oblique (OE); internal oblique (OI) and transverse abdominis (TrA). These trunk muscles are divided into prime movers (those that create movement); and stabilisers (those that support the spinal structures and control unwanted movement)<sup>68</sup>. The stabilising muscles are divided into primary and secondary stabilisers. The primary stabiliser, TrA cannot create significant joint movement, while the secondary stabilizer OI, is efficient at stabilising the spine but can also produce joint movement. The classification of muscles into movement and stability synergists depends on the biomechanics, anatomical site, physiological properties of the muscle and the programming of the movement with which it is involved<sup>69</sup>. The lateral abdominal muscles may have an important role to play in the stabilisation of the lumbar spine, thus they are important targets in the management and prevention of lower back pain in both the sporting and non-sporting population<sup>70-72</sup>.

Stability of the lumbar spine requires passive stiffness through osseous and ligamentous structures and active stiffness through muscle contraction<sup>73</sup>. At the end range of motion there are passive structures which prevent hypermobility or instability, and in the mid range active elements play a far greater role in maintaining lumbar spine stability. To date, there have been few attempts to investigate muscle thickness asymmetry of the trunk muscles and their role in low back pain. The presence of pain, however, is known to reduce the optimal functioning of the central nervous system (CNS) and therefore alter the ability to maintain the active component of spinal stability<sup>74</sup>.

The greatest relative muscle thickness occurs in OI, followed by OE, with TrA being the thinnest of the three muscles. This relative muscle thickness is expressed as a percentage of total muscle thickness and may be a useful measurement in assessing muscle asymmetry. It is possible that effects of unilateral pathology can influence the relative contribution of each muscle to the total thickness<sup>75</sup>.

Resting muscle symmetry in both the non-sporting and cricketering populations have previously been assessed<sup>75;76</sup> (see Table 1.1). A comparison of studies shows that the cricketering population tends to have a greater resting TrA muscle thickness (mm) compared to the non-sporting population. Furthermore, comparison of the sides of the abdominal muscles showed symmetry<sup>76</sup>. Internal oblique resting muscle thickness

(mm) was thicker in the cricketing population when comparing results of previous studies. This muscle was thicker on the cricketers' left side (dominance was not determined), however, not significantly thicker<sup>76</sup>. This finding was unlike those of Rankin et al., (2006) who reported that OI muscle thickness was symmetrical in non-cricketing, male subjects<sup>75</sup>. Furthermore, Rankin et al., (2006) found that when assessing symmetry of the relative (%) muscle thickness, OI, OE and TrA deficits ranged between 13 - 24%, with TrA having the greatest deficit between the sides.

**Table 1.1: Absolute resting muscle thickness values (mm) in subjects with no low back pain (95% confidence limits in brackets)**

Author	Age Weight	OE (mm)		OI (mm)		TrA (mm)	
		Right	Left	Right	Left	Right	Left
Rankin et al., (2006) <sup>75</sup>	40.6 ± 14.1 yrs	9.7 ± 2.3	9.6 ± 2.1	11.8 ± 2.7	11.7 ± 2.8	4.5 ± 1.3	5.1 ± 1.3
	82.5 ± 11.9kg	(5.1 – 14.3)	(5.4 – 13.8)	(6.4 – 17.2)	(6.1 – 17.3)	(1.9 – 7.1)	(2.5 – 7.7)
Hides et al., (2006) <sup>76</sup> *	21.3 ± 2.1 yrs			15.4 ± 1.8	16.5 ± 2.4	6.8 ± 1.7	7.0 ± 1.5
	75.8 ± 6.3kg						
Critchley & Coutts (2002)	18-60 yrs		5.5		8.5		4.4
			(3.7 - 10.0)		(4.6 - 14.9)		(3.4 - 6.7)

\* Only Hides et al., (2006)<sup>76</sup> assessed muscle thickness in cricketers

Abbreviations: OE, external oblique; OI, internal oblique; TrA, transverse abdominis; yrs, years

External and internal oblique muscles are associated with the production of rotational movements of the trunk<sup>77</sup>. They thus assist in controlling the forces that cause the spine to flex laterally. Researchers have found that OE and OI muscles vary in amount of activation depending on the direction of limb movement and their activation is linked, in turn, to the control of spinal orientation<sup>78-83</sup>.

Transverse abdominis is the deepest of the abdominal muscles and functions separately from the other abdominal muscles. Its primary function is to contract in anticipation of forces applied to the trunk in stabilising the lumbar spine<sup>83-86</sup>. Further, TrA assists in spinal stability during periods of maximal stress by resisting rotational forces on the motion segment<sup>86;87</sup> and assists with inter-segmental control in a non-direction specific manner<sup>71</sup>. This is achieved through its multiple attachments to the transverse processes via the thoracolumbar fascia. Cresswell (1993) found that TrA experienced bursts of increased electromyographic (EMG) muscle activity during periods of high acceleration and deceleration of the trunk during trunk flexion and

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extension movements<sup>88</sup>. This is due to the fact that TrA is phasic and these bursts of EMG activity occurred on top of baseline activity to further protect the spine.

In cricket, especially during fast bowling, players undergo frequent periods of acceleration and deceleration during trunk flexion and extension movements of both the trunk and shoulder muscles. It is important, therefore, that TrA functions normally to stabilise the spine. However, TrA muscle function is impaired in the presence of lower back pain<sup>67;71;89</sup>. This impairment in muscle function has been shown in the delayed onset of TrA activation when individuals with chronic lower back pain perform rapid limb movements<sup>80</sup>. OE and OI activation in individuals with chronic LBP was also found to be delayed, with unidirectional movements<sup>78;80;82</sup>. In contrast, pain free individuals activate their TrA muscle prior to the movement of the deltoid muscle, while OI and OE are activated after the initial movement of the deltoid muscle<sup>78;80;82</sup>. Furthermore, TrA threshold activation was increased during leg movement was not activated independently of the superficial abdominal muscles in patients with LBP<sup>85</sup>. Thus TrA appears to be deficient during specific functions in patients with LBP. According to Hodges (1999), TrA is controlled independently of other trunk muscles and is the principle abdominal muscle affected in patients with LBP<sup>71</sup>. Therefore, it should be trained separately in rehabilitation programmes.

The standard clinical test of TrA function is the low abdominal hollowing task. During this manoeuvre the patient is instructed to: “take a deep breath in and as you exhale pull your belly button up and inwards towards your spine”<sup>90-92</sup>. This causes the inward movement of the lower abdominal wall without the simultaneous movement of the spine or pelvis. This task is achieved through predominant contraction of the TrA muscle, with smaller contributions from the more superficial abdominal muscles<sup>86;93-96</sup>. Jull et al., (1995) analysed this technique using surface EMG and found that there was minimal superficial muscle activity during abdominal hollowing<sup>97</sup>. Urquhart et al., (2004) investigated abdominal muscle recruitment during a range of voluntary tasks<sup>92</sup>. The authors found that the greatest EMG activity for TrA was during the abdominal hollowing task with the patient in a supine position. This position also accounted for the most independent muscle activity of TrA. In individuals with a history of lower back pain both Jull et al., (1995) and Richardson et al., (1995) found that they were unable to perform an abdominal manoeuvre<sup>70;97</sup>. Clinical trials, which have focused on abdominal hollowing to retrain the function of the TrA muscle, have found that it successfully decreases lumbopelvic pain<sup>98;99</sup>.

People, both with and without lower back pain, have been found to preferentially recruit TrA during abdominal hollowing prior to training with only minimal change in muscle thickness of OI and OE muscles<sup>76;91;100</sup>. The relative lack of change in OE and OI muscle thickness validates the theoretical rationale for using abdominal hollowing as a foundational component to lumbar stabilisation programmes that preferentially activate TrA.

Furthermore, measurement of EMG during isometric contractions has been used to assess the change in muscle thickness from rest to contraction in order to validate this change in muscle thickness as a measurement of muscle activity<sup>101</sup>. Isometric contractions of the abdominal muscles produced a non-linear increase between TrA and OI muscle thickness and percentage maximum voluntary contraction (MVC). Twenty to 30% of MVC was associated with relatively large changes in muscle thickness. Therefore, muscle thickness changes of the abdominal muscles using ultrasound measurement, are only a reliable measure of muscle activity during small contractions. Muscle activity can only be determined when one is looking at a change in muscle thickness and not at a static muscle image. This linear relationship between changes in muscle thickness of TrA and OI and a contraction level up to 30% MVC, shows that the measurement of changes in muscle thickness provide a valid clinical measure of muscle function<sup>101;102</sup>. Therefore the size of TrA and OI may indirectly provide a measurement of its force-generating capacity<sup>103;104</sup>. However, there is no relationship between OE and percentage MVC as OE does not thicken on contraction<sup>103;104</sup>.

Compared to individuals without LBP, patients with a history of LBP use different strategies of trunk muscle activity in tasks involving isometric contractions of the leg muscles. This difference is measured as a change in thickness of both the TrA and OI muscles using ultrasound imaging<sup>101</sup>. An example of these different muscle activation strategies was shown in a study by Hodges & Richardson (1998) who demonstrated that LBP subjects must perform a faster limb movement in order to induce TrA muscle activity<sup>85</sup>. A further example is that in pain free individuals, the TrA muscle is activated non-specific to the direction of the limb movement, however, in people with a history of lower back pain the TrA muscle is activated specific to the direction of limb movement<sup>105</sup>.

Change in muscle thickness during abdominal hollowing is expressed as a proportion of muscle thickness at rest. According to Ferreira et. al., (2004) the mean thickness of TrA was found to be less in patients with LBP, whilst no difference was found between the groups for OE and OI in the non-cricketing population<sup>105</sup>. Rankin et al., (2006) reported that individuals with lower back pain have differences when measuring rest to contraction changes in abdominal muscle thickness compared to pain free individuals<sup>75;91;105</sup>. Critchley and Coutts (2002) found that those with lower back pain had a smaller mean increase (mm) in TrA thickness during abdominal hollowing compared to the pain free group (see Table 1.2)<sup>90</sup>. The differences for change in muscle thickness for OI and OE were small and not significant. However, OI tended towards a greater increase in thickness in the group that had chronic lower back pain.

**Table 1.2: Absolute lateral abdominal resting thickness and abdominal hollowing measurements (mm) for subjects with and without lower back pain<sup>90</sup>**

Critchley & Coutts (2002) <sup>90</sup>	LBP		Control	
	Rest	Hollowing	Rest	Hollowing
Age: 18-60 years				
OE	6.0 ± 2.0	6.8 ± 2.6	5.9 ± 1.6	6.9 ± 1.9
Range	2.6-10.4	2.5-14.9	3.1-8.8	4.0-10.7
OI	7.8 ± 2.6	9.9 ± 3.6	9.3 ± 4.0	11.0 ± 4.3
Range	4.0-13.3	6.3-10.1	6.0-24.5	6.0-26.1
TA	5.8 ± 1.7	6.7 ± 1.6	5.1 ± 1.2	7.7 ± 2.4
Range	4.0-11.4	4.3-9.1	3.0-7.1	3.7-13.8

Abbreviations: OE, external oblique; OI, internal oblique; TrA, transverse abdominis; LBP, lower back pain

#### 1.3.4.2 Posterior lumbar musculature

The deep intrinsic muscles of the spine include psoas, quadratus lumborum, iliocostalis, longissimus and multifidus. These muscles are recruited to control translation and rotation of the lumbar spine at the intervertebral level<sup>70;90;106</sup>. Furthermore, they have a direct influence on segmental stability and control of the lumbar spine due to their attachments to the spinal column. It is thought that changes in the recruitment of these muscles will compromise intervertebral stability. Due to this coordinated co-contraction, exercises that recruit psoas may coactivate with TrA to facilitate lumbar stiffness<sup>64-66</sup>. This would suggest that asymmetries in TrA muscle thickness might influence coactivation of the psoas muscle<sup>107</sup>.

Asymmetries of the para-spinal muscles have been found in young fast bowlers<sup>108;109</sup>. The greater volume of muscles occurs on the bowling arm side of the trunk and is associated with overuse and poor technique and possibly predisposes these athletes to specific injuries of the lumbar spine<sup>13;59;108</sup>. There may be a mechanical coupling between loading associated with unilateral pars defects and morphometric changes in the paraspinal musculatures<sup>108</sup>. There is likely to be a greater amount of unilateral loading of the lumbar spine in fast bowlers, which gives rise to a larger mean quadratus lumborum asymmetry or vice versa.

Research has shown quadratus lumborum to be the most asymmetric muscle of the abdomen in fast bowlers with a percentage difference between sides of greater than 10%, followed by psoas with 5.7%, erector spinae 4.9% and 4.5% difference in multifidus<sup>108;109</sup>. Quadratus lumborum is activated in a range of trunk movements, including extension, axial rotation and lateral flexion<sup>59</sup>. Therefore asymmetric activation during the strenuous loading phase of the delivery action may be a stimulus for hypertrophy of this muscle on the bowling arm side. While the muscle is known to play an important role in the intrinsic stabilisation of the lumbar spine<sup>89</sup>, the precise mechanism underlying quadratus lumborum asymmetries remains unclear. These asymmetries, however, may be a marker for assessing medium to long term changes in risk for unilateral neural arch injuries<sup>59</sup>.

According to Engstrom et. al. (1996) a greater than 10% deficit in quadratus lumborum muscle volume has been associated with an increased number of stress fractures of pars interarticularis at the 4<sup>th</sup> lumbar vertebral level on the contralateral side to the bowling arm<sup>108</sup>. This association may be due to quadratus lumborum primarily creating lateral flexion of the trunk at front foot impact (when the ground reaction forces are at their highest) with resultant unilateral muscle hypertrophy and a subsequent increase in stress fractures of the pars interarticularis<sup>110</sup>.

A recent longitudinal study found that all symptomatic young fast bowlers who had a L<sub>4</sub> pars lesion had a greater volume of quadratus lumborum on the bowling arm side<sup>59</sup>. During the second and third years of the study the greater pre-injury quadratus lumborum muscle volume on the bowling arm side in all injured bowlers was consistent with preferential muscular hypertrophy as a result of repetitive unilateral activation during the dynamic delivery phase of the bowling action. There was a significant association between increased quadratus lumborum asymmetry and the development

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of L<sub>4</sub> pars lesions in adolescent fast bowlers, with the muscle asymmetry predating the symptomatic pars lesions. Substantial shoulder counter-rotation in the delivery stride (greater than 20 to 40°) was also consistently associated with pars lesions in bowlers and may play a role in quadratus lumborum asymmetry<sup>10;111</sup>. A greater lateral flexion on the opposite bowling arm side at ball release is also associated with an increased risk of pars interarticularis defects<sup>31</sup>.

A recent study by Ranson et. al. (2008) investigated the cross-sectional area of the lumbar paraspinal muscles at various intervertebral levels on MR imaging in fast bowlers<sup>112</sup>. The authors found that quadratus lumborum (levels L<sub>1</sub>, L<sub>3</sub> and L<sub>4</sub>), multifidus (levels L<sub>3</sub>, L<sub>5</sub> and S<sub>1</sub> and erector spinae (combined iliocostalis and longissimus; level L<sub>2</sub>) were greater on the dominant side compared to the non-dominant side. Whereas the cross sectional area of psoas was found to be greater on the non-dominant side at L<sub>5</sub>. However, only the quadratus lumborum muscle demonstrated a difference of greater than 10% between the dominant and non-dominant sides.

Other posterior lumbar muscles include the multifidus and psoas. Multifidus works bilaterally with other lumbar muscles to produce extension of the lumbar spine. It acts as a stabiliser in rotation, counter-balancing the flexion force produced simultaneously with rotation by the oblique abdominal muscles<sup>113;114</sup>. Stokes et. al., (2005) found a difference of 10% in multifidus cross-sectional area between the dominant and non-dominant sides in male cricketers<sup>113</sup>. However, there were no significant differences of cross-sectional area between the sides and no trends of asymmetry related to handedness. Both multifidus and psoas provide stability to the spine and are sensitive to pathological changes. Using imaging techniques, Barker et. al., (2004) and Stokes et. al., (1992) have been able to show wasting of multifidus in patients with the presence of lower back pain<sup>107;115</sup>. Unisegmental atrophy is represented by a reduced multifidus cross-sectional area, which positively correlated with the symptomatic side of the body and spinal level in acute unilateral lower back pain<sup>116;117</sup>. Furthermore the reduced cross-sectional area of multifidus at the symptomatic level was positively correlated with the duration of symptoms<sup>107</sup>. A study by Hides et. al., (2001) found that the resolution of lower back pain in the control group did not reflect a change in localised atrophy<sup>117</sup>. However, a lumbar stabilising intervention did show more rapid multifidus muscle recovery in patients with lower back pain, although there was still the presence of asymmetry. A further lumbar stabilisation intervention study by Danneels

et. al., (2001) found that this type of intervention did not increase the cross sectional area of the multifidus muscle in patients with chronic lower back pain<sup>118</sup>.

These morphometric changes in the deep paraspinal muscles may in fact provide indirect evidence for changes in recruitment of these muscles<sup>116;119</sup>. Therefore, assessing the morphometric changes of the paraspinal muscles using MR imaging could be a useful predictor of the changes in muscle activity due to injury. Furthermore, MR imaging has been reported to be a highly reliable and valid measure of paraspinal muscle cross-sectional area when used to assess muscle morphology in male fast bowlers<sup>106</sup>.

Flor et al., (1983) reported that erector spinae activity was found to increase during trunk movements in those patients with low back pain, therefore one may assume that erector spinae cross-sectional area may be different in individuals with low back pain<sup>120</sup>. This indeed was the case in rowers with lower back pain. McGregor et. al., (2002) found greater cross-sectional areas of erector spinae and multifidus (about 120% and 180% greater, respectively) in rowers with lower back pain, compared to rowers without lower back pain<sup>121</sup>. A further investigation by Renkawitz et.al., (2006) found a significant association between lower back pain and neuromuscular imbalance of erector spinae as measured by EMG, with no association between these variables in athletes without lower back pain<sup>122</sup>.

In summary individuals with lower back pain have an impaired function of the TrA muscle and therefore a decreased ability to adequately stabilize the lumbar spine. There have been few investigations of the resting muscle thickness and muscle function of cricketers. Evidence shows that cricketers have asymmetry of the internal oblique muscle, with the non-dominant side demonstrating a greater thickness. Fast bowlers also have an asymmetry in quadratus lumborum. Cricketers sustain a high number of lower back injuries and lumbar pathology, and perhaps would benefit from being taught to retrain their stabilising muscles and decrease asymmetries that may predispose them to injury.

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## 1.4 REHABILITATION OF PATIENTS WITH INJURIES TO THE LUMBAR SPINE

### 1.4.1 Introduction

Lower back pain affects a significant number of people throughout the world<sup>123-125</sup>. The aetiology of most lower back pain in the non-sporting population is unknown and controversy still exists with regard to its treatment<sup>124;125</sup>. However, in cricketers, lower back pain and injury has been attributed to a combination of factors, including repetitive loading of the musculoskeletal system (overuse), incorrect technique and poor preparation<sup>3-8;10;11;13-15;30;126</sup>. Furthermore, fast bowlers are at a higher risk for injury, compared to batsmen and spin bowlers<sup>6;6;35</sup>. The occurrence of specific lumbar pathology, including disc degeneration and spondylolysis, is also often seen in fast bowlers<sup>13;14;16;25;27;40;43;55;127</sup>. Therefore, all available literature indicates the need for cricketers to incorporate preventative strategies into their training to protect their lower back.

The TrA combined with the other abdominal muscles (internal (OI) and external oblique (OE)), pelvic floor, lumbar paraspinal muscles and the diaphragm make up the “core”<sup>73</sup>. This group of muscles works in a coordinated way to form a muscular corset that stabilises the spine. Strengthening the core muscles is therefore advocated as a means of preventing and rehabilitating lower back pain<sup>73</sup>. The term core strengthening has become synonymous with lumbar stabilisation<sup>73</sup>.

One of the important functions of the abdominal muscles is to stabilise the spine, which is a feature that is often neglected<sup>68;128</sup>. In functional situations the muscles surrounding the trunk are required to co-contract isometrically to attenuate the protective mechanism of spinal stability<sup>70</sup>. Lack of stability of the lumbar spine is an ‘excessive range of abnormal movement for which there is a lack of protective muscular control’, showing a failure to maintain correct vertebral alignment. Thus, stability can be defined as the ability of the body to control movement throughout an entire range of motion of the lumbar spine<sup>128</sup>. Instability at the spinal segment level is a loss of control or excessive motion in the spinal segment’s neutral zone and is associated with injury, degenerative disc disease and muscle weakness<sup>64;65</sup>. This loss of control of the neutral zone can be returned to within physiological limits by regaining effective muscle control.

In the general population, exercise is a widely prescribed treatment for chronic lower back pain and is effective in improving function and reducing pain<sup>129-131</sup>. Currently, a wide range of exercises are prescribed for patients with lower back pain, even though many have not been properly researched or validated<sup>132</sup>. There is also no consensus regarding the specific exercise technique, intensity, or active intervention<sup>131;132;132;133;133;133-135</sup> needed to manage lower back pain. General exercise programs, focusing on fitness, strength, endurance and functional training, are found to be appropriate in the late stages of lower back rehabilitation<sup>136</sup>. However, they do not directly address the physical impairments of the neuromuscular system in the presence of lower back pain. There is sufficient scientific evidence in favour of intervention programs that combine strength training, flexibility and cardiovascular fitness in the treatment of lower back pain<sup>131;133;133</sup>. It has therefore, been suggested that rehabilitation should focus on retraining stability (segmental control), strength and neuromuscular function through the precise co-contraction of the deep trunk muscles (transverses abdominis and lumbar multifidus) in order to decrease pain, increase stability and improve functional ability<sup>64;65;137;138</sup>. Spinal stability is achieved through an appropriate interaction between the abdominal and trunk muscles namely rectus abdominis and external oblique and the abdominal muscles which control lumbar spine stability (deep multifidus, transverses abdominis, quadratus lumborum and psoas major)<sup>19;98</sup>. It is postulated that few athletes with adequate abdominal and posterior lumbar muscle strength may experience injuries related to hyperlordotic movement including fast bowling<sup>10</sup>.

#### **1.4.2 Composition of a lumbar stabilisation intervention**

It is important to retrain TrA independently of internal and external oblique and rectus abdominis in the early phase of a rehabilitation program as TrA contributes to spinal control and this muscle is reported to be the muscle in particular which has impaired function in patients with LBP<sup>82;83;85;86;88;139</sup>. Moreover, the training of the multifidus muscle is also an important component during the early phases of rehabilitation in patients with LBP, as the co-contraction of TrA and multifidus assists in stabilising the lumbar spine<sup>86;98;100;117;140;141</sup>. Therefore the preferential activation of these two muscles should be an important focus of rehabilitation of lower back pain. The importance of retraining these muscles is further shown by a study on patients with LBP who were prescribed exercises for deep trunk muscles experiencing fewer episodes of recurrent LBP<sup>98;142</sup>.

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Although the recruitment of TrA is emphasized initially during the method of abdominal hollowing, all trunk muscles are important for the restoration of normal function and progression of the rehabilitation program involves strategies for re-education of the whole abdominal and lumbar muscles<sup>100</sup>. Abdominal hollowing was established by Hides et al., (1996) and O'Sullivan et al., (1997) in randomized control trials in patients with acute and chronic LBP<sup>98;117</sup>. They found a decrease in pain and an increase in function of the TrA muscle with exercise interventions involving retraining of TrA through the inward movement of the lower abdomen. These authors have also pointed to the need to retrain TrA in various positions, including supine and standing positions in early rehabilitation and during functional activities, as the exercise training is progressed<sup>98;117</sup>.

According to O'Sullivan (2000) and Richardson and Jull (1995) a core stabilization program should be structured as a progressive, three phase rehabilitation program with each phase advancing on the former<sup>97;138</sup>. These authors describe phase one as the cognitive stage of the program as it involves the retraining of TrA. Retraining is achieved by way of facilitating isometric contraction of TrA while simultaneous contraction of multifidus and focusing on controlled breathing of the central and lateral diaphragm in neutral lordosis is taught. Contraction of TrA is achieved by means of the "drawing up & in" contraction of the pelvic floor and lower & middle fibres of TrA with gentle controlled lateral costal diaphragm breathing & without other muscle substitution. During contraction, thoracic spine extension and excessive lumbar lordosis needs to be avoided while ensuring the independence of the pelvis and lower lumbar spine movement from that of the hip and thoracic spine. In order to ensure correct contraction of TrA without the co-contraction of the superficial abdominal muscles palpatory, electromyographic or ultrasonographic biofeedback can be used. Retraining of TrA is performed in various postures, beginning with non-weight bearing, such as prone, supine and 4-point kneeling and progressing to facilitated weight-bearing postures of sitting and standing. The contraction is sustained for 10 seconds and repeated several times. The contraction is built up to 30 seconds of holding or 10 repetitions of 10 second holding. Continuous holding is avoided as fatigue causes a phasic action brought on by the substitution of type II fast twitch muscle fibres<sup>68;70;138</sup>.

Exercises specific to recruiting multifidus and TrA have been shown to decrease pain and disability in patients with chronic LBP<sup>98</sup>. Using real-time ultrasound, Hides et al.,

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(2001), found that multifidus asymmetry was present with diminished muscle size on the subject's painful side<sup>142</sup>. Furthermore, this deficit makes the subject more prone to further injury. They found that with specific exercises that targeted the stabilising muscles, they were able to reduce injury recurrence to the lumbar spine. The retraining of TrA involves the retraining of slow twitch muscle fibre function by performing isometric loading between 20-30% of a maximum voluntary contraction (MVC). Common errors encountered during this technique include holding in of breath and posterior pelvic tilting as well as a contraction of greater than 30% MVC which is too strong to correctly activate TrA. In this phase of the program the subject is not only re-educated on how to use the stabilising muscles correctly but also to unlearn any incorrect movement patterns<sup>70</sup>.

The second phase of the program is described as the associative stage, as it concentrates on the activation of TrA with the co-contraction of the local trunk muscle system whilst maintaining neutral spine and progresses to eventual normal spinal movements<sup>138</sup>. Co-contraction exercises are performed in order to refine movement patterns in situations where the participant may experience or anticipate pain or feel 'unstable'. Exercises for this phase have been previously described by O'Sullivan (2000) and Norris (1995)<sup>128;138</sup>. One important exercise routine during this stage is that of bridging which elicits the co-contraction of the abdominal muscles, the spinal extensors and the hip extensor muscles<sup>128</sup>.

The third and final phase of the progressive program is known as the autonomous stage and focuses on dynamic stability of the spine during functional activities in order to improve correct motor task performance<sup>138</sup>. The participant is trained to co-contract the muscles while doing functional movements. It involves, aerobic training, plyometric training, resistance training, sports specific exercises and proprioceptive training. Some general exercises for this phase have been previously described by O'Sullivan (2000) and Norris (1995)<sup>128;138</sup>.

In summary a progressive lumbar stabilisation exercise program is effective in reducing the occurrence of lower back pain and therefore could be beneficial to cricketers. According to current published literature no previous studies have assessed the effect of this specific intervention in a group of cricketers. Due to the fact that cricketers experience a high occurrence of lower back pain, an intervention of this nature warrants investigation.

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### **1.4.3 Previous intervention studies in fast bowlers**

Three intervention studies have been conducted with cricketers to alter their bowling technique in order to reduce injury. Burnett et. al., (1996) studied the effect of a half-day educational program on back injuries and bowling technique for young cricketers (mean age = 13.6yrs), coaches and parents after the cricketers' first testing period<sup>16</sup>. The coaching seminar consisted of information about fast bowlers bowling with a harmful mixed bowling technique thereby having a high degree of shoulder counter-rotation.

Elliott and Khangure (2002) studied the effect of a coaching intervention to alter the mixed action technique by decreasing the counter-rotation<sup>55</sup>. Twenty-four fast bowlers with a mean age of 13.4 years were tested three times over a period of four years, while a further 17 players (mean age 13.2 years) were tested two to three times over three years. Video footage of the bowlers was captured in the transverse plane from overhead and angles were interpreted using SiliconCoach software. All players had MRI scans following their bowling assessments. The intervention consisted of a coaching clinic during each testing session where all players were encouraged to adopt either a side-on or a front-on bowling action instead of a mixed bowling action. The players attended a further six coaching sessions each year and each were provided with video feedback of their bowling actions. The authors initially reported an increase in lumbar disc degeneration between years 1 and 2, therefore they concluded that the intervention needed more than one year of coaching intervention to be viable. The authors also reported a decrease in shoulder counter-rotation over a three year period from 35.4° to 21.3°, however, the incidence of injuries decreased only marginally<sup>55</sup>. They did find, however, that bowlers who changed their action from a mixed to either side-on or front-on technique, did not show a progression in their severity of disc degeneration. The greatest limitation of this study was that the study population changed over the study period. In the first year there were 41 participants and by the fourth year only 21 participants remained.

A third intervention study was undertaken by Wallis et al., (2002). It entailed the use of a harness while bowling<sup>28</sup>. The harness was defined as "a brace worn by a bowler to restrict the movement of the shoulders during the delivery stride". The participants of this study included 44 bowlers with a mean age of 13 years, who were divided into two groups. One group received a coaching intervention that emphasized correct shoulder

and hip alignment whilst bowling. The second group wore the harness whilst bowling and were given verbal and visual guidance regarding their bowling technique. The harness was designed to reduce the amount of separation between the pelvis and the shoulder and left lateral flexion, thus reducing the occurrence of a mixed action. While it was found that wearing the harness led to a significant decrease in the separation angle at back foot impact, this decrease was not sustained when the harness was removed. The groups' mean separation angle increased from 10.8° to 16.8°. There was also no significant decrease in the shoulder counter-rotation angle. Furthermore, the group who received the coaching intervention showed no significant change in bowling technique after the 8 weeks.

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## 1.5 SUMMARY OF AVAILABLE LITERATURE AND SUBSEQUENT LIMITATIONS

- 1.5.1 There is a high occurrence of lower back injuries among schoolboy cricketers, specifically among fast bowlers. Furthermore, the fast bowling technique and lower back injuries have been linked to radiological abnormalities of the lumbar spine. Therefore, the assessment of young cricketers is important as these athletes are bowling throughout their growth period and may be more prone to serious lower back injuries. As mentioned, previous studies have focused on fast bowlers and have neglected to investigate spin bowlers and batsmen.
- 1.5.2 Fast bowlers have been shown to have muscle asymmetry in the posterior lumbar musculature with quadratus lumborum being linked to pars interarticularis stress fractures. The internal oblique muscle has also been shown to be asymmetrical in cricketers, however, not significantly different. Due to these findings combined with the lack of research of spin bowlers and batsmen there was a need to further investigate muscle asymmetries of abdominal and lumbar musculature and their role in lower back pain across all cricketing disciplines.
- 1.5.3 Cricketers with lower back pain are prone to have impaired function in their TrA muscle and thus a reduced ability to adequately stabilise their lumbar spine. A decrease in lumbar stability is further compromised due to the high compression, shear and ground reaction forces that specifically fast bowlers undergo during bowling. However, the cricketing disciplines of spin bowling and batting also involve rotation, flexion and extension of the trunk. Therefore, all of these movements will increase the stresses on the lumbar spine. However, there is no literature investigating the effect of a lumbar stabilisation intervention in a group of cricketers. Progressive lumbar stabilisation programs have shown to decrease the occurrence of lower back pain in the general population, therefore designing an intervention of this type which addresses the specific needs of cricketers is important.
- 1.5.4 There is no consensus in the literature regarding the degree of shoulder counter-rotation which is harmful to fast bowlers. Previous studies have shown an association between the degree of counter-rotation and radiological abnormalities, however, this association required further investigation.

Importantly previous cricketing interventions have only focused on fast bowlers and have only used coaching and a bowling harness to alter shoulder counter-rotation. Firstly, the bowling harness was unsuccessful in maintaining a change in their bowling technique. Secondly, a coaching intervention only began to see a decrease in shoulder counter-rotation after a three year period. Therefore there is a need to develop an intervention program that has more success initially and is able to maintain any decrease in shoulder counter-rotation.

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## 1.6 OBJECTIVES AND OUTLINE OF THIS THESIS

Current evidence indicates that schoolboy cricketers are at a high risk of lumbar injury, particularly fast bowlers who bowl with a high degree of shoulder counter-rotation. There is a lack of evidence in the literature with respect to research of injuries in all cricketing disciplines. However to date fast bowlers have received the most attention. After reviewing the literature it was apparent that no studies have assessed the effect of a cricket-specific lumbar stabilisation exercise intervention on lower back pain and other physiological variables in cricketers. Previous interventions in cricketers have focused only on fast bowlers specifically to decrease the degree of shoulder counter-rotation. However, these researchers using their interventions either took 2 years to see changes or were unable to maintain changes in the bowling technique of these fast bowlers. Previous lumbar stabilisation interventions have only assessed the general population and focused on the decrease of lower back pain. The abdominal and lumbar musculature and clinical findings on examination as well as lumbar pathology seen on imaging studies has not previously been investigated with respect to a lumbar stabilisation intervention.

Therefore the primary objective of this investigation, using a randomized, control trial design, is to examine the efficacy of a cricket-specific lumbar stabilisation exercise intervention on change in lower back pain status, clinical signs and symptoms, muscle symmetry, shoulder counter-rotation, lumbar pathology on MR imaging in schoolboy cricketers. The results of these investigations are set out as follows in the subsequent chapters:

### **Section 2: Lower back pain and abdominal and lumbar muscle morphometry in schoolboy cricketers**

- 2.1 The aim of Chapter 3 was to assess the occurrence of self-reported lower back pain that was both present on entering the study and experienced in the years preceding the study, in a group of male schoolboy cricketers. Furthermore this chapter investigates the effect of a pre-season cricket specific progressive lumbar stabilisation intervention on the subsequent occurrence or resolution of lower back pain in this group of cricketers. The hypothesis was that schoolboy cricketers have a high occurrence of self-reported lower back pain and that this occurrence can be reduced with the

implementation of a pre-season cricket-specific progressive lumbar stabilisation program and maintained during the cricket season for 6 months.

- 2.2 The aim of Chapter 4 was to assess the morphometry of the lateral abdominal and posterior lumbar musculature in elite schoolboy cricketers with and without lower back pain. This study was structured to provide insight into the thickness of the abdominal musculature and cross-sectional area of the posterior musculature across cricketing disciplines. Furthermore, the relationship between morphometry and lower back pain was investigated. The hypothesis was that there is asymmetry in the lateral abdominal and posterior lumbar musculature in a group of schoolboy cricketers.
- 2.3 The aim of Chapter 5 was to test the efficacy of a pre-season cricket-specific progressive lumbar stabilisation intervention on changes in thickness of the lateral abdominal muscles and cross-sectional area of the posterior lumbar musculature. This chapter evaluated whether these changes in morphometry were influenced by cricketing discipline (bowling or batting) and the presence of lower back pain. Therefore the hypothesis of Chapter 5 was that a lumbar stabilisation intervention can change muscle thickness and improve transversus abdominus muscle function in schoolboy cricketers with lower back pain.

### **Section 3: Clinical and imaging features as determined by MRI in cricketers of different disciplines with and without lower back pain**

- 3.1 In Chapter 6 the development of a new MRI scoring system for disc and bony pathology of the lumbar spine was described. The aim of this chapter was also to assess the inter- and intra-observer reliability of this new classification system with respect to disc and bony pathology at the individual intervertebral levels. Furthermore this chapter laid the foundation for a total pathology score to be calculated to determine overall pathology of the lumbar spine on MRI assessment of these cricketers. The hypothesis was that a new MRI classification system is reliable and repeatable in assessing lumbar pathology of the lumbar spine.

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- 3.2 The aim of Chapter 7 was to assess baseline clinical signs and symptoms and MRI features of lumbar pathology in a group of elite male schoolboy cricketers. The baseline results were also used to determine whether the clinical and imaging features were specific to cricketing disciplines and to relate these changes to the presence or absence of lower back pain. The hypothesis of this chapter was firstly that there is a high occurrence of positive clinical tests and pathology as detected on MRI in the lumbar spine.
- 3.3 Chapter 8 further assessed the clinical and imaging features in this group of schoolboy cricketers. The aim of this chapter was to investigate whether the cricket specific lumbar stabilisation intervention influenced specific positive signs on clinical examination and lumbar pathology as assessed by MR imaging. Therefore the hypothesis of this chapter was that a lumbar stabilisation intervention can decrease the occurrence of positive clinical tests and imaging features of lumbar spine pathology in a group of schoolboy cricket players.

**Section 4: Morphometry, clinical and imaging features and shoulder counter-rotation in the group of fast bowlers**

- 4.1 The aim of Chapter 9 was to investigate the degree of shoulder counter-rotation in the group of elite schoolboy fast bowlers and the relationship of this variable to lateral abdominal and posterior lumbar muscle morphometry, clinical and imaging features of lumbar spine injury. The degree of shoulder counter-rotation which is harmful was further investigated. Therefore, the hypothesis of this chapter was that the degree of shoulder counter-rotation in fast bowlers is associated with thickness changes of the lateral abdominal and posterior lumbar musculature and findings on clinical examination and imaging studies in schoolboy fast bowlers.
- 4.2 The aim of Chapter 10 was to assess the effect of the pre-season cricket-specific progressive lumbar stabilisation intervention (and the subsequent maintenance thereof) on change in degree of shoulder counter-rotation in these young fast bowlers. The hypothesis was that a cricket-specific lumbar stabilisation intervention is effective in decreasing the degree of shoulder counter-rotation in a group of schoolboy fast bowlers. A further hypothesis of

this chapter was that the intervention will cause thickness changes of the abdominal and lumbar muscle morphometry and decrease the occurrence of positive clinical findings and imaging features of pathology to the lumbar spine in schoolboy fast bowlers.

Therefore, the aim of this thesis is to investigate the effect of a pre-season cricket specific progressive lumbar stabilisation intervention and its subsequent in-season maintenance on morphometric changes in the abdominal and lumbar musculature, clinical findings, imaging features as determined using MRI, and shoulder counter-rotation in a group of male schoolboy cricketers.

The overall hypothesis of this thesis was that a pre-season cricket-specific progressive lumbar stabilisation exercise intervention would reduce the occurrence of self-reported lower back pain, alter abdominal and lumbar muscle morphometry, reduce pain on clinical examination and the presence of pathology on MR imaging of the lumbar spine of schoolboy cricketers with and without lower back pain, as well as decrease the degree of shoulder counter-rotation during the delivery stride in young fast bowlers.

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## CHAPTER 2

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### Methodology

The methodology of this investigation entailed a complex, experimental design, in order to generate data that would provide scope for sufficient depth of analysis of the issues being researched.

#### 2.1 STUDY DESIGN

This was a prospective intervention study on 46 male schoolboy cricketers, with (n=28) and without (n=18) lower back pain. The group consisted of fast bowlers (n=18), spin bowlers (n=13) and batsmen (n=15). Cricketers were recruited from within Western Province cricket and were participating at either under 17 or under 19 representative level. Participants ranged in age between 15 and 18 years. A power calculation to determine the sample size required for this study could not be performed as no previous studies have been undertaken to assess the effect of rehabilitation on the outcome measures used in this study.

The under 19 and under 17 provincial and school cricket season is made up of pre-season (July-October), in-season (October – April) and post-season or off-season (April – July) periods. All subjects underwent pre-season testing (June), thereafter they were randomly divided into two, almost equal groups for the first part of the intervention study. The control group performed traditional pre-season fitness training, whereas the intervention group took part in an 8-week progressive lumbar stabilisation program. Following the 8-weeks, both groups were re-tested immediately before the ensuing season. The intervention group then attended part two of the intervention consisting of lumbar stabilisation maintenance exercise sessions throughout the cricket season and all subjects were re-tested immediate post-season (April).

The subjects were randomized into either the intervention or control group on entrance to the study. There were due to be two equal groups of 23 cricketers in each, however, due to the fact that two brothers who participated in the study were originally randomized into separate groups needed to travel together. Therefore, one of the

brothers was placed into the intervention group with his sibling for convenience purposes. Group 1 (n=24) comprised fast bowlers, spin bowlers and batsmen either with or without lower back pain. This group underwent the eight week pre-season intervention program as well as intervention sessions performed every two weeks during the season in addition to their traditional pre-season training.

Group 2 (n=22) also consisted of fast bowlers, spin bowlers and batsmen both with and without lower back pain. This group served as the control group and continued with their traditional pre-season and in-season training. This training included endurance, speed, agility and general strengthening of the global muscles.

All participants were given a subject information sheet prior to the onset of the research, explaining the study (Appendix A). All participants gave informed consent, which in the instance of most of them being minors (16-21 years), mostly meant parental consent and participant assent (Appendix B).

## **2.2 PATIENT EVALUATION**

### **2.2.1 History**

#### **2.2.1.1 Injury history questionnaire**

A thorough medical and injury history was taken for all participants on entering the study (Appendix C). Injuries were recorded by the researcher (Biokineticist), using an injury questionnaire as a complaint of pain either being current or previously sustained during the preceding two years.

#### **2.2.1.2 Cricket history questionnaire**

A full cricket history questionnaire was completed by all participants pre-season (Appendix D). This was to determine whether they were fast bowlers, batsmen or spin bowlers; how long they had been playing cricket for and their cricket training history.

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### **2.2.1.3 Oswestry questionnaire**

An Oswestry questionnaire to assess functionality in participants with lower back pain was completed on entering the study. It was repeated immediately after the 8-week intervention and then again post-season (Appendix E).

### **2.2.1.4 Injury management: access to medical treatment**

This questionnaire was designed to specifically determine participant access to medical treatment. The questionnaire was administered post-season to assess injury treatment during the season. It was decided to include this aspect of the investigation, as it became apparent during the study that some players would have received no treatment on injury, even from their province (Appendix F).

## **2.3 PHYSICAL EXAMINATION**

### **2.3.1 Anthropometric measurements**

Anthropometric measurements were taken according to the method described by Durnin and Womersley (1974) and are presented below<sup>126</sup>. Anthropometric measurements such as height (cm), weight (kg) and skinfold thickness were collected. Skinfold thickness was taken by first marking the correct anatomical reference points. The clinician then pulled gently at the folded layer of skin about 1cm above the marked area and placed the calipers at right angles to the fold. The caliper then measures the subcutaneous fat in this fold. Three readings were taken at each site and averaged. Caliper measurements (mm) were taken for triceps, biceps, subscapular, abdominal, supra-iliac, front mid-thigh and medial calf. These measurements were then used to calculate sum of seven skinfolds (mm), body fat percentage (%), fat mass (kg); lean body mass (kg), muscle mass (kg) and body mass index; (Appendix G).

Equations for calculating variables:

Sum of seven skinfolds (mm) = triceps + biceps + subscapular + supra-iliac + thigh + calf (all on dominant side) + non-dominant abdominal skinfold

Body mass index = weight /height<sup>2</sup>

Body fat % =  $100(4.570/D - 4.142)$

where  $D = 1.1533 - (0.0643 \times L)$  if under 17 years or

$D = 1.1620 - (0.0630 \times L)$  if 17-19 years

and  $L = \log$  of 4 skinfolds (biceps, triceps, subscapular and supra-iliac)

Fat mass (kg) = body mass (kg) X %fat

Lean body mass (kg) = (Body mass (kg)) - (fat mass (kg))

Muscle mass (kg) =  $[S(0.0553CTG^2 + 0.0987FG^2 + 0.0331CCG^2) - 2445] \times 1000$

where;  $S$  = stature

$CTG$  = corrected mid-thigh girth

$FG$  = forearm girth

$CCG$  = corrected calf girth

( $CTG = TG - \pi(\text{mid-thigh skinfold}/10)$ )

( $CCG = CG - \pi(\text{calf skinfold}/10)$ )

The above anthropometric variables are important when assessing the muscle thickness of individuals with varying anthropometry, as muscle thickness may be influenced by the fat content of the muscle<sup>90</sup>. All anthropometric measurements were recorded pre-intervention and post-season.

### **2.3.2 Clinical assessment of the lumbar spine**

A clinical assessment of the lumbar spine and trunk was performed pre- and post-season by a sports physician (Appendix H). This was done in order to assess trunk flexibility, and clinically evaluate pain in the lumbar-sacral region. The clinical tests were deemed to be “positive” during movement and on palpation of structures if pain was elicited during the movement or on palpation.

The following clinical tests were performed:

Range of motion (ROM): this was performed to assess joint and muscle stiffness as stiffness may be caused by joint injury<sup>143</sup>. ROM was performed in all directions of movement at the specific joints. In the case of the lumbar spine the following movements were performed:

- *Trunk flexion* was performed starting with the patient standing in anatomical position and then bending forward from the trunk thus

decreasing the normal forward curve of the lumbar spine and reaching towards the ground as far as they could<sup>144</sup> (see Figure 2.1). Trunk flexion was measured as the distance between the fingertips and the ground in centimeters (cm). The presence or absence of pain during forward trunk flexion was reported by the participant.



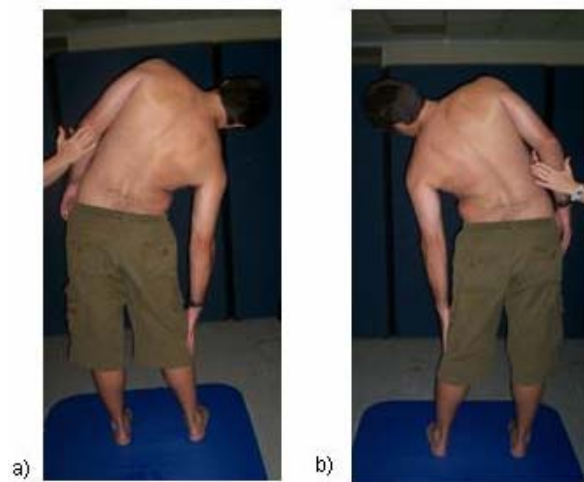
Figure 2.1: View of forward trunk flexion showing how the movement was performed from a) starting position in standing to b) reaching hand forward towards the ground

- *Lumbar extension* was measured with the patient starting in anatomical position and then extending the trunk backwards so that the normal forward curve of the lumbar spine increased<sup>39</sup> (see Figure 2.2). The presence or absence of pain during lumbar extension was reported by the participant.



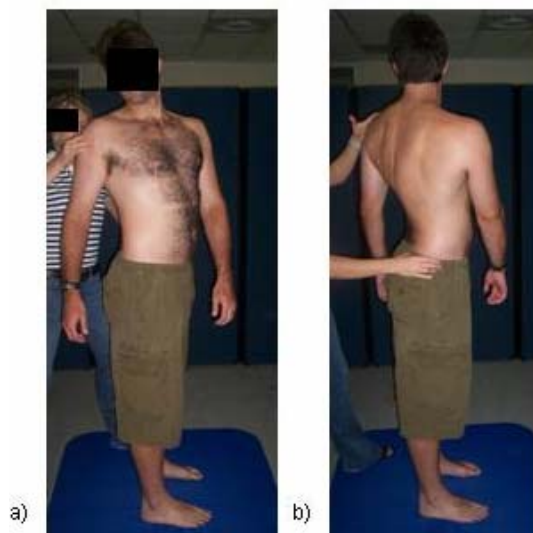
Figure 2.2: View of lumbar extension showing how the movement was performed

- *Lateral trunk flexion* in the coronal plane of the dominant and non-dominant sides was performed with the patient starting from the anatomical standing position and sliding their hand down the lateral side to as far as they could reach on either side<sup>39</sup> (see Figure 2.3). Lateral flexion was measured in centimeters (cm) from the ground to the fingertips. The presence or absence of pain during lateral trunk flexion was reported by the participant.



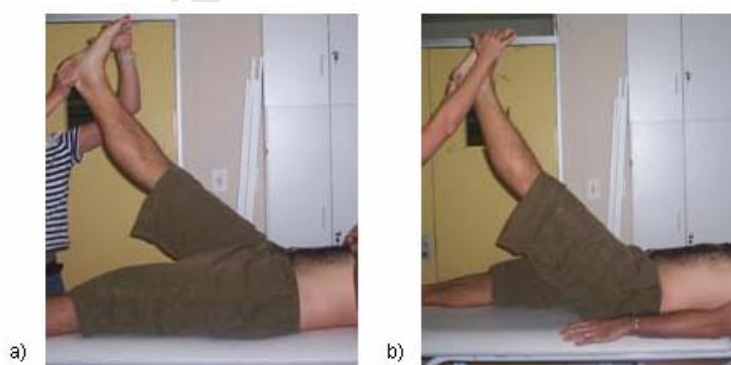
**Figure 2.3: View of lateral trunk flexion to the a) dominant and b) non-dominant sides showing how the movement was performed**

- *Trunk rotation* in the transverse plane was performed with the patient starting from the anatomical position and rotating the trunk to the dominant and non-dominant sides keeping the lower body still<sup>39</sup>. This was maintained by the clinician (see Figure 2.4). The presence or absence of pain during dominant and non-dominant trunk rotation was reported by the participant.



**Figure 2.4:** View of trunk rotation to the a) dominant and b) non-dominant sides showing how the movement was performed

- *The straight leg raise*, to determine hamstring ROM was performed with the patient supine<sup>143</sup>. The clinician placed one hand under the Achilles tendon and the patient was instructed to keep their knee extended. The leg was then lifted, perpendicular to the bed, until full range of motion had been reached (see Figure 2.5). The straight leg raise was measured using a goniometer placed on the greater trochanter as the change in degrees ( $^{\circ}$ ) from horizontal to full hip flexion.



**Figure 2.5:** View of straight leg raise of the a) dominant and b) non-dominant legs showing how the movement was performed

Lumbar vertebral palpation: was performed with the player lying supine and the lumbar vertebrae being palpated centrally over the spinous processes, laterally over the apophyseal joints and transverse processes to determine presence or absence of pain (see Figure 2.6).



Figure 2.6: View of lumbar vertebral palpation

Paraspinal lumbar palpation: this was performed by palpating the lumbar spine on the dominant and non-dominant sides to determine the presence or absence of pain (see Figure 2.7).

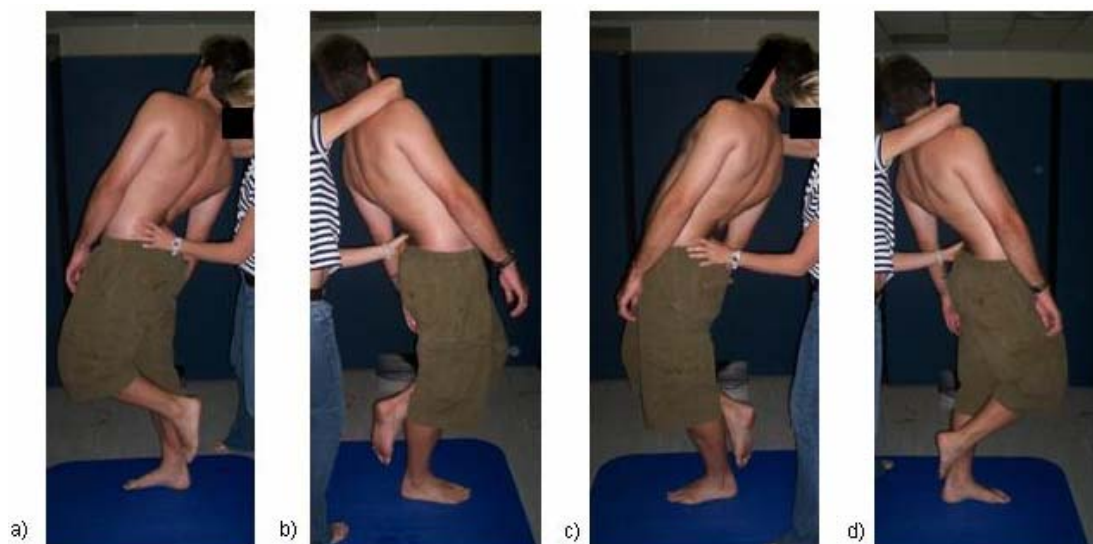


Figure 2.7: Paraspinal lumbar palpation, a) non-dominant palpation, b) dominant palpation

Palpation was also performed over the sacroiliac joint and iliolumbar ligaments. All of the above palpation methods were performed to detect tenderness<sup>143</sup>.

Single leg hyperextension rotation test: this test involved the patient standing on one leg (either dominant or non-dominant) in the anatomical position and passively being moved backwards into lumbar extension with trunk rotation either to the dominant or non-dominant side (see Figure 2.8). The presence or absence of pain during this test was reported by the participant. It is thought

that pain due to spondylolysis is elicited in unilateral lesions when performing this test by standing on the ipsilateral leg. This test is thought to be the most reliable in reproducing pain caused by lumbar spondylolysis<sup>8;54;56</sup>.



**Figure 2.8: Single leg hyperextension rotation test showing how the movement was performed a) dominant leg rotated trunk to dominant side, b) dominant leg rotated trunk to non-dominant side, c) non-dominant leg rotated trunk to dominant side, d) non-dominant leg rotated trunk to non-dominant side**

**Gross neurological examination:** A gross neurological examination to evaluate motor and sensory deficits of the lower limbs and to detect abnormalities in reflexes was performed<sup>145</sup>.

### **2.3.3 Injury record**

Throughout the season, detailed injury reports were recorded, for any cricketers in the study who were injured. These injuries were further assessed by a sports physician and appropriate clinical management was prescribed if warranted.

## 2.4 SPECIAL INVESTIGATIONS

### **2.4.1 High-resolution soft tissue ultrasound imaging of the lateral abdominal musculature**

Ultrasound scanning is a non-invasive method of imaging skeletal muscles without exposing patients to radiation<sup>143</sup>. This method also allows for dynamic movement making it possible to evaluate the change in thickness of the abdominal muscle during abdominal hollowing. A real-time ultrasound scanner (Toshiba NEM1020, Tochigi, Japan) with a 12 MHz linear transducer head was used to measure the lateral abdominal muscle thickness of internal oblique (OI), external oblique (OE) and transversus abdominis (TrA) at rest (mm). The repeatability of the thickness measurement of these abdominal muscles using ultrasound has previously been established<sup>146;147</sup>. Critchley and Coutts (2002) established intra-class correlation coefficients of 0.95, 0.98 and 0.94 for the external oblique, internal oblique and transverses abdominis muscles respectively<sup>147</sup>. Lateral abdominal wall ultrasound scanning was performed pre-season, post-intervention and post-season.

#### **2.4.1.1 Subject positioning**

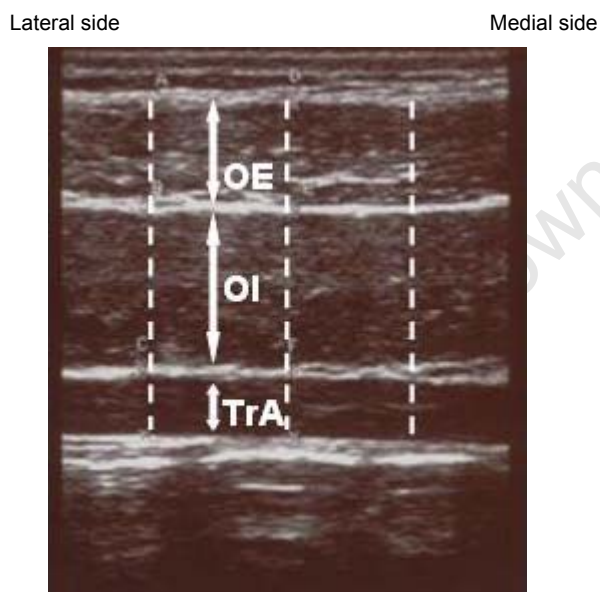
Positioning of all subjects was standardized. Subjects lay supine as described by Rankin et al (2006)<sup>75</sup>.

#### **2.4.1.2 Transducer head placement**

The transducer head was placed transversely 2.5 cm anterior to the mid-point between the ribs and the superior border of the iliac crest. The medial edge of the transducer head was placed 10cm from the midline. This position allowed for simultaneous imaging of the transversus abdominis, internal oblique and external oblique muscles<sup>101;146;147</sup>.

### 2.4.1.3 Ultrasound measurement

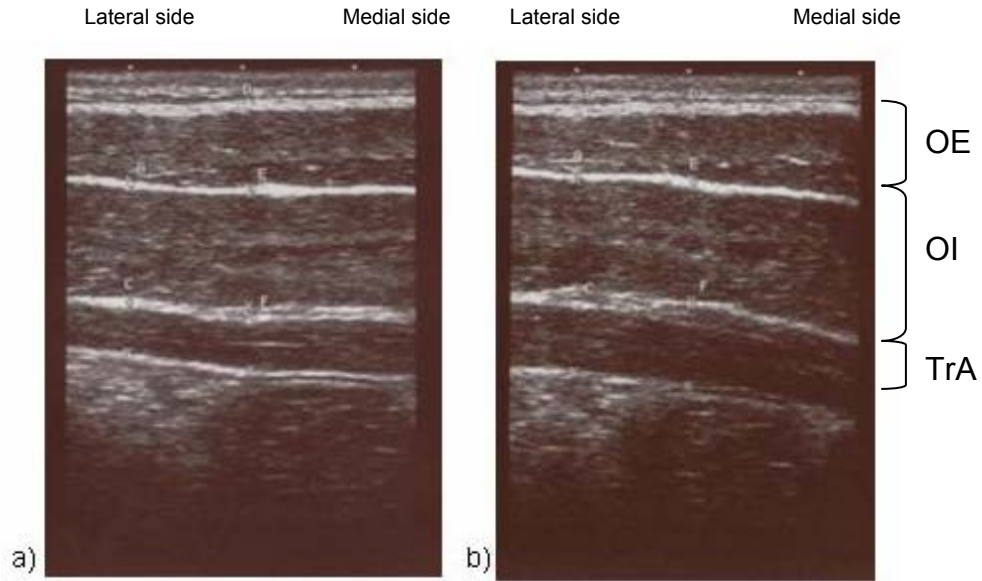
Participants were first instructed to remain still for the resting muscle thickness imaging. Once accurate visualization of the three abdominal muscles (transversus abdominis, external oblique and internal oblique) was obtained, the image was frozen. The muscle thickness measurements (mm) were made using the automatic caliper function, with three readings being taken for each muscle as per Figure 2.9.



**Figure 2.9: Ultrasound of antero-lateral abdominal musculature showing thickness measurements of OE, OI and TrA muscles**

**Abbreviations: OE, external oblique; OI, internal oblique; TrA, transversus abdominis**

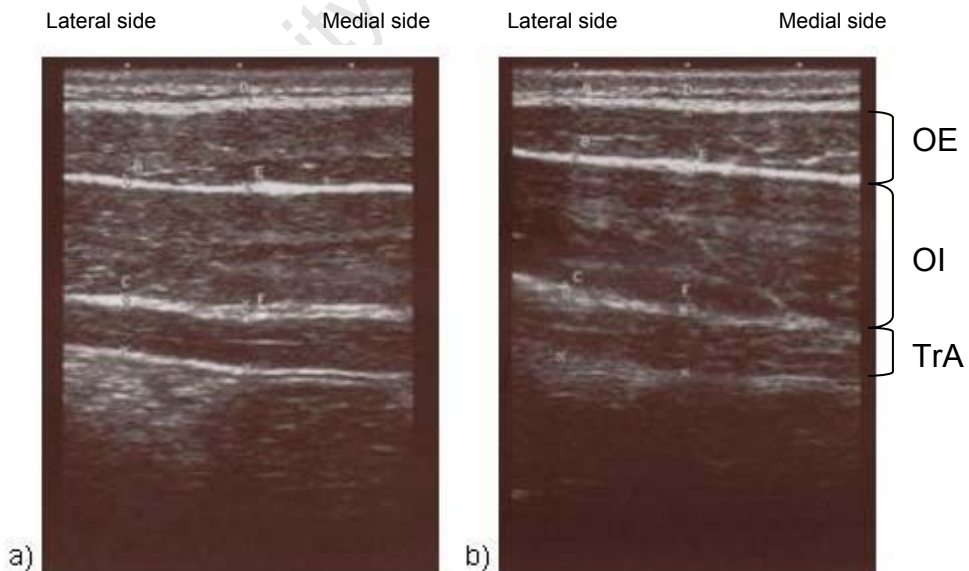
Subjects were then instructed to perform abdominal hollowing as this manoeuvre is known to isolate the activation of transversus abdominis (see Figure 2.10)<sup>91;92;147</sup>. Hollowing was explained to the subject as follows: “take a deep breath in and as you exhale pull your belly button up and inwards towards your spine at 30% of a maximal contraction”. This manoeuvre generates an inward movement of the lower abdominal wall without the associated movement of the spine or pelvis<sup>91;92;147</sup>. Furthermore by contracting the lower abdominal muscles on exhalation, movement of the lateral abdominal wall during breathing was standardized.



**Figure 2.10: Ultrasound image of the antero-lateral abdominal musculature showing the change from a) resting muscle thickness (TrA thickness = 3.9mm); to b) contraction during abdominal hollowing (TrA thickness = 5.5mm). As one can see there is little change in OI (9.6mm to 9.5mm) and OE (5.9mm to 5.1mm). Note that with contraction during abdominal hollowing TrA muscle thickness increases from its resting thickness measurement.**

**Abbreviations: OE, external oblique; OI, internal oblique; TrA, transverse abdominis**

Ultrasound scanning of muscle thickness was performed on both the dominant and non-dominant sides to determine muscle symmetry (see Figure 2.11).



**Figure 2.11: Ultrasound image of the antero-lateral abdominal musculature at rest showing the differences between the a) dominant (OE = 5.9mm, OI = 9.6mm, TrA = 3.9mm) and b) non-dominant (OE = 4.2mm, OI = 10.9mm, TrA = 5.2mm) sides. Note that this image shows that the thickness of the abdominal muscles on the dominant and non-dominant sides are different.**

**Abbreviations: OE, external oblique; OI, internal oblique; TrA, transverse abdominis**

#### 2.4.1.4 Measurement of abdominal muscle thickness using ultrasound

Muscle thickness was measured and expressed in this study as total abdominal wall thickness (OE + OI + TrA; mm), absolute muscle thickness (mm), relative muscle thickness (%; percentage of total abdominal wall thickness) and change in muscle thickness from a state of rest to contraction. The latter was used as an indication of muscle function ( $\Delta mm$ ).

The following equations were used to calculate the above variables:

*Equation I:* Total abdominal muscle wall thickness (mm) = OE + OI + TrA

*Equation II:* Relative muscle thickness (%) = (individual muscle ÷ total abdominal wall muscle thickness) x 100<sup>75</sup>

*Equation III:* Percentage difference (%) = [(dominant – non-dominant) ÷ dominant] x 100

The change in thickness was expressed as a proportion of the thickness during contraction:

*Equation VI:* Contract – Rest =  $\Delta mm$ <sup>105</sup>

Percentage changes in muscle measurements between testing sessions as expressed in the various tables in this thesis:

*Equation V:* (pre intervention – post intervention) ÷ pre intervention x 100

*Equation VI:* (pre intervention – post season ÷ pre intervention x 100

*Equation VII:* (post intervention – post season ÷ post intervention x 100

Change between the testing sessions for the sides' percentage differences was expressed as:

*Equation VIII:* % difference pre - % difference post

#### 2.4.2 Magnetic resonance imaging (MRI)

All players underwent MRI scanning of the thoracolumbar and sacral spine using a Siemens Magnetom Symphony Maestro Class 1,5T scanner. MRI scans are reported to be safer than X-ray or Computed Tomography (CT) scanning due to the fact that MRI scanning is radiation free<sup>38</sup>. MR imaging was specifically used to determine disc degeneration, disc protrusion, bone stress injury, vertebral endplate and facet joint pathology. Standard sagittal (see Figure 2.12) and axial (see Figure 2.13) T1- and T2-weighted sequences, plus additional sagittal and axial short tau inversion recovery (STIR) sequences (see Figure 2.14) of the lumbar spine were taken. An additional assessment during the post-season MRI scan was performed which took the form of a high resolution Dual Echo Steady State (DESS) 1mm cut and was performed as it has been shown to be extremely sensitive for pars interarticularis injuries (see Figure 2.15).

This additional sequence was added to the protocol to further evaluate the presence of lumbar bone stress injury as initially it was expected that the pars stress injuries would have shown up on the selected scans performed. When this was not found to be the case it was decided, by the consultant radiologist, to include the DESS scan on post-season testing. MRI scanning was performed at 12 weeks pre-season and both groups were reassessed immediately post season. The results of the MRI scans were interpreted by a radiologist with specific interest in musculoskeletal imaging.



**Figure 2.12:** Image showing an example of a standard sagittal T2- weighted sequence of the lumbar spine as observed on MR imaging. Note that this view assists the radiologist in diagnosing degeneration of the intervertebral discs and pathology of the endplates

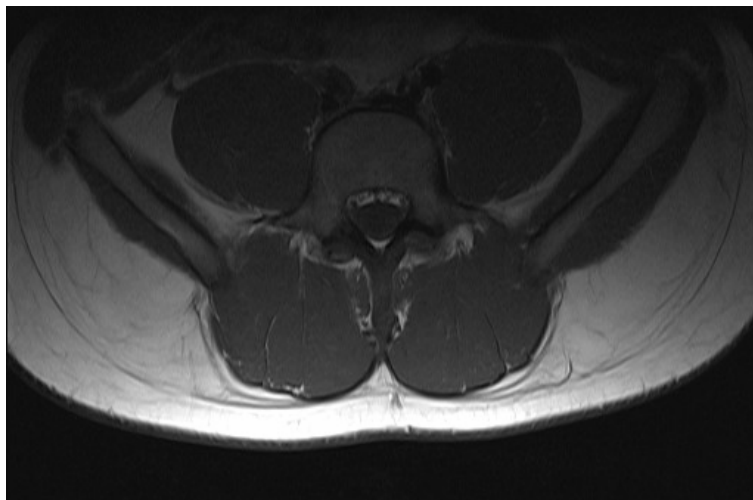
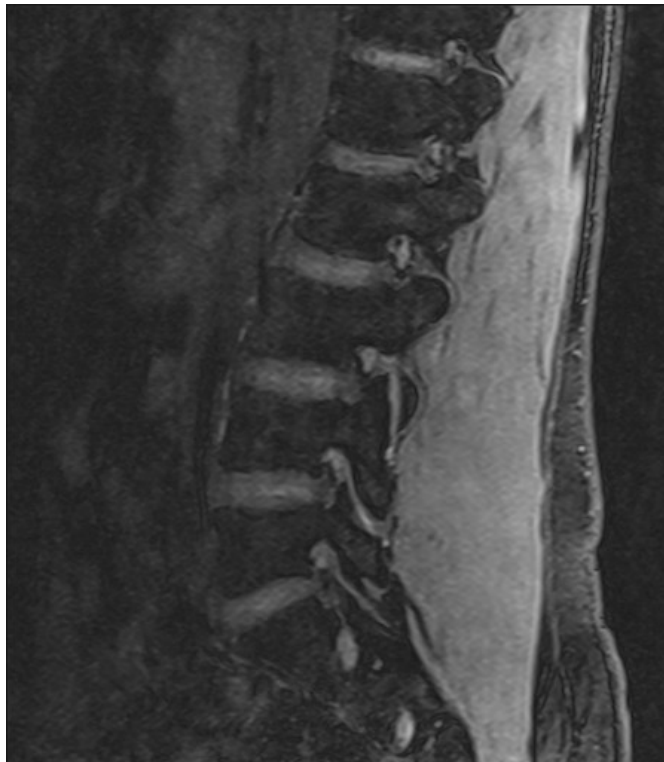


Figure 2.13: Image showing an example of a T1-weighted axial sequence of the lumbar spine as observed on MR imaging. Note that this view assists the radiologist in diagnosing discal, facet joint and nerve root pathology.

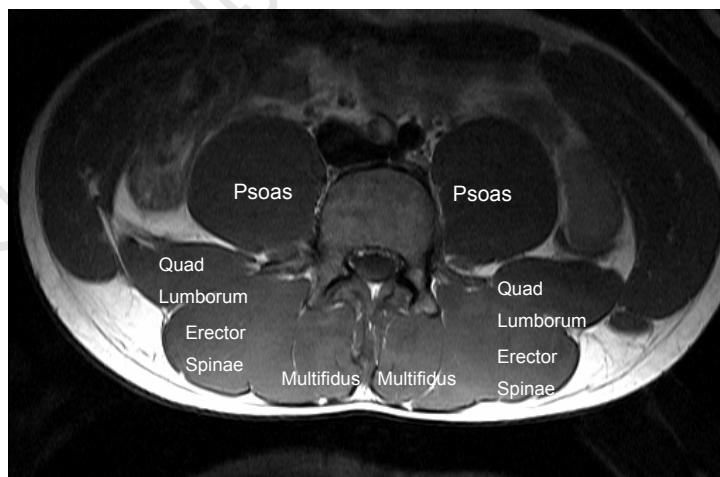


Figure 2.14: Image showing an example of a STIR sequence of the lumbar spine as observed on MR imaging. Note that this view assists the radiologist in diagnosing intervertebral disc and endplate pathology.



**Figure 2.15:** Image showing an example of a DESS sequence of the lumbar spine as observed on MR imaging. Note that this view assists the radiologist in diagnosing defects of the pars interarticularis.

MRI axial views were also taken to measure cross-sectional area (CSA) of quadratus lumborum, erector spinae, multifidus and psoas muscles (see Figure 2.16).



**Figure 2.16:** Image showing an example of an MRI axial sequence at the 4<sup>th</sup> lumbar vertebral level. Note that this view enables the radiographer to measure the cross-sectional area of the posterior lumbar muscles

### 2.4.2.1 MRI calculations

The following equations were used to calculate symmetry and percentage change in muscle cross-sectional area:

Percentage difference between the sides was expressed as:

*Equation IX: (dominant – non dominant)/dominant x 100*

The change between pre and post session testing was expressed as:

*Equation X: (pre intervention – post intervention)/ pre intervention x 100;*

*Equation XI: (pre intervention – post season)/pre intervention x 100;*

*Equation XII: (post intervention – post season)/post intervention x 100*

Percentage change between testing sessions for the sides' percentage differences was expressed as:

*Equation XIII: % difference pre - % difference post*

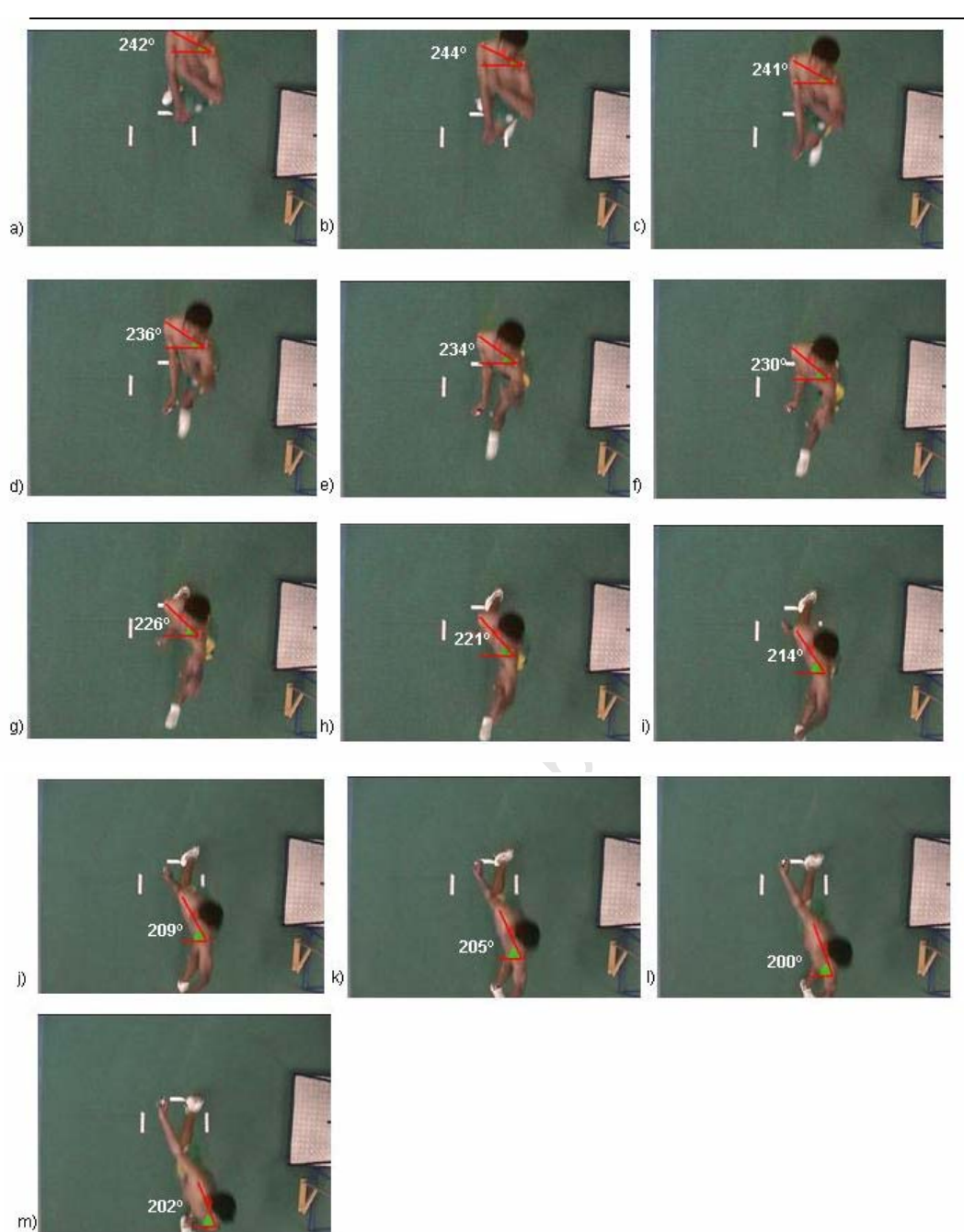
University of Cape Town

## 2.5 ASSESSMENT OF FAST BOWLING TECHNIQUE

An assessment of the fast bowling technique of all fast bowlers was performed using the two-dimensional (2-D) SiliconCOACH pro v 6.1.3 software (Sport and Physical Education Technology Ltd, <http://www.siliconcoach.com/>). The players were assessed 12 weeks pre-season, immediately following an 8-week intervention program and again post-season.

The subjects were filmed from overhead to assess extent of shoulder counter-rotation, measured in the transverse plane. The overhead camera was positioned perpendicular to the ground and directly above the bowler at the time of ball release to obtain validated measurements of shoulder angles. Shoulder alignment was calculated by digitizing the right and left acromion processes to produce a line-of-best-fit between these acromion processes using the software described (see Figure 2.17). All angular measurements in the transverse plane were relative to the pitch alignment in the direction of bowling and measured anti-clockwise. This is shown in Figure 1.2 in Chapter 1; 180° represents a side-on position with the shoulders being aligned with the pitch and 270° representing shoulder alignment near ball release<sup>55</sup>. To calculate the shoulder angle one must subtract the shoulder alignment measurement of the individual from 270°. For example if a bowler's shoulder alignment is measured as 30° his shoulder alignment relative to the pitch is 240°.

SiliconCOACH has been validated by Elliott et. al., (2002)<sup>148</sup> for the measurement of shoulder counter rotation in the transverse plane. 2-D measurements of shoulder counter-rotation have been highly correlated with three-dimensional assessment at back foot impact (0.97) and front-foot impact (0.84), however, shoulder alignments at ball release have a poor correlation (0.58). Shoulder counter-rotation has previously been described to occur between back foot and front foot impact during the fast bowler's delivery stride<sup>10:25</sup>.



**Figure 2.17: Calculation of shoulder counter-rotation using SiliconCoach. The fast bowler in this figure is bowling from the top of each image towards the bottom of each image a) Back foot Impact has a shoulder angle of  $242^\circ$ , b) the maximum shoulder angle follows immediately after back foot impact ( $244^\circ$ ). l) The minimum shoulder angle is  $200^\circ$ .**

**Note that: Shoulder counter-rotation is calculated as the difference between the maximum (b) and minimum (l) shoulder angles, therefore this fast bowler has a shoulder counter-rotation of  $44^\circ$ .**

**After the minimum angle of  $200^\circ$  (l) the shoulder angle starts to increase (m:  $202^\circ$ ) as the fast bowler rotates his trunk towards the batsmen again.**

## 2.6 INTERVENTION PROGRAM

Immediately following the completion of the pre-intervention assessments, the subjects were randomly divided into two groups. Group 1 (intervention group) underwent a pre-season eight-week, cricket specific, progressive lower back stabilization exercise program. Group 2 (control group) took part in traditional, pre-season cricket fitness training with no core stabilization exercises.

The 8-week lumbar stabilisation intervention was a progressive exercise program divided into three phases<sup>70;138</sup>. Each phase of the program was built on the exercises completed in the preceding phase. This intervention program was structured according to research conducted by Richardson and Jull (1995) and O'Sullivan (1997)<sup>70;98</sup>. The program also included a cardiovascular component, which was included during all three phases. All training was supervised to confirm that correct training procedures, loads and techniques were used. *See appendix K for intervention program exercises.*

Phase one, the cognitive phase, focused on retraining the transversus abdominis (TrA) muscle. This was accomplished by teaching the players how to isolate TrA using the abdominal hollowing task<sup>70;138</sup>. Isometric contraction has found to be most beneficial for the re-education of transversus abdominis and multifidus<sup>70</sup>. Therefore in phase one the subject had to achieve a simultaneous isometric co-contraction of TrA and multifidus, whilst maintaining neutral spine. This can be done either in a supine, four-point kneeling or prone position in order to inhibit the rectus abdominis and isolate the TrA and multifidus muscles. The period of isometric contraction was increased as did the number of repetitions performed. The isometric contraction in this phase, when teaching the subjects how to activate TrA, was held for about 3 seconds building up to about 20 second holds. This was in order to train the subjects to be able to hold the contraction during each movement. As the program progressed, the isometric contractions were combined with dynamic functional exercises. This first phase lasted for two weeks and sessions were held three times per week.

Phase two, the associative phase, lasted for three weeks. It included the isometric contraction of TrA performed in conjunction with the activation of the superficial abdominal muscles. This has been shown to increase the strength in various lower back muscles<sup>70;138</sup>. Sessions in this phase occurred three times a week. The aim of phase two was to integrate the function of the local muscles (TrA and multifidus) and

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the action of global muscles (rectus abdominis, external and internal obliques and quadratus lumborum). In this phase the isometric contraction of TrA was performed prior to each movement, thereafter the subject was instructed to hold the contraction throughout each movement pattern. This phase included exercises such as bridging which combines the actions of TrA and multifidus muscles, trunk rotation movements which combine the action of TrA and the oblique muscles and rectus abdominis co-contraction.

Phase three, the autonomous phase, lasted for three weeks with three sessions held per week. It centered around the activation of TrA and the superficial abdominal muscles whilst performing cricket specific conditioning and strengthening exercises<sup>70;138</sup>. Phase three progressed to exercises using cables and weights for strengthening the upper and lower body whilst simultaneously performing the isometric contraction of TrA. This phase incorporated exercises that would be beneficial to the specific tasks performed by the cricketers either while bowling or batting.

The intervention group then attended core stability maintenance exercises classes once every 2 weeks during the cricket season. Both groups were then re-tested with respect to the various parameters post-season. The intervention and control groups were compared to each other to assess the effects of the program.

During the 8 weeks of intervention, the control group attended traditional (unmodified), pre-season cricket training sessions. Sessions were performed once a week and involved training of endurance, speed, agility and the use of general strengthening exercises for the upper and lower body, but did not include any core stability work.

## 2.7 STATISTICAL ANALYSIS

Statistical analyses were performed using the Statistica software package (StatSoft, Inc. (2007). STATISTICA (data analysis software system), version 7.0. www.statsoft.com. The following statistical tests were performed:

- Levene's test of homogeneity of variance, to confirm that data could be analyzed with parametric statistics
- analysis of variance (ANOVA) with repeated measures one-way ANOVA to determine differences between groups,
- Pearson's product moment correlation to determine relationships between variables. The 95% confidence intervals around the correlation coefficient were determined from a spreadsheet downloaded from Hopkins (2006)<sup>149</sup>.
- weighted Kappa coefficients<sup>150</sup> to determine inter- and intra-observer reliability, and
- Fisher exact chi-squared tests to determine associations between variables (non-parametric data).
- Effect sizes as per Cohen's calculation and post-hoc power analysis.

When the F-value was significant after performing the ANOVA with repeated measures and checking Levene's assumptions for homogeneity of variance, a Tukey's HSD post hoc test was used to determine the specific differences (GROUP, TIME and INTERACTION), F-values are represented as  $F_{a,b}=c$ . ( $a$  and  $b$  represent the degrees of freedom between and within groups, with  $c$  being the critical value). The Tukey's HSD post-hoc test was the most stringent of post-hoc tests therefore where this test did not show significance of interactions no further post-hoc test was performed. Statistical significance was accepted at  $p < 0.05$ . All descriptive statistics in tables are expressed as means  $\pm$  SD. Symbols showing significant results in tables and figures are explained in detail below each table and figure.

An increase in muscle thickness (mm), muscle cross-sectional area (cm<sup>2</sup>) and shoulder counter-rotation (°) over time between the testing sessions is represented as negative values, with a decrease shown by positive values. For example if OI muscle thickness increased from pre- to post-intervention by 1.0mm it is represented as -1.0mm.

A detailed description of the particular statistical tests and variables measured can be found in subsequent chapters.

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2.8 SUMMARY OF THE STUDY TIMELINE

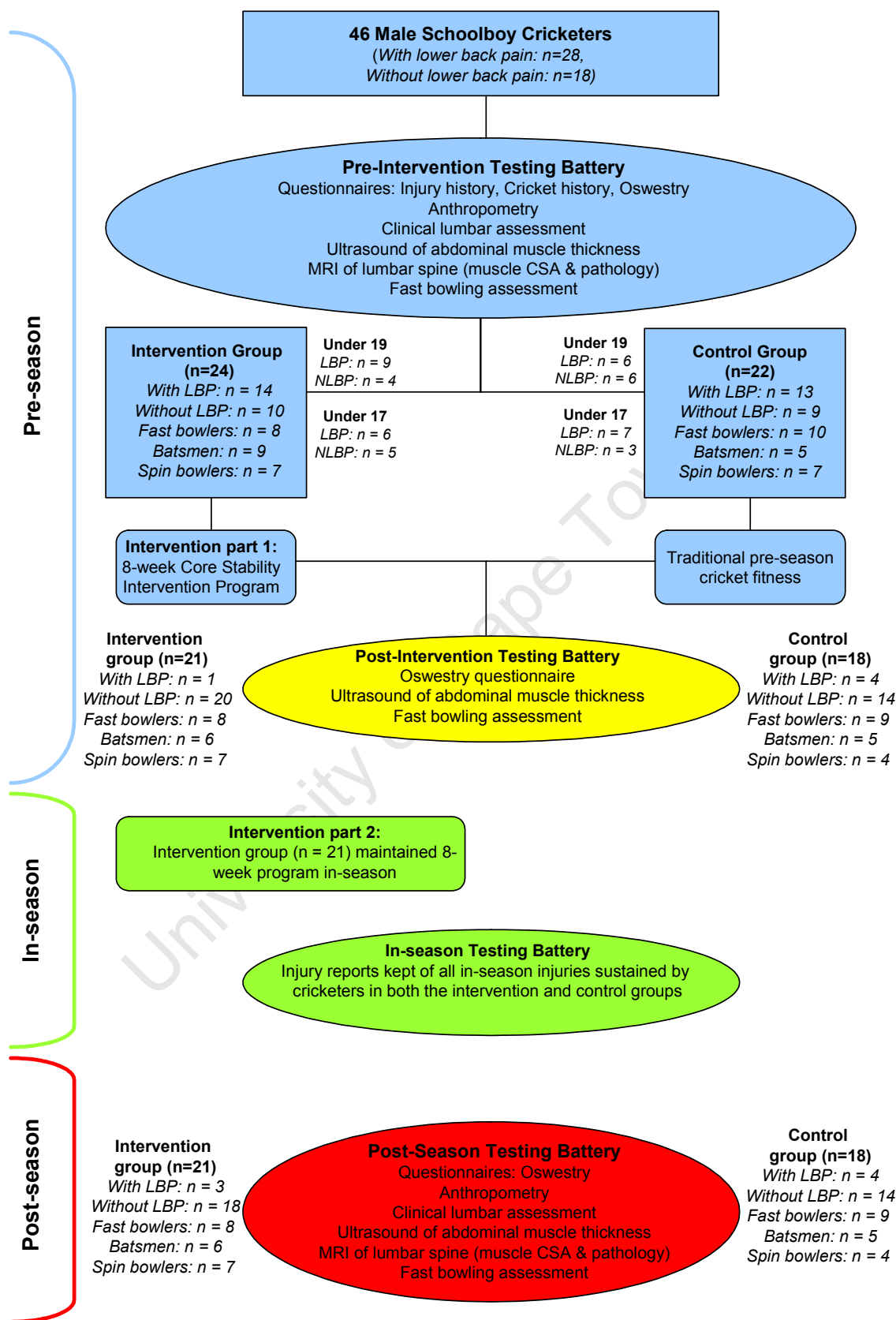


Figure 2.18: Brief outline of study timeline

## SECTION 2

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The next 3 chapters explore the injury occurrence in schoolboy cricketers (Chapter 3) and the relationships between abdominal and lumbar musculature in these cricketers from the following respects: abdominal and lumbar musculature with respect to discipline and lower back pain (Chapter 4) and morphometrical muscle changes after the intervention (Chapter 5).

The chapters in this section are the following:

- Chapter 3: Occurrence of lower back pain in a group of elite schoolboy cricketers
- Chapter 4: Thickness dimensions of the lumbar and abdominal musculature of elite male cricketers with and without lower back pain
- Chapter 5: Abdominal and lumbar muscle symmetry following a lumbar stabilisation intervention in elite schoolboy cricketers

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## CHAPTER 3

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### Occurrence of Lower Back Pain in a Group of Elite Schoolboy Cricketers

#### 3.1 INTRODUCTION

As outlined in Chapter 1, the game of cricket has developed over the years. Furthermore, the rate of injury has increased substantially as more cricketers are exposed to the physical demands involved in this sport. Lower back and trunk injuries account for 18% and 33% of these injuries respectively<sup>3-6</sup>. This finding has created an increased need for injury prevention.

Fast bowling is a major risk factor for injury to both schoolboy and professional cricketers. Indeed, bowlers sustain more than double the occurrence of injuries of batsmen<sup>6</sup>. These injuries can be attributed to a combination of factors, including repetitive loading of the musculoskeletal system (overuse), incorrect technique and poor preparation<sup>3-8;10;11;13-15;30;126</sup>.

Due to the high occurrence of lower back pain in cricketers, it was first necessary to perform an assessment of the occurrence of this sample population's lower back pain prior to the experimental intervention. Furthermore, this part of the study compared previous findings of the occurrence of lower back pain in other groups and the occurrence within this sample population. The work outlined in this chapter also describes the baseline physiological characteristics of the cricketers who participated in this study.

In this chapter, lower back pain is described as a symptom rather than an injury since it does not imply a specific diagnosis. It is recognized that there are limitations in the use of the term 'injury' as this implies that a specific anatomical or pathological diagnosis is made. This was not the case in these cricketers described in this thesis and is a

recognized limitation of this chapter. Therefore, for the purposes of this thesis 'injury' is regarded as pain perceived by the players. Thus, the terminology of 'pain and injury' are used interchangeably. Furthermore, recovery is defined as a resolution of perceived pain as opposed to a player returning to full participation following injury<sup>32</sup>.

The aim of this study was: 1) to assess the prevalence of injuries in a group of schoolboy cricket players who played at representative level; 2) to assess the effect of a cricket specific lumbar stabilisation exercise program on the prevalence of lower back pain and 3) to assess the medical management of injury.

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## 3.2 METHODS

### 3.2.1 Subject characteristics

This was a descriptive study of the injury occurrence in elite male schoolboy cricketers. Forty-six fast bowlers, spin bowlers and batsmen who participated at either under 17 or under 19 levels with a mean age of  $16.6 \pm 0.8$  years were studied.

### 3.2.1 Measurements and calculations

#### 3.2.1.1 Anthropometry

Anthropometric measurements (height (cm); weight (kg) and skinfold measurements (mm)) were collected to assess body fat percentage, body mass index, fat mass (kg), lean body mass (kg) and muscle mass (kg). These measurements were conducted according to the methods described in Chapter 2.

#### 3.2.1.2 Injury history questionnaire

A thorough medical and injury history was recorded for all subjects on entering the study. Injuries were self reported and described as a complaint of pain, either experienced currently or a history of pain. (Refer to Chapter 2; Appendix C).

#### 3.2.1.3 Access to treatment

An access to treatment questionnaire was administered post-season to ascertain the nature of the treatment to which the players had access to on being injured during the season. (Refer to Chapter 2; Appendix F).

#### 3.2.1.4 Oswestry questionnaire

All players completed an Oswestry questionnaire to assess the presence of lower back pain on execution of certain functional tasks. This was recorded as a percentage out of the 66 categories on the questionnaire. The higher the percentage score the greater the lower back pain experienced. (Refer to Chapter 2; Appendix E).

#### 3.2.1.5 Lumbar stabilisation intervention program

An 8-week cricket specific progressive lumbar stabilization exercise program was performed pre-season. As mentioned this program consisted of the cognitive, associative and autonomous phases. The intervention and control groups were assessed pre-intervention and immediately following the 8-week intervention (post-intervention) to determine if changes to occurrence of lower back pain occurred as a result of the intervention program. The groups were further assessed post-season to determine whether the in-season maintenance exercise classes of the intervention had any further effect on lower back pain status. The results are presented as comparisons between intervention and control groups.

#### 3.2.1.6 Statistical analysis

An analysis of variance (ANOVA) with repeated measures was used to determine differences in anthropometric measurements. A Fisher-exact Chi-squared test was performed to determine whether cricketers in the intervention group were more likely to decrease their occurrence of lower back pain following an exercise intervention compared to the control group.

### 3.3 RESULTS

#### 3.3.1 Anthropometry

Anthropometric data comparing the different cricketing disciplines (fast bowlers, spin bowlers and batsmen) are shown in Table 3.1. The fast bowlers had a significantly lower sum of seven skinfold measurements ( $62 \pm 16\text{mm}$ ) ( $p=0.031$ ) and body fat percentage ( $15 \pm 4\%$ ) ( $p=0.037$ ) compared to the spin bowlers ( $87 \pm 38\text{mm}$  and  $19 \pm 5\%$  respectively). There were no other differences with respect to the anthropometric measurements between the cricketing disciplines.

**Table 3.1: A comparison of the anthropometric measurements by cricketing disciplines**

	Fast bowler (n=18)	Spin bowler (n=13)	Batsmen (n=16)	Total (n=47)
Weight (kg)	$66 \pm 7$	$71 \pm 13$	$66 \pm 13$	$67 \pm 11$
Height (cm)	$173 \pm 6$	$174 \pm 9$	$172 \pm 5$	$173 \pm 7$
Body mass index (BMI)	$22 \pm 2$	$23 \pm 4$	$22 \pm 3$	$23 \pm 3$
Sum of skinfolds (mm)	$62 \pm 16^*$	$87 \pm 38$	$68 \pm 23$	$71 \pm 27$
Body fat percentage (%)	$15 \pm 4^\#$	$19 \pm 5$	$16 \pm 4$	$16 \pm 4$
Fat mass (kg)	$10 \pm 3$	$14 \pm 6$	$11 \pm 4$	$11 \pm 4$
Lean body mass (kg)	$56 \pm 6$	$57 \pm 9$	$57 \pm 11$	$57 \pm 9$
Muscle mass (kg)	$33 \pm 9$	$34 \pm 6$	$34 \pm 8$	$34 \pm 7$
Muscle mass (%)	$50 \pm 11$	$49 \pm 5$	$50 \pm 7$	$49 \pm 8$

\*  $p = 0.031$  fast bowlers v spin bowlers

#  $p = 0.037$  fast bowlers v spin bowlers

#### 3.3.2 Occurrence of pain reported by cricketers

##### 3.3.2.1 Previous and current occurrences of pain

The occurrence of injuries to specific anatomical regions separated by cricketing discipline are shown in Table 3.2. Lower back pain accounted for the most injuries ( $n=28$ ; 23%) of injuries by anatomical region, when all cricketing disciplines were combined. Fast bowlers had the highest total occurrence of injury ( $n=46$ ; 38%) in all anatomical regions that were considered. This was followed by batsmen ( $n=39$ ; 33%) and spin bowlers ( $n=35$ ; 29%). The lower back was the most common site of injury across cricketing disciplines (fast bowlers:  $n=14$ , 50%; spin bowlers:  $n=8$ , 29% and

batsmen: n=6, 21%). These percentages are relative to the total injury occurrence for the group of cricketers (n=47).

**Table 3.2: Anatomical region where injury occurred according to cricketing discipline and reported as the number of cricketers injured, with the percentage (%) of the total injury occurrence of injuries for each discipline in brackets**

	Fast bowler (n=18)	Spin bowler (n=13)	Batsmen (n=16)	Total (n=47)
Lower back	14 (50)	8 (29)	6 (21)	<b>28</b>
Shoulder	6 (40)	5 (33)	4 (27)	<b>15</b>
Knee	4 (27)	7 (47)	4 (27)	<b>15</b>
Neck	4 (31)	2 (15)	7 (54)	<b>13</b>
Ankle	2 (22)	5 (56)	2 (22)	<b>9</b>
Thigh	3 (43)	1 (14)	3 (43)	<b>7</b>
Arm/wrist/hand	2 (33)	2 (33)	2 (33)	<b>6</b>
Ribcage	2 (67)	0 (0)	1 (33)	<b>3</b>
Hip muscle	1 (33)	0 (0)	2 (67)	<b>3</b>
Lower limb	1 (33)	0 (0)	2 (67)	<b>3</b>
Toe	1 (33)	1 (33)	1 (67)	<b>3</b>
Groin	1 (50)	0 (0)	1 (67)	<b>2</b>
Hamstring	1 (100)	0 (0)	0 (0)	<b>1</b>
Hip joint	0 (0)	0 (0)	1 (100)	<b>1</b>
Foot	0 (0)	1 (100)	0 (0)	<b>1</b>
<b>Total (Percentage)</b>	<b>46 (38)</b>	<b>35 (29)</b>	<b>39 (33)</b>	<b>120</b>

Table 3.3 shows the anatomical distribution of perceived pain when all 3 cricketing disciplines were analyzed together. The regional pain experienced is separated into pain that players experienced at the time of the study (current), pain experienced in the preceding twelve months, and pain experienced greater than 12 months prior to the commencement of the study. A total of 59 sites were perceived as currently painful. This reflects an increase from the previous 1-12 months (n=56) and especially from the period beyond 12 months prior to the study (n=29). The lower back was found to be the most prevalent region where pain occurred, both on commencement of this study and prior to it.

**Table 3.3: The total number of anatomical sites at which pain was experienced both currently and in the two year period preceding the study**

Type of injury	Current	1-12 months previously	> 12 months previously
Lower back	28	12	6
Ankle	5	1	3
Knee	5	5	0
Groin	4	7	3
Arm/wrist/hand	3	6	8
Neck	3	5	3
Ribcage	3	0	0
Shoulder	3	8	4
Hip muscle	2	1	0
Thigh	2	4	1
Hamstring	1	0	0
Foot	0	1	0
Hip Joint	0	1	0
Lower limb	0	3	0
Toe	0	2	1
<b>Total</b>	<b>59</b>	<b>56</b>	<b>29</b>

An analysis of the activities during which the onset of lower back pain was perceived (see Table 3.4) shows that 43% of pain was sustained during fast bowling, whereas batting accounted for only 21% of the reported occurrence of pain.

**Table 3.4: Activities during which the onset of lower back pain occurred in cricketers (%)**

Activity	Lower back injuries (%)
Fast bowling	43
Batting	21
Fielding	7
Other	29

### 3.3.2.2 Onset of pain sustained by players during the study

More than half (24 out of 46) of the cricketers sustained painful episodes during the study period that were specifically associated with cricketing tasks. Further, as these 24 schoolboy cricketers sustained a total of 39 new occurrences of perceived pain onset, several (n=8) complained of pain more than once. Two players suffered 5 episodes of pain onset each; one player complained of the onset of pain on 3 occasions; five players complained of the onset of pain on 2 occasions each and the remaining 16 players sustained only one episode of pain onset each.

Figure 3.1 shows the occurrence of the complaint of perceived pain per month throughout the study. The most frequent occurrences of perceived pain (n=12) were in February towards the end of the season. The second highest frequency of pain complaints occurred during the pre-season months of August (n=6) and September (n=5). These patterns could be attributed to player fatigue at the end of the season and the possibility that the players began pre-season matches without having had the necessary pre-season preparation. For some, their pre-season tours in September included five consecutive days of matches.

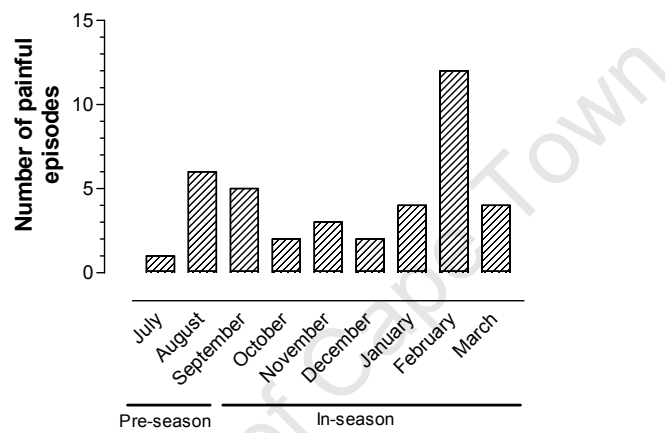


Figure 3.1: Prevalence of the onset of perceived pain by cricketers presented per month throughout the study

Analysis of the anatomical sites at which pain was perceived is shown in Figure 3.2. The majority of pain (n=13) occurred in the lower back region.

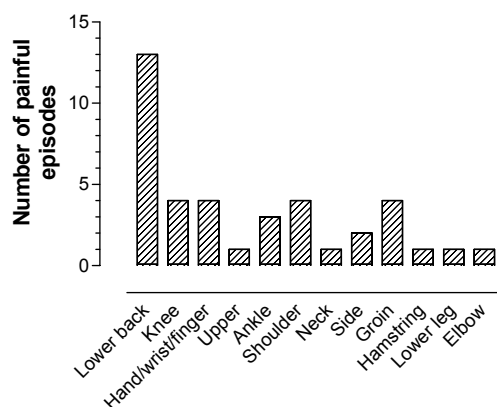


Figure 3.2: Anatomical distribution of perceived pain in cricketers during the study period

An analysis of the occurrence of pain sustained whilst performing cricketing and other sporting activities during the study period is shown in Figure 3.3. This shows that fast bowling was a major initiator of painful episodes (n=14). Spin bowling and batting accounted for only one and three episodes of pain onset respectively. Other cricket specific tasks, such as throwing, diving in the field, sprinting and catching caused a total of 6 new areas of pain. A combination of other activities (not necessarily cricket-related) resulted in a further 15 painful episodes.

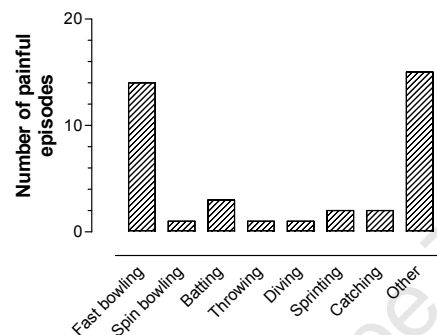


Figure 3.3: Sport specific activities during which the onset of pain occurred in cricketers

Cricketers mostly complained of the onset of pain during matches (n=19) or in practices (n=9), albeit considerably less so in the latter (see Figure 3.4).

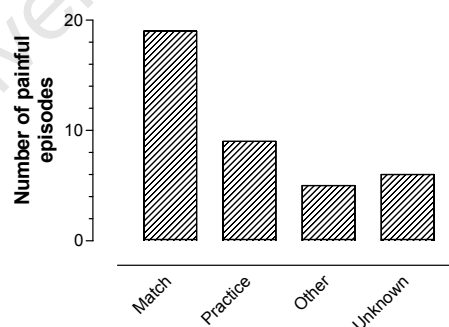


Figure 3.4: Cricketing situations during which the onset of pain occurred  
Note that 'Other' refers to non-cricketing sports activities

The data on new and recurrent episodes of pain are shown in Figure 3.5. This indicates that in this group of cricketers the most frequent pain sustained during the period of the study were new occurrences (n=30) with only nine being recurrent episodes.

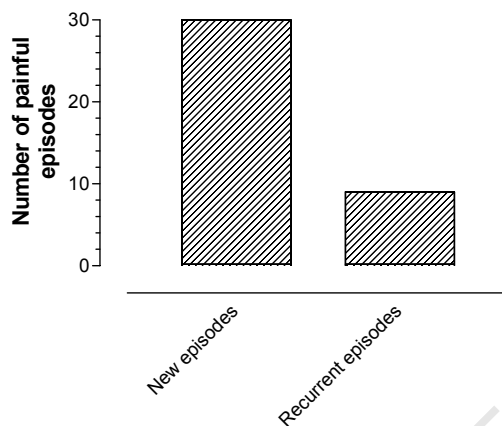


Figure 3.5: New and recurrent episodes of onset of pain during the study period in a group of cricketers

### **3.3.3 Intervention program and maintenance program attendance**

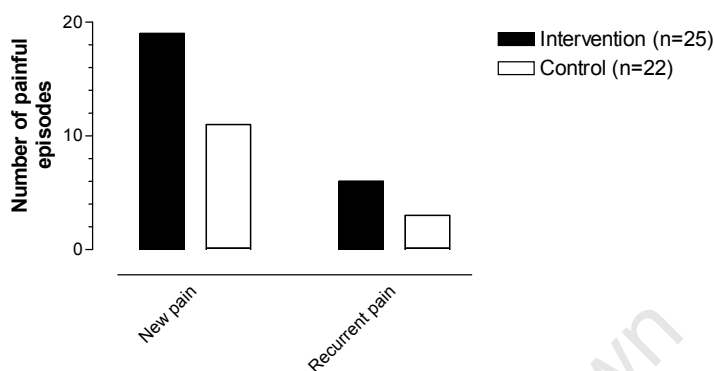
#### **3.3.3.1 Intervention program**

There was an overall attendance of 71% for the entire 8-week intervention program. Phase one (2 weeks) had the highest attendance (81%), followed by phase two (3 weeks: 76%) and phase three (3 weeks: 61%). Therefore as the program progressed compliance decreased. The overall attendance for the in-season maintenance program was 71%. Possible reasons for missed sessions included subjects not having transport as parents and public transport were relied upon; some subjects had to attend a sport's practice; some subjects had school exams to study for and some participants just did not arrive for an exercise session.

#### **3.3.3.2 Perceived pain reported by cricketers in the intervention and control groups**

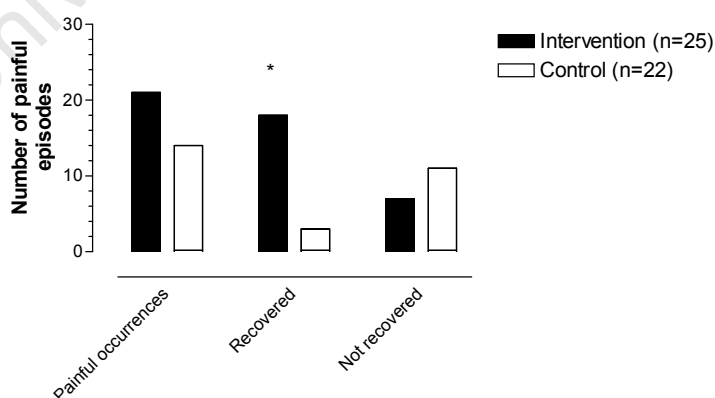
A comparative analysis of onset of perceived pain sustained by the intervention (n=24) and control groups (n=22) found that 14 players in the intervention group (58%) sustained 25 occurrences of pain onset compared to 14 occurrences of pain by ten players (50%) in the control group. One player in each group sustained five episodes of perceived pain, one in the intervention group sustained three, five in the intervention

group sustained two each and 16 players sustained one each. Cricketers in both the intervention and control groups (76% and 79% respectively) recorded a higher occurrence of new rather than recurrent episodes of onset of pain (see Figure 3.6). Fisher-exact chi-squared test showed no significant difference between the groups.



**Figure 3.6: New and recurrent occurrences of acute pain onset experienced by the intervention and control groups**

Figure 3.7 shows the distribution of perceived pain sustained during the study which either resolved or did not resolve by the end of the season. Eighteen (86%) of the 21 episodes of onset of pain sustained by players in the intervention group resolved by the end of the season compared to only 21% (3 out of 14) in the control group. A Fisher exact chi-squared test showed that the resolution of painful symptoms was most likely due to the intervention program ( $p=0.0031$ ).



**Figure 3.7: Recovery of acute painful symptoms experienced by the intervention and control groups**

\* *Intervention v control; recovered:  $p=0.0031$*

### 3.3.4 Lower back pain status following the intervention

On entering the study (see Figure 3.8), fourteen (58%) of the intervention group players reported the presence of lower back pain. However, immediately following the intervention program only one player (4%) in the intervention group continued to complain of lower back pain. Post-season, this number increased to three (12.5%) as two players who had not previously complained of lower back pain sustained injuries through participation in cricket. Of the thirteen (62%) players in the control group who complained of lower back pain on entrance to the study, ten (48%) still complained of pain post-intervention and post-season. A Fisher exact Chi-squared test indicated that the players in the intervention group were more likely to decrease their occurrence of lower back pain following a lumbar stabilisation intervention ( $p=0.0006$ ) as well as maintaining this decrease in lower back pain occurrence post-season ( $p=0.00008$ ) compared to cricketers in the control group.

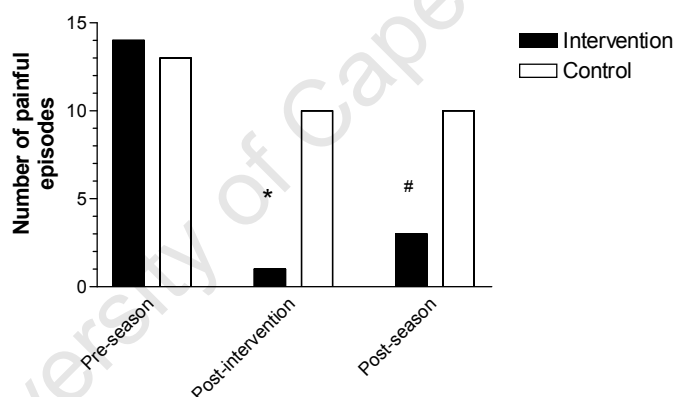


Figure 3.8: Lower back pain pre and post-intervention in the intervention and control groups

\* Post-intervention: Intervention v Control:  $p = 0.0006$

# Post-season: Intervention v Control:  $p = 0.00008$

The degree of lower back pain<sup>III</sup> reported during functional tasks for the groups (intervention and control) analysed by discipline (fast bowlers, spin bowlers and batsmen) was found to be not significantly different pre and post intervention.<sup>IV</sup>

<sup>III</sup> Degree of pain during functional tasks was measured using a scale of 0 to 5, where 0 was no pain experienced during activities and 5 was debilitating pain.

<sup>IV</sup> The tables for the results of the Oswestry questionnaire administered at specific intervals throughout the study are shown in Appendix K Tables: K1 to K3.

### 3.3.5 Pain management: understanding access to medical treatment

It was noticed during the season that some players would not have received adequate pain or injury management, had they not participated in this study. Participants were therefore asked to complete a brief questionnaire to establish their usual patterns of access to medical management of pain, were they not part of a research project. Prior to their involvement in the study, all participants were asked to notify the tester if they sustained any injury or onset of pain during the course of the study. Those who did so were treated appropriately by medical professionals. All players were monitored throughout the study. However, some players in the control group who sustained the occurrence of onset of pain during the season could have notified the tester only at the post-season follow-up.

Of the 45 cricketers who provided information regarding their medical care access (see Figure 3.9), most (76%) said they were financially covered by either medical insurance or their parents. A further 13% had the option of medical treatment being paid for by either their cricket union or other athlete's assistance programs. However, 11% were unable to cover the costs of their treatment for pain.

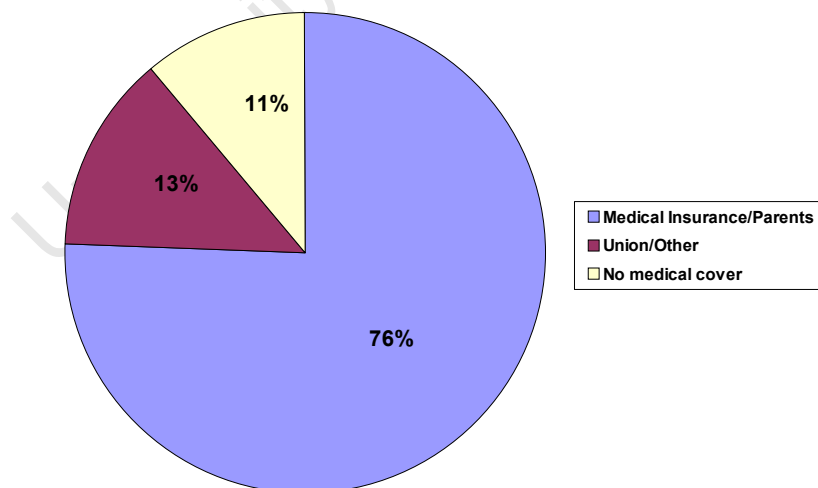


Figure 3.9: Type of access to medical treatment for all subjects (n=45)

The impact of access to medical treatment is seen among the 24 players who sustained episodes of acute onset of pain during the cricket season (see Figure 3.10).

Many were covered by medical insurance or their parents (58%) or they were covered by their cricket union or other athlete's assistance programs (21%). However, 21% had no means of access to medical treatment.

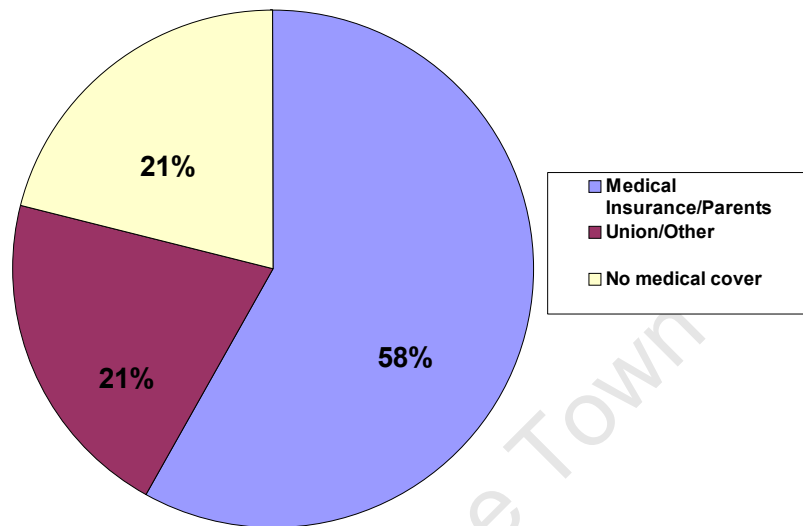
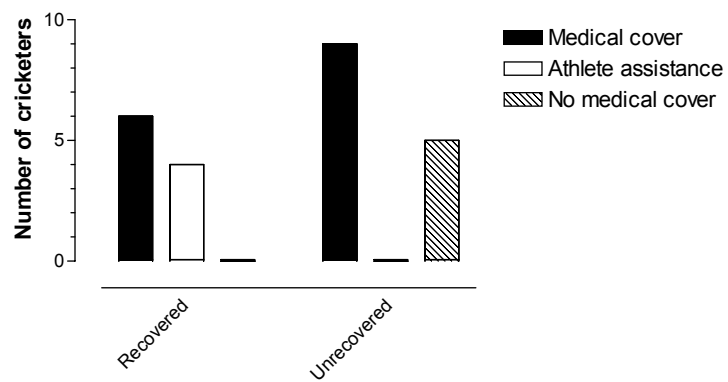


Figure 3.10: Type of access to medical treatment in participants (n=24) who sustained injuries during the study

All ten players (shown in Figure 3.11) whose painful symptoms fully recovered, had medical insurance so that their parents had been able to afford their medical treatment (n=6; 60%) or they were covered by either their cricket union or athlete's assistance program (n=4; 40%). By contrast, of the fourteen players who still complained of pain post-season, only nine (64%) had medical insurance or their parents could afford their medical treatment. Six of these players incurred acute pain onset towards the end of the season (February); therefore their recovery was incomplete by post-season. The other three players sustained acute pain onset between September and November. However, all 9 players continued to play with pain, therefore not allowing for adequate recovery. The five players who had no means of covering their medical costs did not have their injury or symptom of pain diagnosed by a healthcare practitioner. None of these players made us aware of their need for medical treatment at the time they first experienced the onset of pain.



**Figure 3.11: Post Season Recovery and Access to Medical Treatment (Recovered (n=10) and Not recovered (n=14))**

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### 3.4 DISCUSSION

The occurrence of lower back pain and the effects of a lumbar stabilisation exercise intervention program in young cricketers has not been reported previously. Rather, studies have evaluated the effects of changes in bowling technique using coaching and a bowling harness as intervention in reducing the occurrence of lower back injuries<sup>28;55</sup>.

This study highlights the fact that there is a lack of consistency with the assumptions behind certain current definitions. The consensus definition of an injury as “a medical condition that causes a player not to be fully available for selection in a match or during a major match<sup>32</sup>” is inappropriate for schoolboy cricketers as the boys tended to play matches and attend practices regardless of pain and its severity. Moreover, the young cricketers in this study invariably did not inform their coaches of their pain. In this study it was therefore preferred to describe an injury as the occurrence of pain as reported by the players.

Similarly, whereas recovery from an injury has been defined as “when a player is able to return to full participation in at least one match<sup>32</sup>”, the players in the present study did not generally miss matches due to injury. Therefore, recovery, in this study, was defined as the resolution of pain.

Injury incidence has been previously defined as “the number of new injuries which occur over a specific time period<sup>32</sup>”. I had therefore originally anticipated to collect data on duration of batting (minutes) and bowling (overs) over the study period. Study participants were thus required to complete batting and bowling log books. However, most of these young players were not compliant with this request and therefore it was impossible to calculate injury incidence. Furthermore, it was not possible to utilize the definition of injury prevalence defined as “the percentage of players missing from a squad due to injury<sup>32</sup>”. Because (i) this study incorporated various squads and (ii) players continued to play with pain, that is, despite being injured. However, by focusing on the occurrence of injuries (pain) sustained prior to and during the course of the study, I was able to analyze my findings appropriately.

Consistent with previous findings among schoolboy cricketers, the data show that the occurrence of sustained pain or injury are closely associated with the various disciplines and specific activities within cricket<sup>6;35-37</sup>. Thus fast bowlers had the highest

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occurrence of lower back pain prior to this study (50%), followed by spin bowlers (29%) and batsmen (21%).

Further, results of the study indicated that the entire group sustained a total of 90 complaints of pain in the period prior to this cricket season. Given the average age of the players ( $16.6 \pm 0.8$  years), it is clear that some of the players sustained painful symptoms when less than 15 years old and that most of these occurred during the players' growth period. This finding is consistent with previous studies that reported young fast bowlers to be at high risk of injuries because these occur during their growth period when their spines are still immature and are unable to absorb forces effectively<sup>12</sup>. The high occurrence of perceived pain in schoolboy cricketers in this study may be attributed to the lack of basic practice, training principles and specialized coaching at this level. These problems and the fact that not all of the players had access to treatment when pain occurred, places young cricketers at the risk of developing more serious lumbar injuries.

It has been previously suggested that there is a documented need for injury prevention in these young cricketers<sup>3-6</sup>. Having assessed the high occurrence of lower back pain in this specific group of players, a cricket specific intervention program targeted at the rehabilitation and prevention of lower back injuries was implemented. The intervention, a cricket specific core stabilisation program, was implemented over an 8-week period during the pre-season. Player attendance was at 71% for this part of the program which, compares favourably with Koumantakis et. al., (2005) where attendance in their comparative study of a trunk muscle stabilization program and a general exercise program averaged 76% over the 8-week period<sup>151</sup>. Player attendance for the in-season stability maintenance classes was also 71%.

The type of lower back pain in young cricketers appears to be different to that of the general population due to the mechanical stressors of the sport. This was shown in the lack of significant difference between lower back pain and functional disability due to lumbar pain (Oswestry questionnaire), because those with mechanical lower back pain in the general population have reported significant changes in functional disability following an exercise intervention<sup>152</sup>. Therefore, this type of functional injury definition may underestimate the prevalence of lower back pain in this at risk population and this type of questionnaire may not be a sensitive enough method for this cricketing population.

Whereas, 58% of the players in the intervention group reported the presence of lower back pain pre-season whereas only 4% still complained of lower back pain immediately following the completion of an 8-week progressive lumbar stabilisation intervention program. Ten months later, at post-season testing, 12.5% of players in this group reported the presence of lower back pain. All of these were new injuries sustained during the season. None of the players in the intervention group reported the recurrence of lower back pain at follow-up 10 months later. By contrast, of the players in the control group with lower back pain pre-season (62%), nearly all still complained of pain 8 weeks and 10 months later at post-season follow-up.

Whilst there are no data available in cricketers participating in similar programs, these results are consistent with previous findings from lumbar stabilisation programs performed in the general population with chronic lower back pain<sup>98;142</sup>. In one such study the reduction of pain was maintained at 3 and 6 month follow-up and only increased slightly after 30 months<sup>98</sup>. It is likely that the patients in the intervention group may have suffered less recurrent episodes of lower back pain. Hides et. al., (2001) reported a 30% recurrence of lower back pain in adults at a 1 year follow-up after receiving focused retraining of the deep stabilising muscles, whereas the control group reported an 84% recurrence<sup>142</sup>. Given that the recurrence of lower back pain generally occurs in the first year after the initial episode, it is important to implement specific rehabilitation interventions during this period<sup>142</sup>. Therefore, in keeping with previous findings, this study's intervention for a group of young cricketers has proved to be successful in decreasing the occurrence of lower back pain. The results of this chapter are also comparable to the study by Hölmich et, al. (1999) which studied the effect of an 8 to 12 week active training intervention in athletes with groin pain<sup>153</sup>. The researchers found a significant linear trend towards a better effect in the decrease of groin pain in athletes from the active training program compared to athletes who did not participate in active training.

During the course of this study 52% of the participants sustained new or acute onset of pain. This is comparable to previous studies that reported a total of 46% of schoolboy cricketers sustaining episodes of pain during a season<sup>6;34</sup>. In this current study matches accounted for 49% of painful episodes whilst 23% occurred during practices. Fast bowling accounted for 36% of the total episodes of perceived pain whilst batting and spin bowling only resulted in 8% and 3% respectively. Schoolboy fast bowlers

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have been previously reported to sustain between 38% - 47% of occurrences of pain during a season, compared to 30% in the batsmen<sup>34</sup>.

In this study, the majority of pain reported was to the lower back region. Fifty-three percent of these exacerbations of pain in the lower back were sustained by fast bowlers. This is higher than the previously reported percentage of 33%<sup>34</sup>. The difference in the results may have resulted because the previous study was performed seven years prior to this study with the physical demands of cricket having increased over subsequent years. The majority of all occurrences of pain during the study were first episode (74%), with recurrent episodes accounting for only 26% of injuries.

Fifty-eight percent of the intervention group players sustained 25 episodes of perceived pain during the study whilst 50% of the control group sustained 14 episodes. Of all occurrences of acute pain onset sustained during the study period the intervention group reported that 72% recovered as a result of the intervention. This was compared to only 21% recovery in the control group. The greater amount of recovery in the intervention group was found, using a chi-squared analysis, to be most likely due to the intervention program. Therefore, a cricket-specific lumbar stabilisation intervention and in-season maintenance program assists in the recovery of pain. As the control group received traditional pre-season fitness training one could postulate that this modality of training alone is not sufficient to reduce the occurrence of pain.

Of the 39 total episodes of pain sustained by the group during the study, 31% occurred pre-season and 69% during the season. The high number recorded pre-season may be attributed to lack of specific match fitness. Furthermore some pre-season school tours included five consecutive days of cricket matches during September. 31% of the in-season episodes of acute pain onset occurred towards the end of the cricket season. These pre- and in-season results are comparable to previous research reporting that pre-season and end of season produce the highest occurrence of pain onset<sup>37</sup>.

In the process of conducting this research, it became apparent that some players did not have access to adequate immediate medical treatment for pain. As a result I chose to include an access to treatment questionnaire to establish the extent of the problem and its implications. It is clear that had these participants not been involved in the study, they would most likely not have received any pain or injury management. The

intervention group players attended in-season maintenance exercise classes; thus they were more easily monitored with respect to episodes of acute pain. By contrast, the control group only attended pre-season training, post-intervention and post-season testing sessions. As a result, they were more difficult to monitor. Most of the control group participants reported their in-season episodes of acute pain onset only at post-season testing. At this stage it was too late for them to benefit from any immediate medical treatment that could have been made available to them. As a result 21% of the participants who sustained acute pain onset did not have their injuries diagnosed during the study period. The challenge of not reporting onset of pain and interpreting pain as just “being a part of the game” may well be compounded by the costs of medical treatment for those who cannot afford or who do not have medical cover. Unattended symptoms of pain and the failure to properly manage them may result in the increase and severity of injuries in this age group.

Lastly, the demands of cricket and fast bowling in particular, increase the boys' susceptibility to acute exacerbations of pain due to overuse and repetitive loading<sup>33</sup>. If players are unfit or overweight they could be at a greater risk of developing pain. It is therefore important to assess the anthropometric measurements. This study found the fast bowlers to be significantly leaner than spin bowlers. This could be due to the increased fitness required to bowl fast and off longer run-ups. The mean body fat percentage of fast bowlers (15%) and batsmen (16%) are comparable to those of previous studies for this age group (fast bowlers: 9-16% and batsmen 11-18%)<sup>37,154</sup>. Spin bowlers, however, recorded a higher body fat percentage (19%) and sum of skinfolds (87mm) compared to previous studies (body fat %: 10-16% and sum of skinfolds: 67.8mm)<sup>37,154</sup>. A possible explanation for this could be the different cultures and fitness levels of the players in this and previous studies. A further suggestion may be that previous studies were performed ten years prior to this study and the emphasis on spin bowlers was different in South African cricket. This was because the focus was mainly on the development of fast bowlers and not on spin bowlers.

### 3.5 CONCLUSION

Adolescent schoolboy cricketers sustain a high number of injuries, especially in the lower back region and particularly in fast bowlers. The majority of these injuries were sustained during cricket matches, particularly at the beginning and end of the cricket

season. The implementation of a cricket-specific lumbar stabilisation program is effective in significantly reducing the occurrence of lower back pain and increasing the rate of recovery from injury. Importantly, the maintenance of the intervention program was shown to assist in preventing the recurrence of lower back pain when cricketers were tested at a 6-month follow-up. Compliance for both the 8-week intervention and maintenance period was 71%. Furthermore, the consensus injury definition for cricketers needs to be redefined for this specific age group as most schoolboy cricketers tend to play with pain and are unlikely to miss a match or practice session due to injury. Failure to report and monitor their injuries and symptoms of pain, as well as inadequate access to pain and injury management may also increase the occurrence and progression of these injuries. Therefore, access to adequate injury management is important in reducing the occurrence and progression of injuries.

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## CHAPTER 4

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### **Thickness Dimensions of the Abdominal and Lumbar Musculature of Elite Male Cricketers with and without Lower Back Pain**

*This chapter was presented at the 3<sup>rd</sup> World Congress of Medicine and Science in  
Cricket, Barbados 2007.*

#### **4.1 INTRODUCTION**

The rate of injuries to cricketers has substantially increased over the years. These injuries have predominately occurred in the lower back and trunk region with higher occurrence noted amongst fast bowlers<sup>3-6</sup>. Fast bowlers appear to be at a highest risk of injury due to the rotational forces during fast bowling and the high landing forces during the delivery stride, both of which place high demands on the musculoskeletal system. To better understand how injuries occur, it is necessary to investigate the morphometry of the abdominal and lumbar muscles involved in these movements.

The lateral abdominal muscles are involved in rotational trunk movements and play an important role in the stabilisation of the lumbar spine<sup>86;87</sup>. Transverse abdominis (TrA) stabilises the lumbar spine by resisting the rotational forces on the motion segment<sup>86;88;89</sup>. It is possible that this action reduces rotational stress during fast bowling. Indeed, transversus abdominus muscle function is impaired in patients with lower back pain (LBP)<sup>88;89</sup>. Therefore, cricketers with lower back pain who need to resist high rotational lumbar forces during periods of maximal stress on the body might be at risk of further injury if their TrA muscle function is already impaired.

TrA muscle function is measured as a change in muscle thickness from rest to contraction and is a valid indication of the extent of muscle activation at 30% MVC<sup>101;102</sup>. TrA muscle contraction is facilitated by the low abdominal hollowing task<sup>90-92</sup>. Abdominal hollowing causes an increase in TrA thickness and is accompanied by an increase in EMG activity in asymptomatic subjects<sup>76</sup>. However, individuals with LBP

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show a smaller increase in TrA thickness during abdominal hollowing<sup>90</sup>. It is thought that individuals with a history of LBP use different strategies of trunk muscle recruitment compared to those without LBP<sup>101</sup>.

The posterior lumbar muscles assist in stabilising the lumbar spinal segments through coordinated co-contraction with lateral abdominal wall muscles<sup>64-66</sup>. Asymmetries in the relative size of the posterior muscles have been reported in young fast bowlers<sup>108</sup>. Greater muscle volume usually occurs on the bowling arm (dominant) side of the trunk and may be associated with overuse and poor bowling technique, which in turn, may predispose these athletes to lumbar spine injury<sup>13;59;108</sup>. Quadratus lumborum is the most asymmetric of the lumbar muscles in fast bowlers<sup>108;109;112</sup>. An asymmetry of greater than 10% is associated with stress fractures of the pars interarticularis at the 4<sup>th</sup> lumbar vertebral level<sup>108;109</sup>.

The morphometric changes of the deep posterior muscles may provide indirect evidence for chronic changes in the recruitment of these muscles<sup>116;119</sup>. If morphometric changes in these muscles are associated with injury causing lower back pain, then it is of value to identify if possible muscular asymmetries exist in fast bowlers as well as the other cricketing disciplines. This may further assist in profiling the athlete at risk of injury to the lumbar spine and establish a baseline measurement to evaluate the efficacy of a rehabilitation intervention.

Abdominal muscle symmetry in a group of pain free cricketers has previously been investigated<sup>76</sup>. However, no study has assessed players with lower back pain or cricketers involved in the different disciplines of batting and spin bowling. Previous studies of posterior lumbar musculature have focused only on fast bowlers with and without lower back pain. There is a need, therefore, to investigate muscle morphometry of all cricketers with and without lower back pain and according to cricketing discipline.

The aim of this part of the study was to establish a profile of muscle morphometry in elite schoolboy cricketers in all cricketing disciplines and in players with and without lower back pain. To determine this profile, an analysis of 1) muscle thickness was performed of the lateral abdominal musculature of cricketers at rest and during contraction produced by abdominal hollowing and 2) posterior lumbar musculature cross-sectional area.

## **4.2 METHODS**

### **4.2.1 Study design**

This was a descriptive study investigating the size of the lateral abdominal and posterior lumbar musculature of both the dominant and non-dominant sides of elite male schoolboy cricketers. Forty-six cricketers with and without lower back pain from the under 17 and 19 age groups were assessed. Data of bowling or batting dominance were reported in order to relate any muscle asymmetries to the cricketer's dominant or non-dominant side.

### **4.2.2 Measurements and calculations**

#### **4.2.2.1 Measurement of antero-lateral abdominal wall thickness using high resolution soft tissue ultrasound imaging**

The following resting muscle thickness measurements were calculated using the: absolute resting muscle thickness (mm), relative resting muscle thickness (%), total lateral abdominal wall resting thickness (mm); percentage difference between dominant and non-dominant sides (%) and change in muscle thickness during abdominal hollowing ( $\Delta$ mm). See equations I to IV and methods described in Chapter 2.

#### **4.2.2.2 MRI evaluation**

Axial views of the lumbar spine were taken during MR imaging in order to determine the cross-sectional area of the lumbar muscles (psoas, quadratus lumborum, multifidus, longissimus and iliocostalis) at the 4<sup>th</sup> lumbar vertebral level. Muscle morphometry is expressed as absolute cross-sectional area (cm<sup>2</sup>) and percentage difference between dominant and non-dominant sides (%). See equation IX and methods described in Chapter 2.

#### 4.2.2.3 Lower back pain

Lower back pain was recorded as self reported as current pain localised to the lumbar region (As was described in Chapter 3). Participants were divided into those with (n=27) and without lower back pain (n=18) to assess any possible role of differences in their muscle morphometry to the occurrence of lower back pain.

#### 4.2.2.4 Statistical analysis

A Levene's t-test was performed to determine any significant differences in muscle morphometry between those with and without lower back pain. An analysis of variance (ANOVA) with repeated measures was performed to determine significance of muscle morphometry between the cricketing disciplines with and without lower back pain. The Tukey's HSD post-hoc test was the most stringent of post-hoc tests performed when the F-value showed significance. The effect size of cricketers with and without lower back pain in their separate cricketing disciplines was calculated using Cohen's formula<sup>155</sup>. This formula is expressed as the difference between the means of both groups divided by the average of the standard deviations for both groups. The effect sizes were assessed using the following criteria: <0.2 = trivial; 0.2-0.6 = small; 0.6-1.2 = moderate; 1.2 – 2.0 = large and >2.0 = very large.

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## 4.3 RESULTS

### 4.3.1 Subject characteristics

The cricket players had a mean age of  $16.6 \pm 0.8$  years, a mean weight of  $67.8 \pm 10.5$ kg and a mean body fat percentage of  $16.2 \pm 4.3\%$ . (See chapter 3 for a detailed breakdown). There was no correlation between any of the anthropometric measurements and the muscle thickness and cross-sectional area measures therefore, these variables did not influence the thickness or cross-sectional area of the muscles investigated.

### 4.3.2 Lateral abdominal musculature

The total abdominal muscle wall thickness measurements (mm) of the three lateral abdominal muscles are shown in Figure 4.1. When combining the total resting muscle thickness of all the participants, the muscles on the non-dominant side ( $25.8 \pm 3.9$ mm) were significantly thicker compared to the dominant side ( $24.5 \pm 4.4$ mm) ( $F_{1;43}=9.1$ ;  $p=0.004$ ). This figure also shows that there was a significant interaction for total abdominal wall muscle thickness between lower back pain and side ( $F_{1;43}=5.58$ ;  $p=0.023$ ). A Tukey's post-hoc test indicated that cricketers without lower back pain (NLBP) had a significantly thicker total muscle thickness on the non-dominant side ( $26.9 \pm 3.6$ mm) compared to the dominant side ( $24.1 \pm 4$ mm) ( $p=0.006$ ).

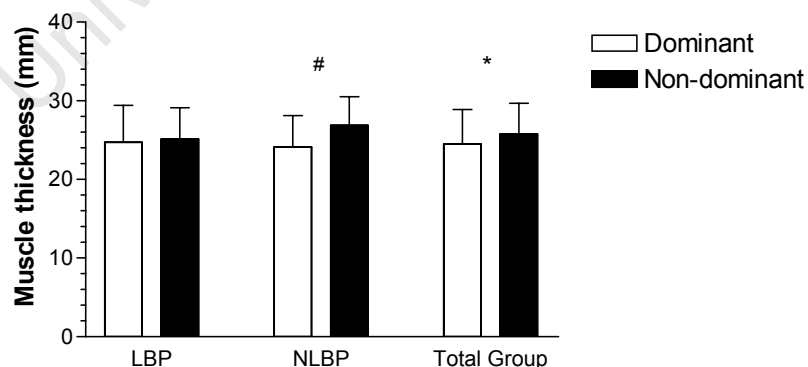


Figure 4.1: Total muscle thickness (OE, OI and TrA) for cricketers with (n=27) and without lower back pain (n=18)

Abbreviations: LBP, lower back pain; NLBP, no lower back pain

\* Dominant v non-dominant Total:  $p = 0.004$ ; # Dominant v non dominant NLBP:  $p = 0.006$

Table 4.1 shows the absolute resting muscle thickness percentage difference between dominant and non-dominant sides in cricketers with and without lower back pain. Cricketers without lower back pain were asymmetrical between transverse abdominis on the dominant and non-dominant sides ( $p=0.002$ ) compared to cricketers with lower back pain. Thus the cricketers without lower back pain had a thicker TrA muscle on the non-dominant side compared to the dominant side

**Table 4.1: Absolute resting muscle thickness percentage difference (%) between dominant and non-dominant sides in cricketers with and without lower back pain**

Muscle	LBP (n=27)	NLBP (n=18)
OE	$-0.3 \pm 30.1$	$-12.7 \pm 42.5$
OI	$-7.9 \pm 14.4$	$-18.7 \pm 29.0$
TrA *	<b><math>0.9 \pm 15.5</math></b>	<b><math>-16.3 \pm 18.4</math></b>

*Abbreviations: OE, external oblique; OI, internal oblique; TrA, transverse abdominis; LBP, lower back pain; NLBP, no lower back pain*

\* TrA LBP v NLBP:  $p=0.002$

Table 4.2 shows the change in muscle thickness during abdominal hollowing in cricketers with and without lower back pain. Cricketers with lower back pain had a greater change in muscle thickness during abdominal hollowing for dominant OI ( $p=0.04$ ), dominant TrA ( $p=0.009$ ) and non-dominant TrA ( $p=0.04$ ) compared to cricketers without lower back pain.

**Table 4.2: Change in muscle thickness ( $\Delta$ mm) during abdominal hollowing in cricketers with and without lower back pain**

Muscle	Side	LBP (n=27)	NLBP (n=18)
OI	Dom *	$1.0 \pm 1.0$	$0.4 \pm 0.9$
	ND	$1.2 \pm 0.9$	$0.6 \pm 0.6$
TrA	Dom #	$2.0 \pm 0.9$	$1.2 \pm 0.9$
	ND @	$1.9 \pm 1.3$	$1.2 \pm 1.1$

*Abbreviations: OE, external oblique; OI, internal oblique; TrA, transverse abdominis; LBP, lower back pain; NLBP, no lower back pain*

\* OI Dom, LBP v NLBP:  $p=0.04$

# TrA Dom, LBP v NLBP:  $p=0.009$

@ TrA ND, LBP v NLBP:  $p=0.04$

Figure 4.2 shows the absolute resting muscle thickness measurements (mm) of the three lateral abdominal muscles (OE, OI and TrA). When combining all participants there was a significant main effect for absolute muscle thickness of OI on the non-dominant side ( $F_{1,42}=11.68$ ;  $p = 0.001$ ). Thus the OI muscle was thicker on the non-dominant side compared to the dominant side for the total group of cricketers. However, there was no difference between muscle thickness measurements between the dominant and non-dominant sides with respect to TrA and OE.

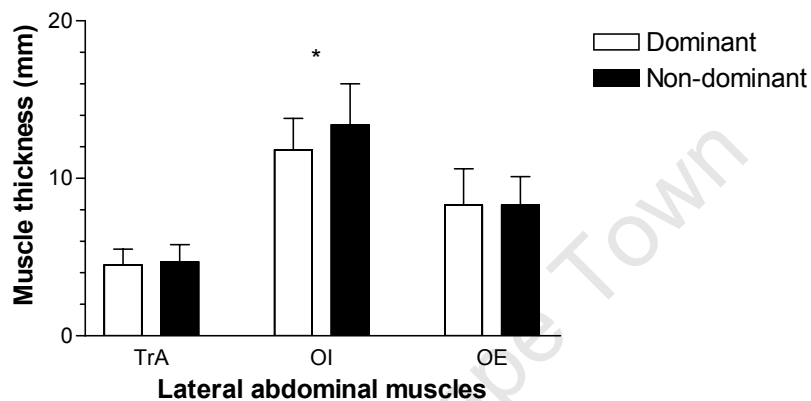
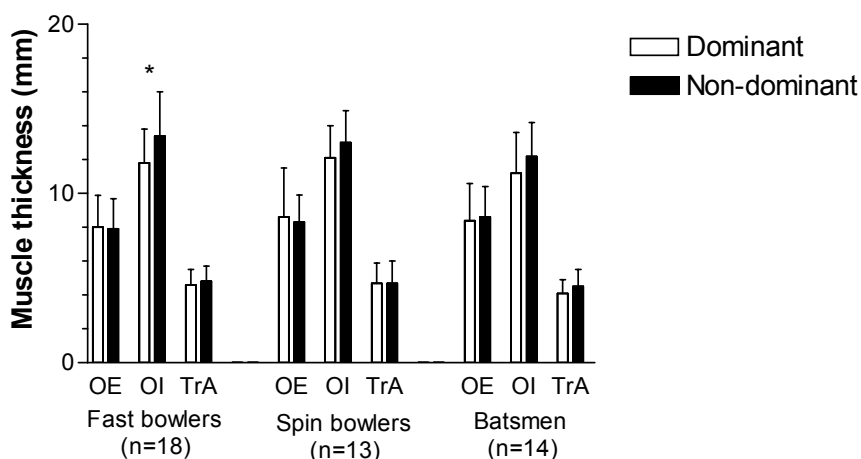


Figure 4.2: Absolute muscle thickness measurements (mm) of transverse abdominis, internal oblique and external oblique in a group of cricketers (n=45)

Abbreviations: OE, external oblique; OI, internal oblique; TrA, transverse abdominis

\* Dominant v non-dominant OI :  $p = 0.001$

The absolute resting muscle thickness (mm) measurements of the lateral abdominal musculature are shown in Figure 4.3. The OI muscle in the fast bowlers was significantly thicker on the non-dominant side ( $13 \pm 3\text{mm}$ ) compared to the dominant side ( $12 \pm 2\text{mm}$ ) ( $p=0.038$ ).



**Figure 4.3: Absolute muscle thickness measurements (mm) of transverse abdominis (TrA), internal oblique (OI) and external oblique (OE) by discipline in cricketers (n=45)**

**Abbreviations: OE, external oblique; OI, internal oblique; TrA, transverse abdominis**

**\* Fast bowlers: dominant v non-dominant OI:  $p = 0.038$**

There were no differences in dominant and non-dominant total abdominal wall muscle thickness (mm), relative resting muscle thickness (%) and change in muscle thickness during abdominal hollowing ( $\Delta$ mm) across cricketing disciplines. There were also no significant differences in absolute resting muscle thickness (mm) and relative resting muscle thickness (%) comparing cricketers with and without lower back pain. Furthermore, there were no differences in relative resting muscle thickness (%) when comparing cricketing disciplines with and without lower back pain.<sup>v</sup>

The cricketing disciplines were analysed with respect to cricketers with and without lower back pain. Separating the cricketers into their respective disciplines in each of these two groups reduced the sample numbers analysed (fast bowlers: with LBP n=14, without LBP n=4; spin bowlers: with LBP n=8, without LBP n=5); batsmen: with LBP n=5, without LBP n=9), therefore, the statistical power when performing statistical analysis using analysis of variance was reduced. This lack of statistical power may have thus demonstrated significance where in fact there was none, thus producing a false positive. Therefore, the effect sizes between fast bowlers with and without lower back pain for dominant (0.47) and non-dominant (0.92) OI were calculated, showing a small and moderate effect size respectively. The data for total abdominal wall muscle thickness, internal oblique muscle symmetry and change in TrA muscle thickness are

<sup>v</sup> See Appendix K, Table K4 to K8 for non-significant result tables

shown in the appendix.<sup>vi</sup> Furthermore, there was no difference in resting relative muscle thickness when comparing cricketing disciplines with and without lower back pain.<sup>vii</sup>

### 4.3.3 Posterior lumbar musculature

#### 4.3.3.1 Players separated into cricketing disciplines

Figure 4.4 shows the cross-sectional area (cm<sup>2</sup>) of the longissimus posterior lumbar muscle of fast bowlers, spin bowlers and batsmen. There was a significant difference between the cross-sectional area of the longissimus muscle on the dominant (7.1 ± 1.3cm<sup>2</sup>) and non-dominant sides (6.7 ± 1.3cm<sup>2</sup>) when combining the total group of cricketers (n=47) (F<sub>1,43</sub>=4.40; p = 0.041).

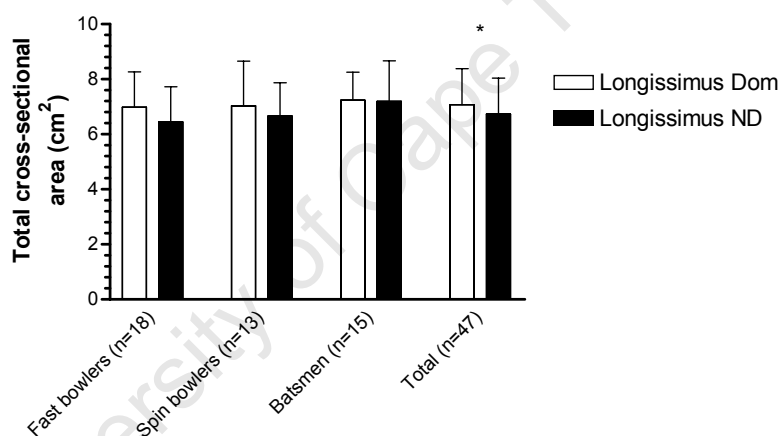


Figure 4.4: Cross-sectional area of longissimus lumbar muscle on the dominant and non-dominant sides in the different cricketing disciplines

Abbreviations: Dom, dominant; ND, non-dominant

\* Dominant v non-dominant p = 0.041

There were no further significant differences in the percentage difference between the dominant and non-dominant sides of the other posterior lumbar muscle's cross-sectional area (psoas, quadratus lumborum, multifidus and iliocostalis) for the total group of cricketers or across cricketing disciplines. Therefore, the abovementioned

<sup>vi</sup> See Appendix K, Figures K1 and K2 and Table K9 for results of significance in small sample groups

<sup>vii</sup> See Appendix K, Table K10 for resting relative muscle thickness with respect to cricketing discipline with and without lower back pain

muscles' cross-sectional area across cricketing disciplines appears to be symmetrical<sup>VIII</sup>.

#### 4.3.3.2 Players separated into cricketers with and without lower back pain

Table 4.3 shows the posterior lumbar muscle cross-sectional area for cricketers with and without lower back pain. The cross-sectional area of the quadratus lumborum muscle on the dominant side was found to be significantly greater in cricketers with lower back pain compared to players without lower back pain ( $p=0.035$ ).

**Table 4.3: Posterior lumbar cross-sectional area (cm<sup>2</sup>) separated into cricketers with and without lower back pain**

Muscle	Side	LBP (n=28)	NLBP (n=18)
Psoas	Dom	20.0 ± 3.1	20.2 ± 3.5
	ND	20.0 ± 3.3	20.1 ± 3.2
Quadratus Lumborum	Dom *	<b>8.8 ± 1.7</b>	<b>7.7 ± 1.4</b>
	ND	8.5 ± 1.7	8.0 ± 2.0
Multifidus	Dom	6.9 ± 1.6	6.8 ± 1.1
	ND	7.1 ± 1.8	6.8 ± 1.3
Longissimus	Dom	7.1 ± 1.4	7.0 ± 1.2
	ND	6.9 ± 1.5	6.5 ± 0.9
Iliocostalis	Dom	12.3 ± 2.9	13.6 ± 2.7
	ND	12.1 ± 2.8	13.6 ± 2.9

**Abbreviations: LBP, lower back pain; NLBP, no lower back pain; Dom, dominant side; ND, non-dominant side**

**\* Dominant LBP v NLBP:  $p=0.035$**

The percentage difference of individual muscle cross-sectional area of the posterior lumbar muscles across cricketing disciplines with and without lower back pain also showed no significant differences. Therefore the dominant and non-dominant sides were symmetrical independent of pain.<sup>IX</sup>

<sup>VIII</sup> See Appendix K, Table K11 and K12 for the posterior lumbar cross-sectional area results separated into cricketing disciplines and for total group

<sup>IX</sup> See Appendix K, Tables K13 and K14 for results of posterior lumbar percentage difference in cross-sectional area

#### 4.4 DISCUSSION

Previous studies have shown that individuals with lower back pain use different abdominal muscle recruitment strategies and have different lumbar muscle morphometry compared to individuals without lower back pain<sup>71;75;80;85;90;91;101;105</sup>. Whilst, Hides et. al., (2006) assessed resting muscle thickness and TrA muscle function during abdominal hollowing in an asymptomatic group of young cricketers<sup>76</sup>, there are no normative data describing the morphometry and muscle function with respect to schoolboy cricketers with lower back pain and across cricketing disciplines. Thus the current study is the first to describe normative data in symptomatic cricketers. It is important to note that all findings relating to cricketing disciplines with and without lower back pain should be treated with caution due to the small number of cricketers in these groups. This limitation of the study is apparent and further research needs to be conducted to determine if the significance found is in fact the case.

The first important finding of this study was that the combined group of cricketers had a thicker lateral abdominal wall (OE + OI + TrA) on the non-dominant side. Further analysis indicated that this asymmetry was specific to cricketers without lower back pain. Analysis with respect to the order of thickness of the abdominal wall muscles was consistent with previous findings<sup>75</sup>, indeed the OI muscle had the largest muscle thickness, followed by OE and TrA. Thus the order of thickness in cricketers was found to be the same as the general population despite the rigorous nature of the sport.

Further analysis of the separate muscles of the abdominal wall revealed that OI was thicker on the non-dominant side whilst OE and TrA were not different between sides. Thus the abdominal wall asymmetry described is due to the differences in thickness of OI. Further investigation indicated that the asymmetry of OI was only present in the fast bowling group and specific to the bowlers without lower back pain. This is likely to be an adaptation of the fast bowling technique as non-dominant OI is partly responsible for the strong forward rotation of the shoulder during the delivery stride<sup>10;25;29</sup>. It is of interest that these differences in OI were not present in fast bowlers with lower back pain, spin bowlers and batsmen. However, as once again due to the limitation of the small sample these significant results may demonstrate significance where in fact there is none and this finding should be interpreted with caution. Further research should be conducted assessing the cricketing disciplines with and without lower back pain using a larger sample group to either validate or disprove these

results. However, should this finding indeed be the case, then as mentioned above, it may be a possible protective mechanism for fast bowlers. Our finding in this study, however, does support that of Hides et. al.,(2006) who also found OI to be thicker on the non-dominant side in asymptomatic cricketers. However, a limitation of the study by Hides et. al., (2006) was that cricketers were not separated into specific cricketing disciplines. Thus this finding is unique to this current study. Furthermore this asymmetry appears to be specific to fast bowling cricketers as a previous study found no asymmetry in the OI muscle between sides in the non-cricketing population<sup>75</sup>. Therefore, further research involving abdominal muscle asymmetry in fast bowlers needs to include a greater number of participants both with and without lower back pain.

A further finding was that cricketers without lower back pain demonstrated more asymmetry in absolute resting transverse abdominis muscle thickness between the dominant and non-dominant sides compared to cricketers with lower back pain who appeared to be more symmetrical with respect to these measurements. The TrA muscle was found to be thicker on the non-dominant side in cricketers without lower back pain compared to their dominant side. It is important to point out that TrA assists in spinal stability and is not a rotator<sup>86;87</sup>, therefore it is anticipated that this muscle would not hypertrophy. Furthermore, a study by Hides et. al., (2006) reported symmetry of the resting TrA muscle thickness in asymptomatic cricketers<sup>76</sup>. However, their study assessed resting muscle thickness on MRI, whereas the current study used ultrasound, therefore the difference in the methods may possibly account for the differences in findings. Furthermore, this previous study assessed an older group of cricketers, compared to the younger cricketing group in the current study. This greater muscle thickness on the non-dominant side is, however, in keeping with the pattern of non-dominant hypertrophy as seen in OI. Therefore, this hypertrophy of non-dominant TrA may be associated with the asymmetrical nature of the biomechanics involved in fast bowling, spin bowling or batting. As this finding is not what would be expected in the TrA muscle, further research is required to assess TrA muscle symmetry in pain free cricketers.

Transverse abdominis muscle function is reported to be impaired in individuals with lower back pain<sup>88;89</sup>. However, unlike previous studies<sup>70;90;97</sup>, findings in this study indicate that change in TrA muscle thickness during abdominal hollowing on both the dominant and non-dominant sides is greater in cricketers with lower back pain

compared to those without lower back pain. Cricketers with lower back pain also had a greater change in dominant OI muscle thickness during abdominal hollowing compared to those without lower back pain. A possible reason for the contrasting findings to previous research may be that this is a young sporting population group is used to resistance training and thus they may not have maintained the 30-40% contraction during abdominal hollowing. Thus an increase in contraction during abdominal hollowing may have caused a non-linear change in muscle thickness. It is possible that even though it appears that the cricketers with lower back pain are still able to preferentially recruit TrA, there may still be delayed onset of activation of this muscle prior to the contraction of the prime movers. However, as EMG was not used as a method of assessment to determine the strength of the contraction or time of the muscle's activation, further research of this cricketing population is required.

Of interest is that the fast bowlers with lower back pain also had a greater change in TrA muscle thickness on the non-dominant side during abdominal hollowing and had more symmetrical TrA muscle function compared to bowlers who were pain free. However, this finding should be interpreted with caution as there was a limitation of this being a small group of pain free fast bowlers (n=4) and therefore possibly a false positive. It is also possible, however, that previous studies did not disseminate cricketing disciplines or participants were not cricketers. A further possibility is that non-dominant OI is hypertrophied in this group which may limit the ability of TrA to increase sufficiently when contracting due to the OI compressing the TrA muscle. The use of ultrasound measurement may also not be sensitive enough for the assessment of TrA muscle function in this athletic group. However, in saying this, the reason for these differences is not directly apparent and therefore needs further investigation with larger sample groups to either validate or disprove these findings.

All of the posterior lumbar musculature in fast bowlers has previously been shown to be significantly greater in muscle volume on the dominant compared to the non-dominant side<sup>108</sup>. A recent study by Ranson et. al. (2008) confirmed that not only is the muscle volume greater on the dominant side but also the cross-sectional area at specific lumbar levels of quadratus lumborum, multifidus and erector spinae<sup>112</sup>. Our study found that dominant quadratus lumborum in the combined group of cricketers with lower back pain was greater than in cricketers without pain. However, unlike previous studies<sup>59;108;109;112</sup>, there was no significant difference found in this muscle when specifically analyzing the fast bowling group. It is possible that this divergence in

results is due to the fact that the previous studies assessed muscle volume and not cross-sectional area as was the case in this study. Furthermore, cross-sectional area was only measured at the 4<sup>th</sup> lumbar vertebral level and not at multiple levels. Further research is thus required to investigate lumbar muscle cross-sectional area at multiple lumbar vertebral levels.

Furthermore, longissimus (one of the erector spinae muscles) cross-sectional area was larger on the dominant side when combining the cricketing disciplines compared to the non-dominant side. Erector spinae has been suggested to hypertrophy due to relatively large trunk forces<sup>120</sup>. Therefore due to the asymmetrical nature of the cricketing disciplines and the forces acting on the lumbar spine, the longissimus appears to have hypertrophied. This muscle was not found to be significantly different in cricketers with and without lower back pain, which is unlike that found in rowers, who demonstrated a larger muscle cross-sectional area in rowers with lower back pain<sup>121</sup>.

#### 4.5 CONCLUSION

The findings of this study suggest that asymmetry of the abdominal and lumbar muscles indeed occur in cricketers. Total abdominal wall and resting absolute internal oblique muscle thickness was greater on the non-dominant side in the combined group of cricketers. Cricketers without lower back pain demonstrated asymmetry in total abdominal wall muscle thickness and asymmetry in resting TrA muscle thickness with the non-dominant side being thicker. Cricketers without lower back pain had a lower change in muscle thickness of the OI and TrA muscles during abdominal hollowing, compared to those with lower back pain. Furthermore, fast bowlers demonstrated asymmetry of resting absolute internal oblique muscle thickness, with the non-dominant side being thicker than the dominant side. The posterior muscle, longissimus, was found to be asymmetrical in the combined group of cricketers with the dominant side having a greater cross-sectional area than the non-dominant side. Furthermore, dominant quadratus lumborum was found to have a greater cross-sectional area in cricketers with lower back pain compared to those without lower back pain.

## CHAPTER 5

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### **Abdominal and Lumbar Muscle Symmetry Following a Lumbar Stabilisation Intervention in Elite Schoolboy Cricketers**

*An abstract for this chapter has been accepted for presentation at the 2<sup>nd</sup> World Sports  
Injury Conference, Norway, June 2008*

#### **5.1 INTRODUCTION**

Although many papers propose rehabilitation and strengthening to decrease lower back injury<sup>70;98;136;138;142</sup>, however, to the best of my knowledge, this is the first study that assessed the effects of a lumbar stabilisation intervention program on muscle thickness and cross-sectional area of the lateral abdominal and posterior lumbar musculature respectively, in cricketers with and without lower back pain. Previous lumbar stabilisation intervention programmes have focused on the re-training of transverse abdominis in a non-cricketing population<sup>70;98;136;138;142</sup>. These studies have assessed only the effect of the programs on the recurrence of lower back pain and not changes in muscle thickness. In Chapter 3 it was shown that this intervention significantly reduces the occurrence of lower back pain in schoolboy cricketers.

Cricketers, specifically fast bowlers, being athletes who adopt a hyperlordotic movement such as fast bowling, are at risk of sustaining injuries<sup>156</sup>. Spinal stability can be achieved through an appropriate interaction between the abdominal and lumbar muscles which control lumbar spine stability<sup>19;98</sup>. O'Sullivan et al., (1997) demonstrated that rehabilitation should focus on retraining the precise co-contraction of the deep trunk muscles (transverses abdominis and lumbar multifidus) to decrease pain, increase stability and functional ability<sup>98</sup>.

An intervention study that focuses on lumbar stabilisation is important as the function of the TrA muscle is reduced in patients with LBP<sup>85</sup>. It is believed that the TrA muscle can be trained independently of the other abdominal muscles in order to regain its

functional ability<sup>71</sup>. Hence the need to assess the effect of an intervention program on changes in TrA muscle thickness during abdominal hollowing. It is well known that lumbar muscles are synergistic and work in bilateral pairs, yet injuries to the lumbar spine seldom occur symmetrically<sup>72:157</sup>. The second important reason for conducting this intervention study was to assess the abdominal and posterior muscle symmetries and determine changes following the intervention program.

The aim of this study was, therefore, to assess the effect of a lumbar stabilisation intervention on morphometric changes to the lateral abdominal and posterior lumbar musculature in a group of elite schoolboy cricketers.

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## 5.2 METHODS

### 5.2.1 Study design

This was an intervention study investigating the lateral abdominal and posterior lumbar muscle morphometry pre and post-intervention of elite male schoolboy cricketers. Data collected on 39 cricketers from all disciplines, with and without lower back pain and completed all three testing sessions were analysed. Detail reporting on bowling or batting dominance was obtained in order to assess symmetry.

### 5.2.2 Measurements and calculations

#### 5.2.2.1 Measurement of antero-lateral abdominal wall thickness using high resolution soft tissue ultrasound imaging

The following measurements of muscle thickness of external oblique, internal oblique and transverse abdominis, following the intervention were calculated using equations V to VII and methods described in Chapter 2; absolute resting muscle thickness (mm), relative resting muscle thickness (%), total lateral abdominal wall resting thickness (mm) and percentage difference between dominant and non-dominant sides (%).

#### 5.2.2.2 MRI measures

The muscle morphometry of psoas, quadratus lumborum, multifidus, longissimus and iliocostalis are expressed as relative cross-sectional area (cm<sup>2</sup>) and percentage difference between dominant and non-dominant sides (%). These parameters were assessed pre-intervention and post-season using equations X to XII and methods described in Chapter 2.

#### 5.2.2.3 Intervention program

An 8-week cricket specific progressive lumbar stabilization program was performed pre-season. As mentioned in Chapter 2, this program consisted of the cognitive, associative and autonomous phases. A detailed description of the intervention can be

found in Chapter 2. The intervention and control groups were assessed pre-intervention and immediately following the 8-week intervention (post-intervention) to determine if changes occurred as a result of the intervention program. The groups were further assessed post-season to determine whether the in-season maintenance exercise classes had any further effect on muscle morphometry. During the 8-week intervention the control group performed traditional pre-season cricket training, with no training occurring during the cricket season. The results are presented as comparisons between intervention and control groups.

#### 5.2.2.4 Lower back pain

Lower back pain was defined as self reported lower back pain as detailed in Chapter 2. On the basis of these symptoms, participants were divided into cricketers in the intervention and control group with and without lower back pain following the intervention period with the purpose of assessing any differences in their muscle morphometry with change in lower back pain status. The group without lower back pain included cricketers who either resolved their lower back pain or did not experience any lower back pain during the intervention period. The group with lower back pain included cricketers who either continued to complain of lower back pain or developed new onset of pain during the study period.

#### 5.2.2.5 Statistical analysis

Statistical analysis was performed using analysis of variance (ANOVA) with repeated measures to determine changes in muscle morphometry over time. Due to the small sample size and thus a lack of statistical power, further post-hoc analysis was not performed as it was likely to show significance where in fact it did not exist. Therefore, only the main effect is reported when significant. Levene's t-test was performed to assess changes in muscle morphometry where there were only two groups to assess.

## 5.3 RESULTS

### 5.3.1 Subject characteristics

Participants had a mean age of  $16.7 \pm 0.8$  years; a mean weight of  $67.5 \pm 9.7$ kg and a mean body fat percentage of  $16.0 \pm 4.3\%$ . There were no significant differences between these anthropometric measures in the different groups (see Chapter 3).

### 5.3.2 Lateral abdominal muscle thickness

#### 5.3.2.1 Analysis of combined cricketing disciplines

Table 5.1 shows changes in total resting abdominal wall muscle thickness for combined disciplines. There was a significant interaction for dominant total abdominal wall muscle thickness between groups over time ( $F_{2,74}=3.89$ ;  $p=0.025$ ). Thus the total abdominal wall muscle thickness on the dominant side appeared to significantly increase in the intervention group immediately post-intervention compared to the control group.

**Table 5.1: Percentage change (%) in total lateral abdominal wall thickness pre- and post-intervention**

	Side	Intervention (n=21)	Control (n=18)
Pre-intervention v Post-intervention *	Dom	$-7.4 \pm 12.7$	$3.9 \pm 13.0$
	ND	$-0.1 \pm 14.4$	$-4.2 \pm 15.5$
Pre- intervention v Post-season	Dom	$-4.1 \pm 19.8$	$7.9 \pm 15.6$
	ND	$5.7 \pm 11.7$	$6.3 \pm 17.7$
Post-intervention v Post-season	Dom	$2.9 \pm 14.3$	$4.0 \pm 10.6$
	ND	$1.3 \pm 13.7$	$10.0 \pm 10.9$

**Abbreviations: Dom, dominant side; ND, non-dominant side**

**\* Intervention v control\*Time:  $p = 0.026$**

Table 5.2 shows the change over time in percentage difference between dominant and non-dominant total resting abdominal wall muscle thickness. The intervention and control groups responded differently over time ( $F_{2,74}=6.91$ ;  $p=0.0018$ ). It appears, however, that the intervention group reduced their percentage difference in total abdominal wall muscle thickness ( $-11.6 \pm 15.7\%$  to  $0.1 \pm 11.2\%$ ) during the 8-week intervention program compared to the control group. Thus the intervention group's

dominant and non-dominant total abdominal wall, appear to become more symmetrical. Furthermore, it appears that there is little change from post-intervention to post-season therefore the intervention group possibly maintained their changes in abdominal wall muscle symmetry.

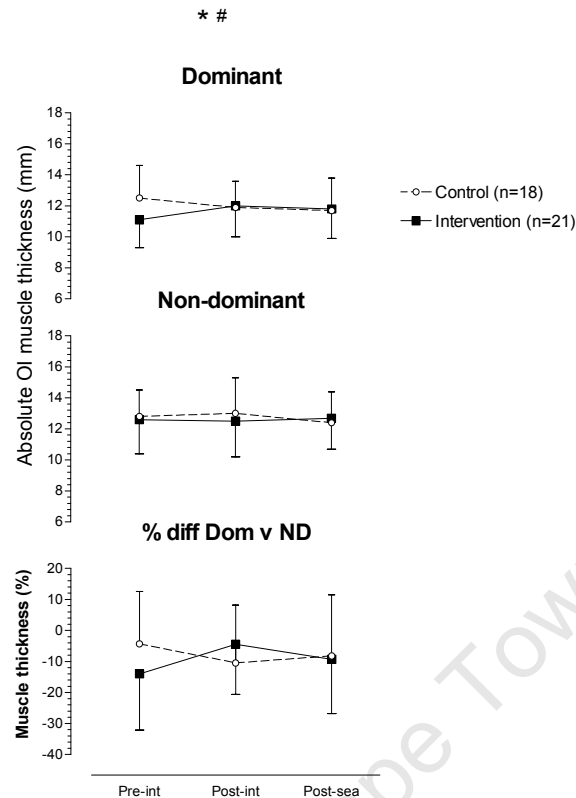
**Table 5.2: Change (%) in percentage difference between dominant and non-dominant total resting muscle thickness for the intervention and control groups over time**

	Intervention (n=21)	Control (n=18)
Pre-intervention v post-intervention *	-11.7 ± 16.6	8.6 ± 15.9
Pre-intervention v post-season	-9.4 ± 18.4	2.3 ± 20.4
Post-intervention v post-season	-2.3 ± 13.0	-6.3 ± 18.1

*Negative values show a greater non-dominant side compared to the dominant side*

\* *Significant main effect: p=0.0018*

Figure 5.1 shows the change in absolute dominant and non-dominant resting internal oblique muscle thickness (mm) over time. The intervention and control groups responded differently with respect to change in dominant OI over time ( $F_{2,74}=4.21$ ;  $p=0.019$ ). It appears that the intervention group increased their dominant OI muscle thickness during the 8-week intervention period and maintained the change by post-season testing ( $11 \pm 2\text{mm}$  to  $12 \pm 2\text{mm}$  to  $12 \pm 2\text{mm}$ ), compared to the control group who demonstrated a decrease in dominant OI muscle thickness. Percentage difference in OI between the groups over time is also shown in Figure 5.2. The groups responded differently over time ( $F_{2,74}=3.31$ ;  $p=0.042$ ) with the intervention group appearing to become more symmetrical over the 8-week intervention period ( $-14 \pm 18\%$  to  $-4 \pm 16\%$ ), compared to the control group who appeared to become more asymmetrical during the same period ( $-4 \pm 17\%$  to  $-11 \pm 19\%$ ).



**Figure 5.1: Change in absolute internal oblique resting muscle thickness and percentage difference between dominant and non-dominant sides over time**

**Abbreviations: Pre-int, pre-intervention; Post-int, post-intervention; Post-sea, post-season**

**\* Significant main effect for dominant OI  $p=0.019$ :**

**# Significant main effect for percentage difference:  $p=0.042$**

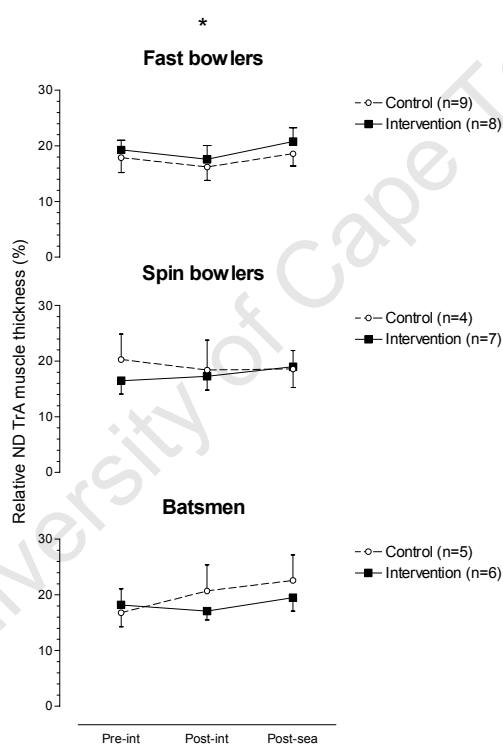
There were no further significant differences found for percentage change (%) absolute resting muscle thickness (OE and TrA) between the intervention and control groups during the intervention period. Furthermore, there were no significant changes for percentage difference between dominant and non-dominant sides in the abovementioned. There were also no significant changes in relative resting muscle thickness in the intervention and control groups during the intervention period.<sup>x</sup>

### 5.3.2.2 Analysis separated by cricketing discipline

Figure 5.2 shows the change in relative resting non-dominant TrA muscle thickness over time (%). There was a significant interaction between discipline and group

<sup>x</sup> See Appendix K, Tables K15 to K17 for non-significant changes in OE and TrA absolute resting muscle thickness and percentage difference during the intervention period

(intervention and control) with respect to change in relative non-dominant TrA muscle thickness over time ( $F_{4;66} = 2.95$ ;  $p=0.026$ ). It appears that the non-dominant TrA muscle thickness of the batsmen in the control group increased from pre- ( $17 \pm 3\%$ ) to post-intervention ( $21 \pm 5\%$ ) and further increased post-season ( $23 \pm 5\%$ ). This was compared to the non-dominant TrA muscle thickness of the batsmen in the intervention group which appeared to have little change throughout the course of the study. Furthermore, there appeared to be no changes in non-dominant TrA muscle thickness of the fast bowlers and spin bowlers in either the intervention or control groups during the course of the study. However, this finding needs to be interpreted with caution due to the few cricketers in the spin bowlers ( $n=4$ ) and batsmen ( $n=5$ ) in the control group and the significance demonstrated here may be a false positive.



**Figure 5.2: Change in relative non-dominant TrA resting muscle thickness (%) over time by cricketing discipline**  
**Abbreviations: Pre-int, pre-intervention; Post-int, post-intervention; Post-sea, post-season**

\* **Significant main effect:  $p=0.026$**

There were no further significant changes in relative resting muscle thickness, nor were there any changes in absolute resting muscle thickness and percentage

difference between dominant and non-dominant sides across cricketing disciplines during the intervention period.<sup>XI</sup>

#### **5.3.2.3 Cricketers with and without lower back pain**

During the intervention period the cricketers in the intervention group significantly decreased their occurrence of lower back pain. Thus, change in abdominal muscle morphometry was compared to change in lower back pain status in the intervention and control groups during the intervention period. There were no significant changes demonstrated in absolute muscle thickness (mm), relative muscle thickness (%), total abdominal muscle thickness (mm), OI or TrA muscle function ( $\Delta$ mm) or percentage difference between dominant and non-dominant sides during the intervention period with respect to change in lower back pain status.<sup>XII</sup> The lack of significance should, however, be interpreted with caution due to the few cricketers with lower back pain in the intervention group (n=3) and cricketers without lower back pain in the control group (n=4).

#### **5.3.3 Posterior lumbar muscle cross sectional area**

There were no significant changes demonstrated in lumbar muscle cross-sectional area (measured at the 4<sup>th</sup> lumbar vertebral level) in either the intervention and control groups during the intervention period.<sup>XIII</sup>

##### **5.3.3.1 Analysis of cricketing disciplines**

There were no significant changes in the absolute cross-sectional area (measured at the 4<sup>th</sup> lumbar vertebral level) percentage difference between the dominant and non-dominant sides of posterior lumbar muscles (psoas, quadratus lumborum, multifidus, longissimus and iliocostalis) during the intervention period.<sup>XIV</sup>

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<sup>XI</sup> See Appendix K, Tables K21 to K25 for non-significant changes in relative & absolute muscle thickness and percentage difference between dominant and non-dominant sides, across cricketing disciplines

<sup>XII</sup> See Appendix K Tables K19 to K23 showing non-significant differences between cricketers with and without lower back pain in the intervention and control groups

<sup>XIII</sup> See Appendix K, Tables K26 and K27 for non-significant changes in lumbar muscle cross-sectional area

<sup>XIV</sup> See Appendix K Table K28 for change in posterior muscle cross-sectional percentage difference by cricketing discipline in the intervention and control groups

### 5.3.3.2 Cricketers with and without lower back pain

As mentioned, during the intervention period the cricketers in the intervention group significantly decreased their occurrence of lower back pain, however there was little change in lower back pain status of the cricketers in the control group. Change in individual lumbar muscle cross-sectional area during the intervention period was analysed with respect to change in lower back pain status in cricketers in the intervention and control groups during this period. There were no significant changes demonstrated in the cross-sectional area of psoas, quadratus lumborum, multifidus, longissimus and iliocostalis or percentage difference for individual lumbar muscles, between cricketers with and without lower back pain in the intervention and control groups.<sup>xv</sup> It is important to mention that a limitation of this analysis was the few cricketers with lower back pain in the intervention group (n=3) and cricketers without lower back pain in the control group (n=4).

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<sup>xv</sup> See Appendix K, Tables K29 and K30 for change in posterior muscle cross-sectional area with respect to cricketing discipline with and without lower back pain in the intervention and control groups

## 5.4 DISCUSSION

In Chapter 3 it was shown that the cricket specific lumbar stabilisation intervention was implemented over an 8-week period during the pre-season. Furthermore, the attendance was at 71% for both the 8-week program and the in-season stability maintenance classes.

A number of significant results were found with respect to the lateral abdominal musculature between the intervention and control groups post-intervention. Firstly, the total resting abdominal muscle thickness on the dominant side in the combined group of cricketers in the intervention group had significantly increased, immediately post-intervention when compared to that of cricketers in the control group. This increase in total muscle thickness on the dominant side, or hypertrophy of the muscle, was maintained post-season in the intervention group. Prior to the intervention program, total muscle thickness was significantly greater on the non-dominant side compared to dominant side (Chapter 4). Therefore, the apparent increase in dominant total thickness was most likely caused by intervention group players' abdominal wall becoming more symmetrical immediately post-intervention. As there appeared to be no further change in symmetry between the post-intervention and post-season measurements, cricketers were evidently able to maintain this change in abdominal wall muscle symmetry. Since this muscle thickness change can perhaps be attributed to cricket specific trunk exercises implemented during the intervention program, it is possible to conclude that an 8-week cricket specific lumbar stabilisation program changes total muscle thickness and decreases asymmetry. This finding also indicates that in-season maintenance classes twice a week is sufficient to maintain these muscle thickness changes despite the asymmetrical nature of the cricketing activities.

In Chapter 3, it was reported that a significant number of cricketers in the intervention group decreased their lower back pain during the intervention. Therefore, cricketers were separated into those with and without lower back pain following the intervention period. Cricketers without lower back pain included cricketers whose lower back pain either resolved during the intervention period or cricketers who remained pain free. Cricketers with lower back pain included those who either continued to complain of lower back pain or developed a new onset of pain during the study period. There were no changes demonstrated in abdominal muscle morphometry when comparing groups with respect to this change in lower back pain status. A lack of change in muscle

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thickness during the intervention may be due to the intervention being performed as a group and not one-on-one classes targeted at the individual cricketer, particularly during phase one of the intervention. Furthermore, pain alters muscle recruitment<sup>85</sup> and it may therefore be more beneficial to structure interventions that involve individual classes for participants with lower back pain. A further reason may be that pain to the lumbar region resolves first and changes in muscle thickness and symmetry may take longer. Thus it is possible that the length of the first three phases of the intervention should be increased at the same intensity to possibly assist these cricketers in altering their muscle thickness. The lack of changes in muscle thickness in the players with lower back pain may also be due to the lack of active physiotherapy treatment for these players' injury. Thus they may have not responded favourably to the intervention program due to the site of pain requiring manual release using physiotherapy techniques. Furthermore, the start of the cricket in-season following the 8-week intervention, and thus the cricketers taking part in their regular asymmetrical cricketing activities, including fast bowling, spin bowling and batting, may have delayed any change in muscle symmetry due to a possible biomechanical cause.

Seasonal effects associated with playing cricket, rather than the intervention program could possibly explain why some muscle thickness changes occurred in the control rather than the intervention group, from pre-intervention through to post-season. This appears to be the case for changes in relative non-dominant TrA muscle thickness, which increased in the control group batsmen over time whereas the intervention group's relative non-dominant resting TrA muscle thickness did not significantly change. A possible reason for the lack of change in relative TrA muscle thickness and no significant changes in TrA muscle function following the intervention could be due to the fact that the effect of an intervention program on TrA muscle thickness has not been previously established. Therefore, it is possible that TrA would hypertrophy with stability training or that this type of training may in fact alter only the recruitment of the TrA muscle. Furthermore, ultrasound measurement of TrA thickness has not been validated as a sensitive measure in the sporting and young population. The gold standard of investigation for TrA function is fine-wire EMG. However, this technique was not an available tool for this study. Furthermore, a decrease in the occurrence of lower back pain may be the initial response to the intervention program and a subsequent increase in TrA muscle function may take a longer period of time.

Analysis of the individual posterior lumbar musculature demonstrated no change in the cross-sectional area or with respect to the percentage difference between the dominant and non-dominant sides in the presence of a lumbar stabilisation intervention program. A lumbar stabilisation intervention by Danneels et. al., (2001) also found no increase in the cross-sectional area of multifidus in patients with chronic lower back pain<sup>118</sup>. An increase in muscle cross-sectional area is referred to as muscle hypertrophy which is the result of an accumulation of proteins through the increased rate of protein synthesis<sup>158</sup>. A possible reason for the lack of change in cross-sectional area of the posterior musculature following the intervention could be due to the fact that strength training is mostly a neural adaptation for the first 6 weeks of training and only thereafter does muscle hypertrophy tend to become evident<sup>159;160</sup>. As the main intervention program only lasted 8 weeks and focused more on stability than strength training it is possible that more time is required for these muscles to significantly hypertrophy. Following the 6 weeks when hypertrophy may begin to occur it is necessary to progressively overload the muscles to increase muscle hypertrophy further as less muscle mass is recruited following the initial adaptation<sup>161</sup>. The maintenance phase exercises classes only occurred every second week during the season, therefore this frequency of maintenance may not be sufficient to induce muscle hypertrophy. Furthermore, a high load and low repetitions at a high frequency are suggested to advance muscle hypertrophy<sup>162-167</sup> and neither the 8-week intervention, nor the maintenance phase included resistance training with high loads and low repetitions. A further reason for the lack of change in muscle hypertrophy following the intervention may be due to the fact that the program involved complex multi-joint exercises and complexity of exercises has been suggested to increase the neural adaptation phase and affect the time course for muscle hypertrophy to occur<sup>168</sup>. Furthermore the cross-sectional area was only measured at the 4<sup>th</sup> lumbar vertebral level and this factor may not add insight into any possible changes in muscle volume for individual muscles and at other vertebral levels as a result of the intervention.

## 5.5 CONCLUSION

A progressive, 8-week cricket-specific lumbar stabilisation intervention program is able to increase the total abdominal wall and internal oblique muscle thickness on the dominant side in combined cricketing disciplines. Furthermore, these increases in total wall and internal oblique muscle thickness on the dominant side assisted in decreasing

the pre-intervention asymmetry in these muscles. Importantly, the 7-month in-season maintenance program was able to maintain these changes in muscle symmetry. There were no changes in the resting thickness or function of the abdominal muscles or cross-sectional area of the lumbar muscle in cricketers whose lower back pain status changed during the intervention. Furthermore, there was no hypertrophy in the cross-sectional area of the individual lumbar muscles during the intervention period.

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### SECTION 3

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In this section I will explore the clinical symptoms and lumbar pathology evident in this group of schoolboy cricketers from the following angles: developing a new MRI classification system (Chapter 6), baseline findings for clinical signs and symptoms and lumbar pathology as detected on MRI (Chapter 7), the effect of a lumbar stabilisation intervention on clinical signs and symptoms and lumbar pathology seen on MRI (Chapter 8).

Chapters in this section:

- Chapter 6: Inter-observer and Intra-observer Reliability of a Novel Classification System to Grade Lumbar Pathology in Elite Male Schoolboy Cricketers
- Chapter 7: Clinical evaluation of the Lumbar Spine and Pathological Features on Spinal Magnetic Resonance Imaging in Schoolboy Cricketers
- Chapter 8: Clinical Evaluation and MR Imaging of the Lumbar Spine: Effects of a Lumbar Stabilisation Intervention

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## CHAPTER 6

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### **Inter-Observer and Intra-Observer Reliability of a Novel MRI Classification System to Grade Lumbar Pathology of Elite Male Schoolboy Cricketers**

#### **6.1 INTRODUCTION**

Previous research has indicated that fast bowlers, who experience lower back pain, have evidence of radiological abnormalities on imaging studies<sup>25;27;44</sup>. Magnetic resonance imaging (MRI) is an important diagnostic tool to assist the clinician in assessment and diagnosis of pathology of the various structures comprising the lumbar spine<sup>13;42</sup>. Findings described in Chapter 3 indicated that not only fast bowlers but also spin bowlers and batsmen experience a high occurrence of self-reported lower back pain. There is therefore a need to accurately diagnose the lumbar pathology in these cricketers, as an accurate diagnosis is important in the appropriate management and rehabilitation of these athletes.

Previous systems of classification of pathology in the lumbar spine have focused on a single anatomical structure namely the intervertebral disc, nerve root, endplate or pars interarticularis<sup>42;46-48</sup>. To date no imaging classification system has combined all of the above mentioned anatomical structures into a single graded scoring system, which would allow quantification of the extent of imaging features and pathology. Furthermore, the previous classification systems have tested the intra- and inter-observer reliability for the total number of intervertebral discs with pathology<sup>42;46-48</sup>. However, it is also important to determine the specific spinal level at which the imaging of pathological features occur as previous research has shown that fast bowlers develop lumbar pathology which is commonly concentrated at specific vertebral levels<sup>59;108</sup>. Therefore, a valid system would need to quantify changes in all areas of the motion segment at the various spinal levels.

Thus the aim of this study was to develop a novel graded MRI classification system in order to compare the extent of pathologic features on imaging between cricketers. A further aim of this part of the study was to assess the inter- and intra-observer reliability of the classification system of pathological imaging features of the lumbar spine at each intervertebral disc level.

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## 6.2 METHODS

### 6.2.1 Study design

This was a semi-quantitative analysis to classify lumbar spinal pathology changes on MR imaging in 13 elite, male, schoolboy cricketers with a mean age of  $16.7 \pm 0.8$  years.

### 6.2.2 Measurements

#### 6.2.2.1 MR imaging

Sagittal STIR, sagittal T2, axial T1 sequences of the lumbar spine were performed during pre-season testing. At post-season testing an additional sagittal DESS sequence was added due to it being a more sensitive method of detecting pars interarticularis defects. Further detail of these methods is provided in Chapter 2.

#### 6.2.2.2 Development of a graded classification system

A system to grade pathological features on MR imaging was developed in collaboration with a radiologist with special interest in sports imaging, a sports physician, a sports physiotherapist and a biokineticist.

Five radiologists who specialised in MR imaging assessed and scored 13 MRI scans to test for inter-observer reliability. These 13 MRI scans were randomly chosen from imaging performed on all of the participants at the end of the season due to the inclusion of the DESS sequence at this testing session. One of the radiologists repeated the scoring questionnaire on a separate day to test for intra-observer reliability.

The radiologists completed the scoring questionnaire independently of each other and were unaware of the cricketing discipline of the cricketer whose image they were scoring or whether or not the cricketer had lower back pain at the time the image was taken. The five radiologists were required to score the relevant pathology on a graded

scale score sheet (Appendix J). The intervertebral disc levels defined in the score sheet were L<sub>1</sub>; L<sub>2</sub>; L<sub>3</sub>; L<sub>4</sub>; L<sub>5</sub>.

#### 6.2.2.3 Pathology scoring system

By totaling all the scores for lumbar pathology, a total score out of a possible score of 125 was calculated. In other words, endplate, disc tear, nerve root, facet joint pathology and pars interarticularis defects each have 4 grades (0-3), therefore 5 pathologies x 4 grades = a score out of 20; whereas disc degeneration had 5 grades (0-4), therefore 1 pathology x 5 grades = a score out of 5. The 5 lumbar segments analysed could each have a possible score of 25, therefore, the total score for the lumbar spine is 125. Thus, a score of 0 out of 125 indicates a normal lumbar spine free of any pathology. However, a score of 125 indicates severe lumbar pathology of the lumbar spine.

An example of how to calculate a pathology score is as follows:

*If a cricketer has grade II disc degeneration in one intervertebral disc, grade I endplate pathology and a grade II nerve root compression, he would have a total pathology score of 5 out of 125.*

#### 6.2.2.4 Statistical analysis

Statistical analysis was performed using weighted kappa coefficients as a measure of agreement. The standards of Landis and Koch (1977) indicate values of kappa < 0.4 as poor; between 0.4 and 0.75 as good; and > 0.75 as excellent agreement<sup>169</sup>. Results are expressed as kappa correlation coefficients and upper and lower 95% confidence limits.

### 6.3 RESULTS

Disc degeneration, disc tear and nerve root pathology, as well as endplate pathology and pars interarticularis defects were assessed using MR imaging. The total severity of the pathological features of the lumbar spine was further analysed by calculating a total pathology score as described earlier. Figures 6.1 to 6.6 are examples of the different pathologies of the lumbar spine and their varying grades of severity.

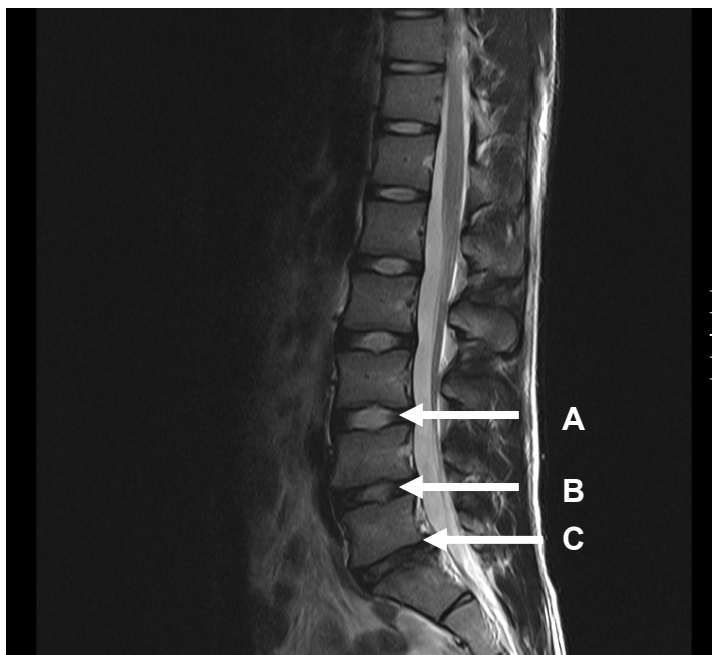


Figure 6.1: Sagittal view of the lumbar spine showing various grades of disc degeneration and endplate pathology at three intervertebral disc levels. A) L<sub>3</sub> grade I disc degeneration and grade I endplate pathology, B) L<sub>4</sub> grade II disc degeneration and grade I endplate pathology, C) grade III disc degeneration and grade I endplate pathology at L<sub>5</sub>.

Note that the arrows in the diagram are pointing to each intervertebral disc namely L<sub>3</sub>, L<sub>4</sub> and L<sub>5</sub>.

The total pathology score for this example would be 9.

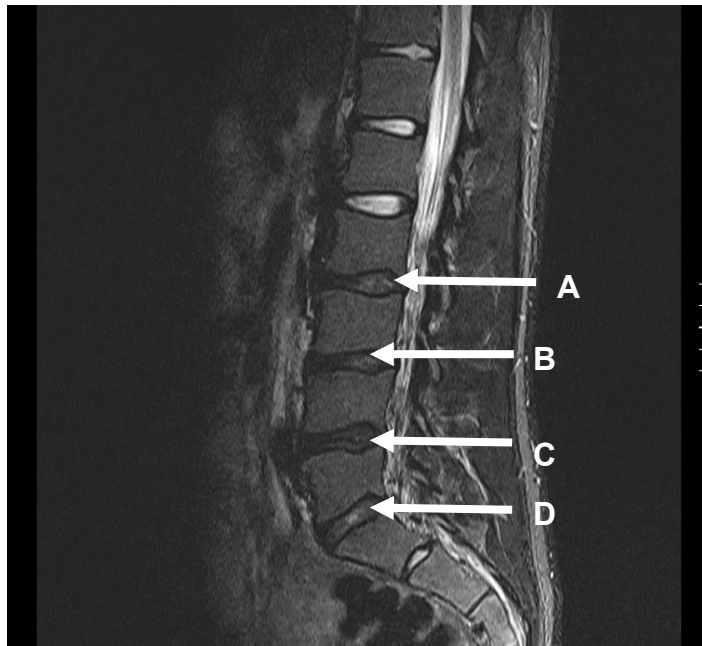


Figure 6.2: Sagittal view of the lumbar spine showing the presence of A) grade II disc degeneration at L<sub>2</sub>, B) grade II disc degeneration at L<sub>3</sub>, C) grade II disc degeneration with grade II endplate pathology at L<sub>4</sub> and (D) grade I disc degeneration with grade I endplate pathology at L<sub>5</sub>. Note that the arrow is pointing at the lumbar intervertebral level where the pathology occurs.

The total pathology score for this example would be 10.

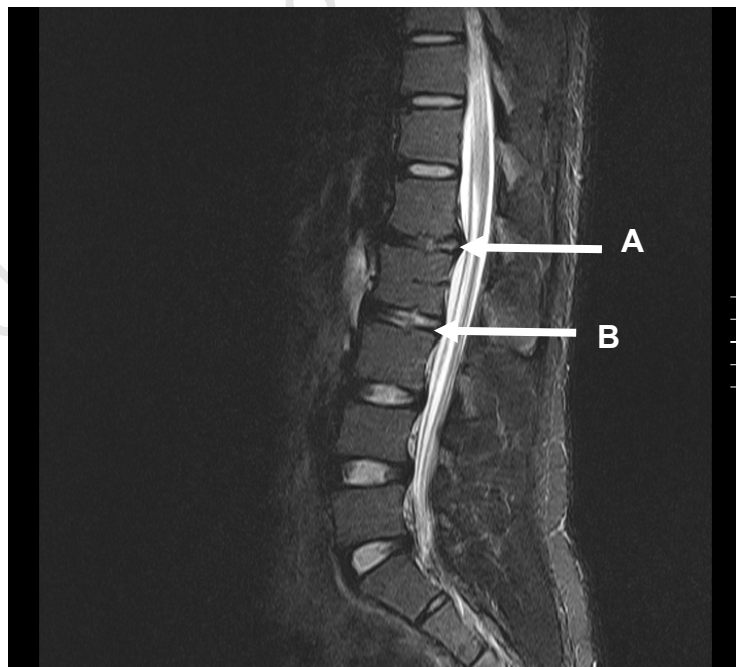


Figure 6.3: Sagittal view of the lumbar spine showing the presence of (A) grade II disc degeneration and grade III endplate pathology at L<sub>1</sub> and (B) grade II disc degeneration and grade II end plate pathology at L<sub>2</sub>. Note that the arrow is pointing at the 1<sup>st</sup> lumbar intervertebral level where the pathology occurs.

The total pathology score for this example would be 9.

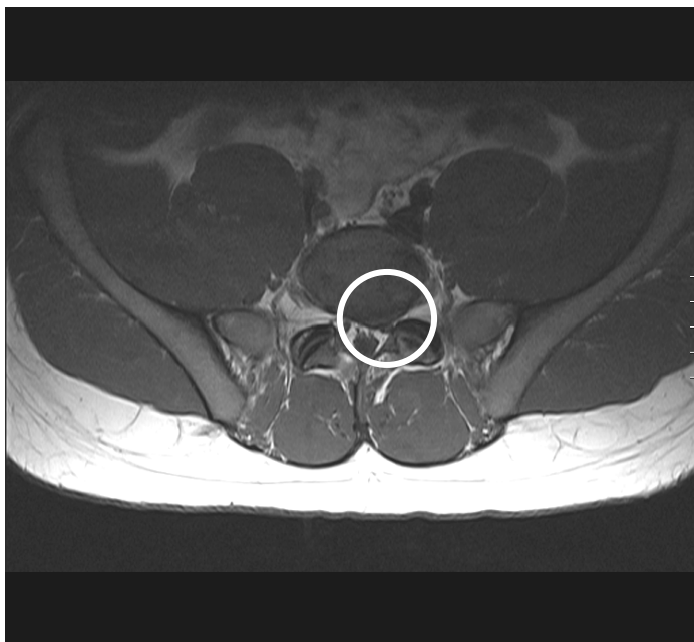


Figure 6.4: Axial view of the 5<sup>th</sup> lumbar vertebral level showing the presence of grade III nerve root pathology on the right. Note that the area that is circled is where the pathology occurs.

Nerve root score for this example would be 3. Note: Only the nerve root score and not the total pathology score is indicated as one cannot determine the disc score from this view.

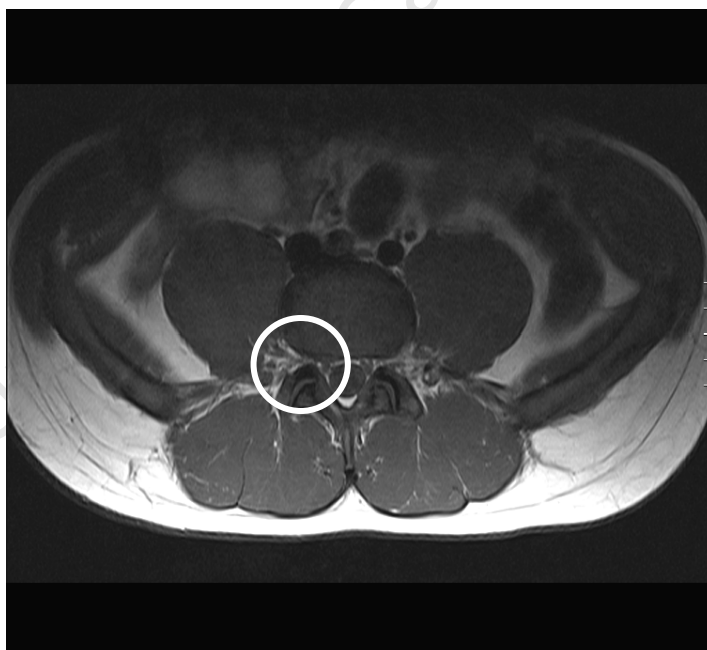


Figure 6.5: Axial view of the 4<sup>th</sup> lumbar vertebral level showing the presence of grade II disc tear and nerve root pathology on the left. Note that the area that is circled is where the pathology occurs.

The total pathology score for this example would be 4.



**Figure 6.6:** Dual Echo Steady State (DESS) sequence of the lumbar spine showing the presence of grade III pars interarticularis defect at L<sub>5</sub>. Note that the arrow is pointing to the lumbar vertebral level where the pathology occurs.

The total pathology score for this example would be 3.

Due to the fact that there were only 13 scans assessed and since the occurrence of higher grading of pathology was rare, the measurements of all graded pathology were reduced into binary categories being 0 (normal) and 1 (abnormal - grades 1 to 3). In the case of pars interarticularis and nerve root pathology, the scores were too low to provide a true estimate of agreement. Figures 6.7 and 6.8 show that there was a high degree of variation in the reports by the different reviewers so that there was some low inter-observer agreements.

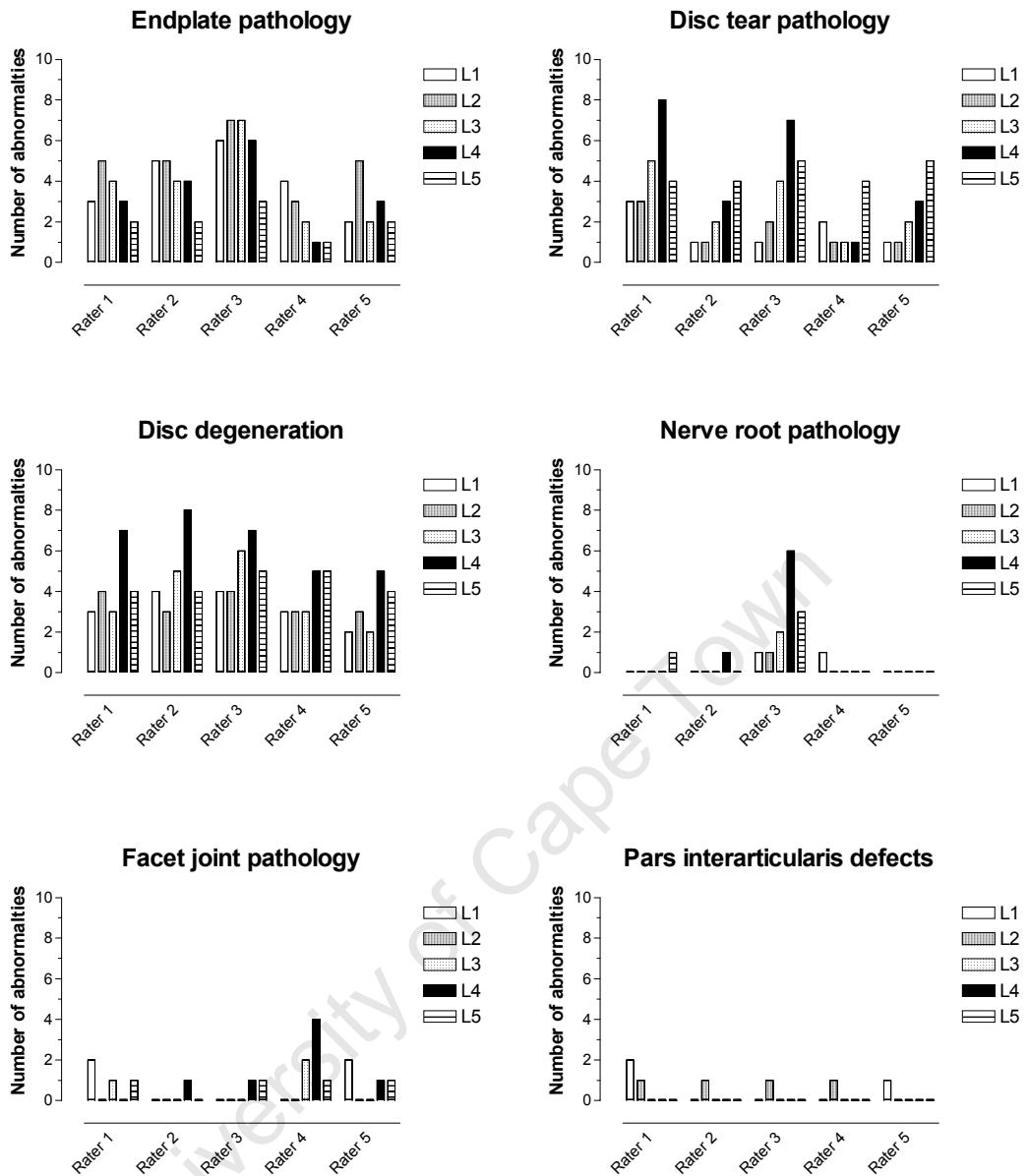


Figure 6.7 Number of abnormalities per intervertebral disc level recorded per rater to determine inter-observer reliability for various lumbar pathologies. Note that there was variation between the 5 reviewers for each type of lumbar pathology and intervertebral disc level.

INTER-OBSERVER AND INTRA-OBSERVER RELIABILITY OF A NOVEL MRI CLASSIFICATION SYSTEM TO GRADE LUMBAR PATHOLOGY OF ELITE MALE SCHOOLBOY CRICKETERS

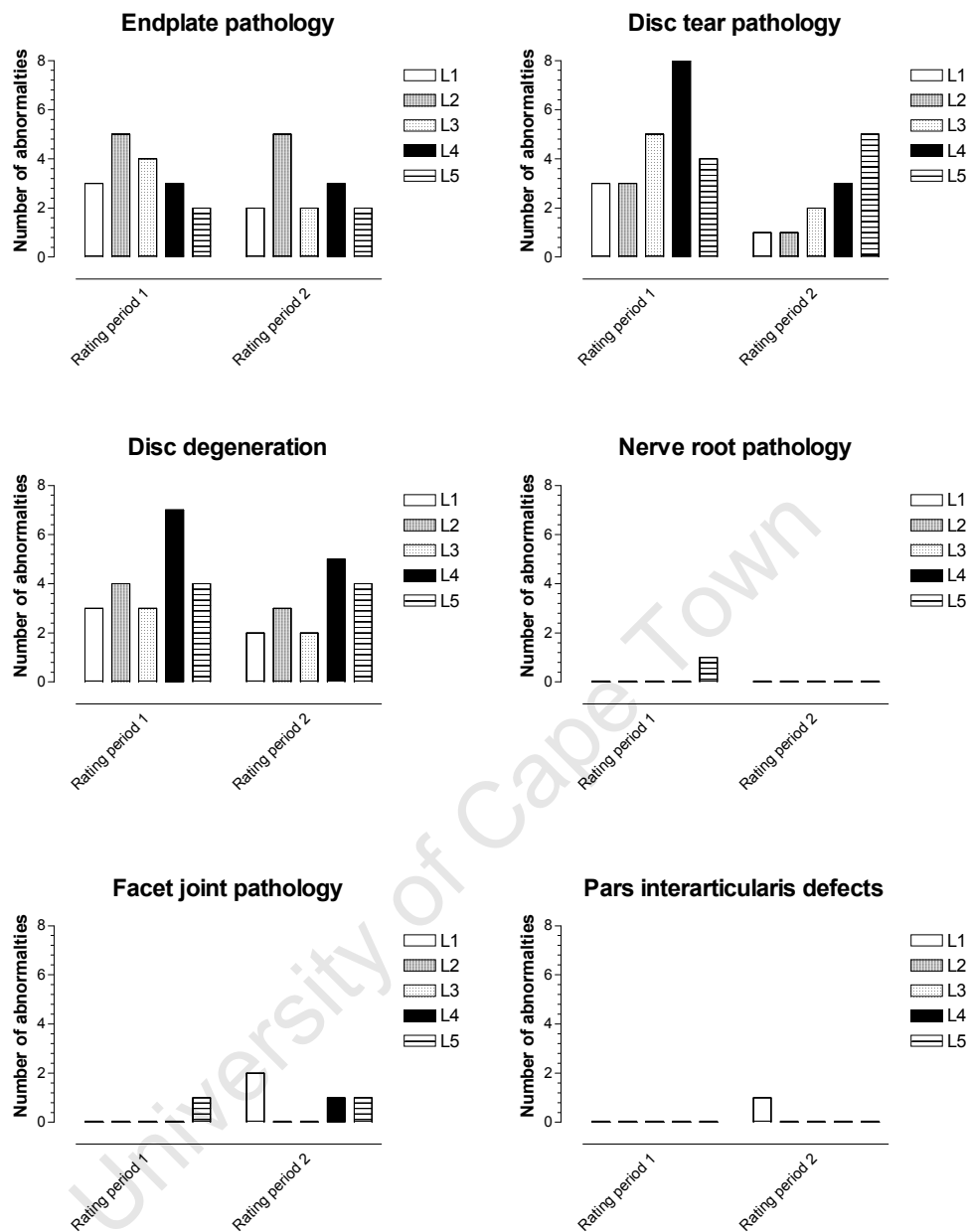


Figure 6.8 Number of abnormalities per intervertebral disc level recorded by the rater to determine intra-observer reliability for various lumbar pathologies (n=13). Note that one rater repeated the reporting of the 13 MRI scans on two separate occasions, therefore rating period 1 was the first report and rating period 2 was the second report. The presence of nerve root compression, facet joint pathology and pars interarticularis defects were few for the 13 MRI scans randomly chosen and reported on for the new classification system.

### 6.3.1 Inter- and intra-observer agreement

#### 6.3.1.1 Grading of intervertebral pathology

##### 6.3.1.1.1 *Disc degeneration*

Table 6.1 shows the inter-observer agreement for binary rating (normal versus abnormal categories) of disc degeneration which was reported to be good (0.56-0.72) at intervertebral disc levels L<sub>1</sub> to L<sub>4</sub>. There was an excellent level of agreement (0.86) between the radiologists for rating of disc degeneration at the L<sub>5</sub> level. Intra-observer agreement for binary rating (normal versus abnormal categories) of disc degeneration was good (0.42-0.75) at levels L<sub>1</sub> to L<sub>4</sub>, with excellent intra-observer agreement of 1.00 at level L<sub>5</sub>. Expected inter-observer agreement for degree of disc degeneration was lower than that of intra-observer agreement. Nevertheless, all levels were rated good to excellent. Both inter- and intra-observer ratings had the lowest agreement for L<sub>2</sub> and the highest level of agreement for L<sub>5</sub>.

**Table 6.1: Binary inter- and intra-observer agreements for level for disc degeneration in cricketers by intervertebral disc level**

Level	Inter-observer Agreement			Intra-observer Agreement		
	Kappa coefficient	95% LCI	95% UCI	Kappa coefficient	95% LCI	95% UCI
L <sub>1</sub>	<b>0.63</b>	0.46	0.80	<b>0.75</b>	0.31	1.00
L <sub>2</sub>	<b>0.56</b>	0.39	0.73	<b>0.42</b>	0.00	0.96
L <sub>3</sub>	<b>0.59</b>	0.42	0.76	<b>0.75</b>	0.31	1.00
L <sub>4</sub>	<b>0.72</b>	0.55	0.89	<b>0.70</b>	0.33	1.00
L <sub>5</sub>	<b>0.86</b>	0.69	1.00	<b>1.00</b>	-	-

**Abbreviations:** LCI, lower 95% confidence limit; UCI, upper 95% confidence limit

There was a greater occurrence of higher scores for intervertebral disc degeneration than for the other types of pathology so that it is possible to assess the reliability of assessment of severity for disc degeneration. Thus instead of scores being reduced into normal and abnormal categories, this pathology could also be assessed in 3 categories, i.e.: 0 (normal), 1 (grade 1),  $\geq 2$  ( $\geq$  grade 2)(see Table 6.2). This indicates the estimated agreement on severity of disc degeneration. The inter-observer agreement for these multiple ratings of disc degeneration was found to be good (0.43-0.65) for intervertebral disc levels L<sub>1</sub> to L<sub>4</sub>, with an excellent level of agreement (0.86) between the radiologists for abnormalities at the L<sub>5</sub> level.

**Table 6.2: Multiple inter-observer agreements for level for disc degeneration in cricketers by intervertebral disc level**

Level	Kappa coefficient	95% LCI	95% UCI
L <sub>1</sub>	<b>0.64</b>	0.47	0.82
L <sub>2</sub>	<b>0.43</b>	0.26	0.60
L <sub>3</sub>	<b>0.57</b>	0.40	0.75
L <sub>4</sub>	<b>0.65</b>	0.48	0.82
L <sub>5</sub>	<b>0.81</b>	0.63	0.98

*Abbreviations: LCI, lower 95% confidence limit; UCI, upper 95% confidence limit*

### 6.3.1.1.2 Disc tear pathology

Table 6.3 shows that the inter-observer agreement of disc tear pathology was good (0.54-0.64) for intervertebral disc levels L<sub>1</sub>, L<sub>2</sub>, L<sub>3</sub> and L<sub>5</sub>. However, a poor level of agreement was found at the L<sub>4</sub> level (0.21). The intra-observer agreement for binary rating (normal versus abnormal categories) of disc tears was good (0.43-0.49) for all intervertebral disc levels excluding L<sub>4</sub>, which was reported as low (0.04). Inter-observer agreement for disc tears was slightly higher than that of intra-observer agreement, with levels L<sub>1</sub> to L<sub>3</sub> and L<sub>5</sub> all rated good. Both inter- and intra-observer agreement ranked low for intervertebral level L<sub>4</sub>.

**Table 6.3: Binary inter- and intra-observer agreements for level for disc tear pathology in cricketers by intervertebral disc level**

Level	Inter-observer Agreement			Intra-observer Agreement		
	Kappa coefficient	95% LCI	95% UCI	Kappa coefficient	95% LCI	95% UCI
L <sub>1</sub>	<b>0.64</b>	0.47	0.82	<b>0.43</b>	0.00	1.00
L <sub>2</sub>	<b>0.64</b>	0.47	0.82	<b>0.43</b>	0.00	1.00
L <sub>3</sub>	<b>0.59</b>	0.42	0.76	<b>0.45</b>	0.00	0.91
L <sub>4</sub>	<b>0.21</b>	0.04	0.38	<b>0.04</b>	0.00	0.43
L <sub>5</sub>	<b>0.54</b>	0.37	0.71	<b>0.49</b>	0.00	0.95

*Abbreviations: LCI, lower 95% confidence limit; UCI, upper 95% confidence limit*

### 6.3.1.1.3 Nerve root pathology

The inter- and intra-observer agreement for nerve root pathology at all intervertebral disc levels could not be calculated due to the small sample size and presence of only subtle pathology.

### 6.3.1.2 Endplate pathology

Inter-observer agreement for the reporting of endplate abnormalities was good (0.47 – 0.60) for all intervertebral disc levels excluding L<sub>3</sub> (see Table 6.4). The intra-observer agreement for binary rating (normal versus abnormal categories) of endplate pathology was good (0.57-0.75) for intervertebral disc levels L<sub>1</sub> and L<sub>4</sub>. An excellent level of agreement was found for levels L<sub>2</sub> and L<sub>5</sub> (0.84-1.00) and a poor agreement found at L<sub>3</sub> (0.16). As expected inter-observer agreement for endplate pathology was slightly lower than intra-observer agreement, nevertheless levels L<sub>1</sub> to L<sub>2</sub> and L<sub>4</sub> to L<sub>5</sub> all rated between good and excellent. However, both kappa coefficients were low at vertebral level L<sub>3</sub>.

**Table 6.4: Binary inter- and intra-observer agreements for level for endplate pathology in cricketers by intervertebral disc level**

Level	Inter-observer Agreement			Intra-observer Agreement		
	Kappa coefficient	95% LCI	95% UCI	Kappa coefficient	95% LCI	95% UCI
L <sub>1</sub>	<b>0.60</b>	0.43	0.77	<b>0.75</b>	0.31	1.00
L <sub>2</sub>	<b>0.59</b>	0.42	0.76	<b>0.84</b>	0.55	1.00
L <sub>3</sub>	<b>0.29</b>	0.12	0.47	<b>0.16</b>	0.00	0.70
L <sub>4</sub>	<b>0.50</b>	0.33	0.67	<b>0.57</b>	0.03	1.00
L <sub>5</sub>	<b>0.47</b>	0.30	0.64	<b>1.00</b>	-	-

*Abbreviations: LCI, lower 95% confidence limit; UCI, upper 95% confidence limit*

### 6.3.1.3 Facet joint pathology

Table 6.5 shows the inter-observer agreement for lumbar facet joint abnormalities, which was reported to be poor (0.20) for intervertebral disc level L<sub>1</sub>. Observer agreement for intervertebral disc levels L<sub>2</sub> to L<sub>4</sub> could not be calculated due to the small sample size and subtle pathology. Furthermore the intra-observer agreement for

facet joint pathology at all intervertebral disc levels could not be calculated due to the small sample size and presence of only subtle pathology.

**Table 6.5: Binary inter-observer agreements for level for facet joints in cricketers by intervertebral disc level**

Level	Kappa coefficient	95% LCI	95% UCI
L <sub>1</sub>	0.20	0.03	0.37

*Abbreviations: LCI, lower 95% confidence limit; UCI, upper 95% confidence limit*

#### 6.3.1.4 Pars interarticularis pathology

The inter- and intra-observer agreement for pars interarticularis abnormalities at all intervertebral disc levels could not be calculated due to the small sample size and presence of only subtle pathology.

## 6.4 DISCUSSION

MR imaging is used frequently in sports medicine especially in the evaluation of elite athletes with lower back pain. This is particularly true amongst fast bowlers with lower back pain. A number of graded classification systems of pathology on imaging have previously been assessed<sup>42;46-48</sup>. However, these were not in an athletic population and each focused only on one particular pathology. The novel feature of this study is that it is comprehensive as it includes all structures of the lumbar spine and was performed in a sporting population. Furthermore, earlier studies evaluated the reliability of MR imaging for assessing total lumbar intervertebral discs with pathology<sup>42;46-48</sup>, whereas this part of the study investigated the reliability of inter- and intra-observer ratings at each lumbar intervertebral disc level. This comprehensive classification system further allows for the calculation of a total pathology score for the lumbar spine. This can assist clinicians in judging the overall severity of injury to the lumbar spine and could perhaps assist in creating future guidelines for return to sport.

There was a high degree of variation at the 95% confidence limits and some low observer agreements between the radiologists. This variation is most likely due to the small sample size ( $n=13$ ) of the images that were studied. This stemmed from the time constraints of the radiologists involved. Although this is a comprehensive assessment, it is time consuming with an approximate evaluation time of over 20 minutes per scan. As high scores indicate increased severity of pathology in conditions that occurred rarely, scores were collapsed into 2 (binary) categories, namely the presence or absence of pathology. As a result, vertebral endplate, disc tear and facet joint pathology agreement could only be assessed according to these binary ratings. Disc degeneration had a higher number of "severe ratings", making it possible to calculate binary as well as multiple ratings (severity) per intervertebral disc level for the assessment of inter-observer reliability.

Inter-observer agreement for the various pathologies ranged from poor to excellent, depending on the vertebral level and the extent of the pathology. The lowest Kappa coefficient was 0.20 for lumbar facet pathology and the highest agreement rating was 0.86 for disc degeneration. Furthermore, intra-observer agreement also ranged from poor (0.16) to excellent (1.00) depending on the vertebral level and extent of pathology. The lowest Kappa coefficient was for endplate pathology and the highest level of agreement was for disc degeneration and endplate pathology. It would be

expected that the inter-observer score would be lower as there is a greater degree of variation between observers. Wilke et. al., (2006) reported that slight differences exist between ratings by observers with different degrees of experience<sup>170</sup>. As the levels of experience of the observers studied in this thesis was not determined, it is possible that this factor may have influenced the levels of agreement.

The classification for disc degeneration was reliable for both binary inter-observer (0.56-0.86) and intra-observer (0.42-1.00) agreement for intervertebral disc levels. Further, the expected inter-observer agreement for the degree of disc degeneration was lower than the intra-observer agreement. Both inter- and intra-observer ratings had the lowest agreement for L<sub>2</sub> and the highest level of agreement for L<sub>5</sub>. Also, disc degeneration agreements with multiple ratings of severity, were reliable for inter-observer agreement (0.43-0.86). These results indicate that Pfirrmann et. al.'s (2001) classification is not only reliable when assessing total abnormal intervertebral discs (0.69-0.81) but is also reliable at specific lumbar intervertebral disc levels<sup>42</sup>.

The above findings of reliability are consistent with those of previous studies assessing graded classifications systems assessing disc degeneration. Pfirrmann et. al., (2001) reported an observer agreement that was substantial to excellent for both inter-observer (0.69-0.81) and intra-observer (0.84-0.90; excellent) agreement for total intervertebral disc pathology<sup>42</sup>. A more recent study by Griffith et. al., (2007), who modified Pfirrmann's classification to assess disc degeneration in the elderly, also found a substantial level of agreement between observers (0.65 to 0.91). However, they stated that Pfirrmann's classification was better able to discriminate between severity of disc degeneration for younger subjects<sup>171</sup>. Brandt-Zawadzki et. al., (1995) also found a sufficient level of observer agreement (0.58 to 0.71) in determining the degree of disc extension beyond the interspace<sup>172</sup>. Furthermore, Raninko et. al., (1995) found that the highest level of agreement for assessing disc degeneration in the entire spine was for the lumbar spine<sup>173</sup>.

The new classification system was found to be reliable for both inter-observer (0.47 – 0.60) and intra-observer (0.57-1.00) for endplate pathology at all lumbar intervertebral disc levels, excluding L<sub>3</sub> (inter-observer: 0.29; intra-observer: 0.16). Poor reliability for L<sub>3</sub> may be an artifact of the size of the sample. The expected inter-observer agreement for endplate pathology was slightly lower than the intra-observer agreement. A

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previous study found that endplate pathology using a different classification system, namely the 3-type Modic system for assessing signal intensity, was reliable<sup>47</sup>.

The assessment of lumbar disc tear pathology was reliable with both inter-observer (0.54-0.64) and intra-observer (0.43-0.49) agreement for all intervertebral disc levels, excluding L<sub>4</sub>. Furthermore, inter-observer agreement for disc tears was slightly higher than that of intra-observer agreement.

The size of the sample reduced the ability to assess inter- and intra-observer agreement for pars interarticularis, facet joint and nerve root abnormalities. Only inter-observer reliability for facet joint pathology at L<sub>1</sub> could be calculated and this was found to be poor. However, pars interarticularis defects and nerve root pathology could not be assessed at any lumbar intervertebral disc levels due to this small sample size. Of interest is that only one cricketer in the entire study presented with a pars interarticularis defect, no cricketers presented with facet joint pathology and few cricketers presented with nerve root pathology. Therefore, the fact that the observer reliability coefficients for these pathologies is either weak or absent does not greatly influence the study and analysis in Chapters 7, 8 and 10. Previous findings show that graded rating scales, based on similar criteria, are reliable for both these types of lumbar pathology<sup>42:48</sup>. Previous studies that have assessed the reliability of graded classification systems for nerve root pathology (Intra-observer agreement: 0.72-0.77; inter-observer agreement: 0.62-0.67) and lumbar spondylolysis found these to be reliable for combined intervertebral disc levels<sup>46-48</sup>.

Many of the difficulties and limitations of the study originate from the fact that only 13 scans were assessed. Furthermore, the pathological findings on MR imaging for this group included for the most part relatively subtle pathology. The cricketers, although having self-reported lower back pain, were still able to continue playing cricket, and as such, they may have not suffered from a greater severity of pathology of the lumbar spine. This study should be repeated with a larger sample size and a wider variation of pathology in injured players who are unable to continue playing cricket due to the presence of more severe lower back pain than was present in these players. Future research using this classification system with a larger sample group of cricketers should further assess the sensitivity of this as a screening tool in this population.

## 6.5 CONCLUSION

This novel classification system is comprehensive since it assesses a variety of anatomical structures of the lumbar spine. Furthermore, it aids in the calculation of a total pathology score to assist in the calculation of the overall severity of injury to the lumbar spine. The small sample size affected the ability to calculate the level of agreement for all types of pathology. However, the levels of agreement that were possible to calculate for both inter- and intra-observer reliability were sufficient to distinguish between the intervertebral disc levels for the different types of lumbar pathology. Furthermore, the radiologists were able to reliably distinguish between severity of disc degeneration at the different lumbar intervertebral disc levels. However, this classification system may not be sensitive enough in identifying subtle pathology in this population. For the purposes of this thesis, the classification appears to be reliable to report on the occurrence of pathology of the lumbar spine, the determination of total pathology scores and to determine if there is any effect of the intervention program in this group of schoolboy cricketers. This evaluation will be the subject of the studies in Chapters 7, 8 and 10.

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## CHAPTER 7

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### **Clinical Evaluation of the Lumbar Spine and Pathological Features on Spinal Magnetic Resonance Imaging in Schoolboy Cricketers**

#### **7.1 INTRODUCTION**

The clinical evaluation of the cricketer with lower back pain includes the taking of a good history, physical examination and imaging studies in order to obtain an accurate diagnosis. In this part of the study the features determined by a clinical examination and findings on imaging studies (MRI) in young elite cricketers, are evaluated. In elite sports the pressures that exist often force the clinician to forgo the clinical examination and refer the athlete directly for advanced imaging studies for the evaluation of lower back pain. Yet, imaging is an expensive method of investigation and is not always easily accessible to the majority of athletes. Thus the clinician must rely on the age-old process of history taking and clinical examination. Furthermore, clinicians must rely on their clinical expertise to evaluate the injured athlete and design rehabilitation programs accurately, thus clinical assessment remains the cornerstone of patient management.

Since fast bowling is a major cause of back and trunk injuries in schoolboy cricketers<sup>5,6</sup>, it is worth exploring the relationship between clinical signs and total pathology score in these sportsmen. Previous studies investigating imaging features of the lumbar spine in cricketers found that all players who experienced lower back pain showed some evidence of radiological abnormalities<sup>25,26</sup>. Cricketing studies assessing imaging features have focused mainly on the presence of disc degeneration and spondylolysis in fast bowlers<sup>13;14;16;25;27;40;43;55;127</sup>. Spin bowlers and batsmen and other forms of disc and bone pathologies have mostly been neglected in these previous studies. This focus may originate from the fact that young fast bowlers are more predisposed to disc and bony pathology as their cartilage is less resistant to the

repetitive stresses of fast bowling and complete ossification has not yet occurred  
27;57;58

Based on both the limited research of all cricketing disciplines and the existence of a wide variety of lumbar pathologies, it was decided to assess specific lumbar clinical signs and symptoms and pathology seen on MR imaging of the lumbar spine in this study of schoolboy cricketers.

The aim of this chapter was to determine the occurrence of pain elicited during clinical examination and pathology as viewed on MR imaging of the lumbar spine in schoolboy cricketers both by cricketing discipline and in the presence or absence of self-reported lower back pain. The documentation of a baseline of occurrence of clinical signs and symptoms and describing the lumbar pathology allowed the foundation for Chapter 8, in which the progression or regression of these variables was assessed following a lumbar stabilisation intervention program.

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## 7.2 METHODS

### 7.2.1 Study design

Participants included 45 male, schoolboy cricketers with a mean age of  $16.7 \pm 0.8$  years. All subjects were recruited from within Western Province cricket and participated at either under 17 or under 19 representative level.

### 7.2.2 Investigations

#### 7.2.2.1 Lower back pain

Lower back pain was defined as the self-reported symptom of pain in the lumbar region at the time of the clinical evaluation and image screening as described in Chapter 2. On the basis of these symptoms, participants were divided into cricketers with and without lower back pain.

#### 7.2.2.2 Clinical assessment of the lumbar spine

A clinical examination of the lumbar and sacral spine was performed by a sports physician to assess the lower back and trunk as previously outlined in Chapter 2.

#### 7.2.2.3 MRI evaluation

MRI scanning of the lumbar spine was performed according to the methodology detailed in Chapter 2. The lumbar spine was scanned in order to determine the occurrence of specific lumbar pathology including disc degeneration, vertebral endplate, disc tear, nerve root and facet joint pathology and pars interarticularis defects. The lumbar pathologies were expressed at the intervertebral disc levels (ie.: L<sub>1</sub>, L<sub>2</sub>, L<sub>3</sub>, L<sub>4</sub>, L<sub>5</sub>) as described in Chapter 6.

#### 7.2.2.4 Statistical analysis

Statistical analysis was performed using an ANOVA to determine differences between disciplines and a Levene's t-test by group to determine differences between subjects with normal and abnormal clinical tests. Further statistical analysis of some of the results was not possible if the sample size was too small ( $n < 10$ ). In these instances only descriptive results and not statistical analyses were presented.

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## 7.3 RESULTS

### 7.3.1 Baseline clinical assessment and pathological findings on MRI scanning in the total cricketing group

Figure 7.1 shows the occurrence of pain on lumbar vertebral and paraspinal palpation and positive clinical tests in the total group of 45 cricketers. The majority of pain elicited on vertebral palpation ( $n=24$ ) and non-dominant ( $n=10$ ) and dominant ( $n=11$ ) paraspinal palpation occurred mostly in the lower lumbar vertebrae ( $L_3$  to  $L_5$ ). Lumbar extension produced the greatest number of positive clinical tests ( $n=10$ ), followed by the single leg hyperextension rotation test with the subject standing on the non-dominant leg and rotating the trunk to the dominant side ( $n=7$ ).

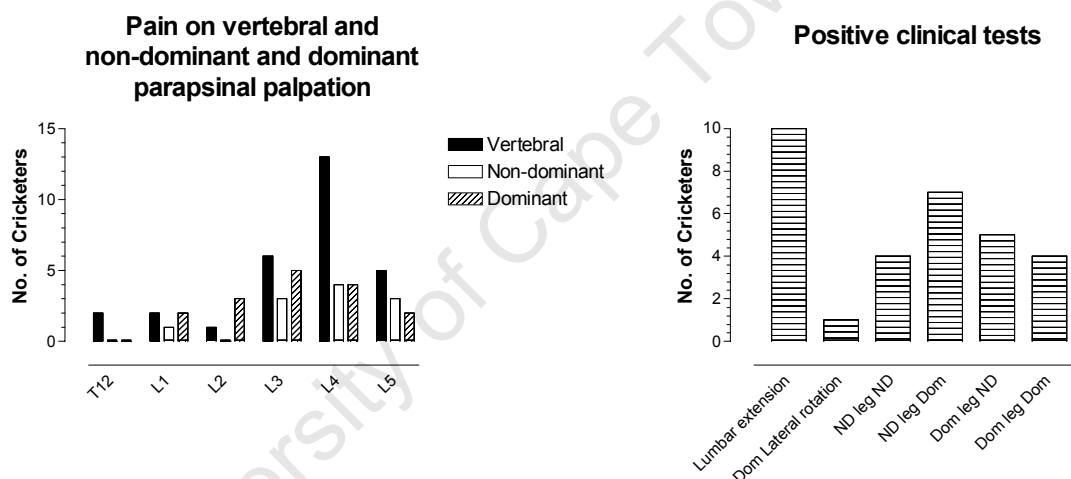


Figure 7.1: Number of cricketers who had pain on palpation and positive clinical tests in a group of 45 cricketers

**Abbreviations:** ND, non-dominant; Dom, dominant

**Note that:** ND leg ND means that the subject stood on the non-dominant leg whilst rotating his upper body to the non-dominant side; ND leg Dom means that the subject stood on the non-dominant leg whilst rotating his upper body to the dominant side; Dom leg ND means that the subject stood on the dominant leg whilst rotating his upper body to the non-dominant side; Dom leg Dom means that the subject stood on the dominant leg whilst rotating his upper body to the dominant side

The mean pathology score calculated for the total group of 45 cricketers was  $9 \pm 4$  out of a total of 125. The occurrence of bony and disc pathologies as seen on MRI that made up this mean score is shown in Figure 7.2. Disc degeneration was the most prevalent of the pathologies noted and was present in all 45 cricketers. The most prevalent severity of disc degeneration amongst the group of cricketers was grade I. A total of 56 endplates abnormalities were found in 45 cricketers, with the highest occurrence being in the lower lumbar vertebrae ( $L_4$  and  $L_5$ ). Disc tear pathology and

nerve root compression was found in 31 and 15 intervertebral discs respectively. No facet joint or pars interarticularis defects detected during baseline testing.

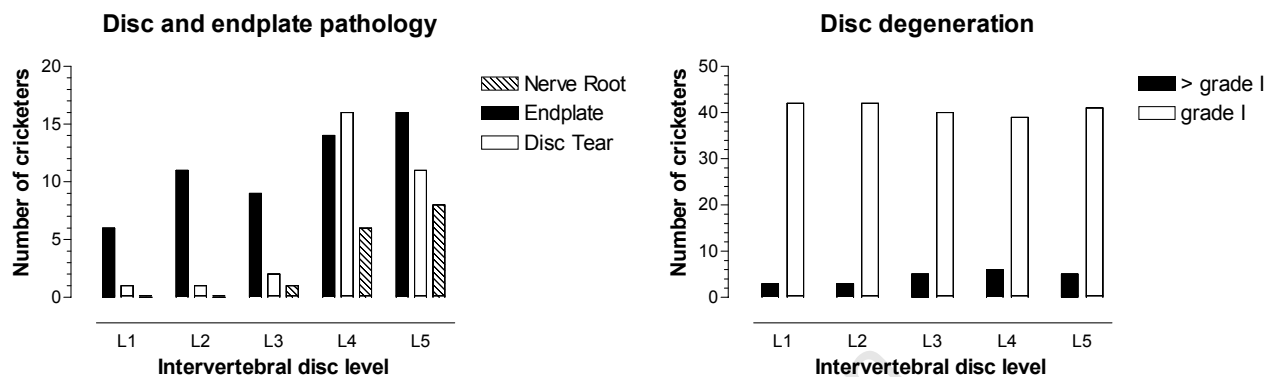
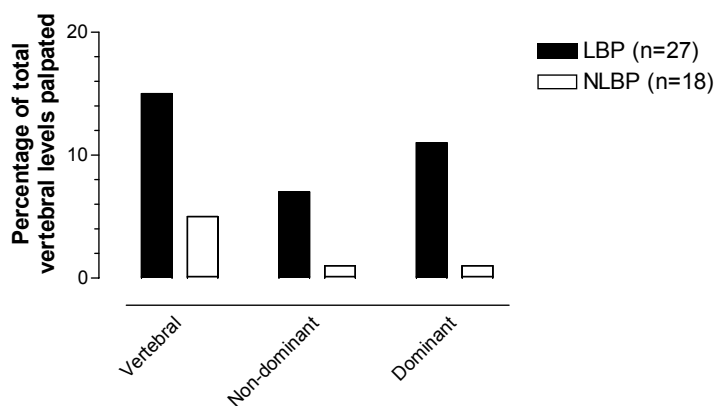


Figure 7.2: Occurrence of lumbar pathology as seen on imaging studies in the total group of cricketers (n=45)

### 7.3.2 Cricketers with and without self-reported lower back pain

#### 7.3.2.1 Baseline clinical assessments results

Twenty-seven cricketers in this sample group reported lower back pain whilst 18 did not report any lower back pain. Figure 7.3 shows the number of cricketers with and without lower back pain who presented with positive clinical tests and pain on vertebral and paraspinal palpation. More cricketers who had self-reported lower back pain experienced pain (indicating a positive clinical test) on single leg hyperextension rotation tests (n=18) compared to players who were pain free (n=2). Further, cricketers who had self-reported lower back pain experienced a higher percentage occurrence of pain on vertebral (15%) and dominant (11%) and non-dominant (n=7%) paraspinal palpation compared to those without lower back pain (5%, 1% and 1% respectively).

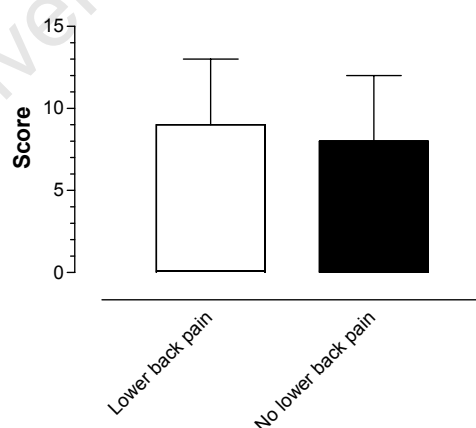


**Figure 7.3: Pain on palpation of the vertebrae and dominant and non-dominant paraspinal regions of the lumbar spine in cricketers with and without lower back pain**

**Abbreviations: ND, non-dominant; Dom, dominant; LBP, lower back pain; NLBP, no lower back pain**

### 7.3.2.2 Mean score for lumbar pathology in cricketers with and without lower back pain

Cricketers were given a score out of 125 to identify the overall severity of combined lumbar pathology as detected by the imaging studies. Figure 7.4 presents the mean pathology scores for all cricketers with ( $9 \pm 4$ ; n=27) and without lower back pain ( $8 \pm 4$ ; n=18) for lumbar clinical assessment results. The mean pathology scores for cricketers with and without lower back pain were not significantly different.



**Figure 7.4: Mean pathology score for cricketers with and without self-reported lower back pain**

To assess the mean pathology scores with the findings of the clinical assessments, the 45 cricketers were separated into players who scored between five and nine out of 125 (n=29) and players who scored greater than 10 out of 125 (n=16) on the pathology

scoring system. Figure 7.5 shows the occurrence of pain during clinical examination (positive tests). Both groups reported a similar frequency of pain during lumbar extension. Cricketers with a mean pathology score greater than 10 had a greater occurrence of positive single leg hyperextension rotation tests (n=15) compared to players with a lower pathology score (n=8). Frequency of pain on palpation was calculated as a percentage of the total number of vertebrae palpated for both the group with a high mean pathology score (n=145 lumbar vertebrae) and a low mean pathology score (n=80 lumbar vertebrae). Cricketers with a higher pathology score (> 10) had a greater occurrence of pain on vertebral palpation (25%) compared to players with a lower pathology score (6%). Cricketers with a pathology score greater than 10 had a greater occurrence of pain on non-dominant paraspinal palpation (14%) compared to cricketers with a lower pathology score (4%). However, cricketers with a lower pathology score (< 10) complained more frequently of pain on paraspinal palpation of the dominant side (6%) compared to cricketers with a higher pathology score (3%).

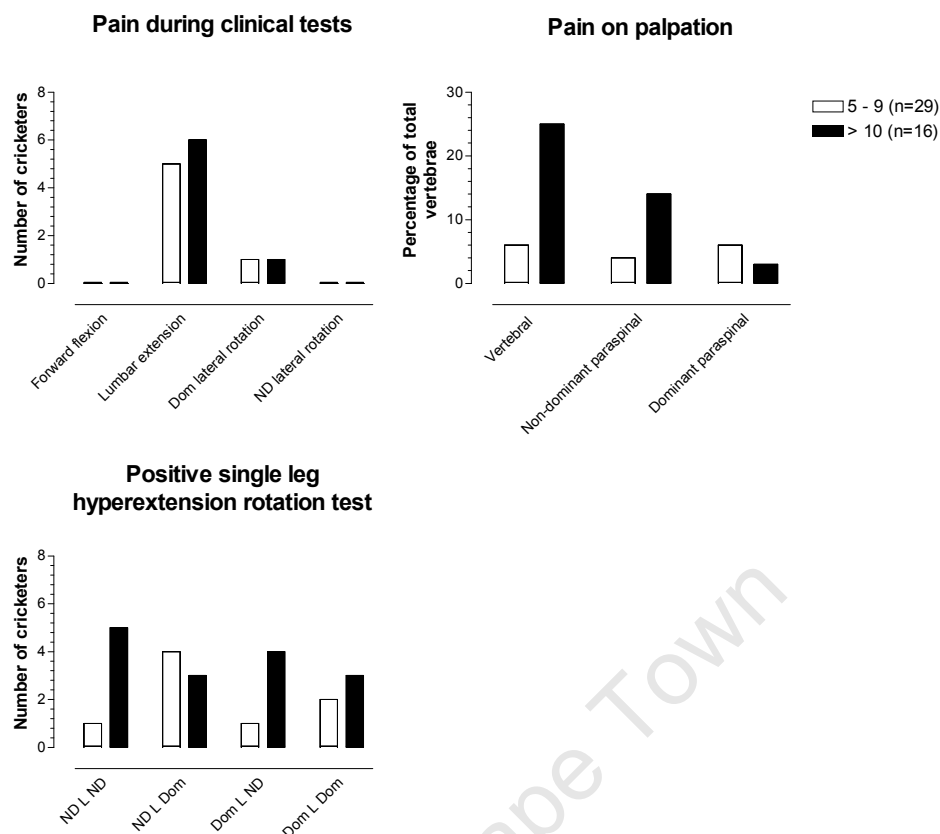


Figure 7.5: Number of cricketers and percentage occurrence of pain during clinical tests comparing cricketers with a mean pathology score above and below 10.

Abbreviations: ND, non-dominant; Dom, dominant

Note that: ND leg ND means that the subject stood on the non-dominant leg whilst rotating his upper body to the non-dominant side; ND leg Dom means that the subject stood on the non-dominant leg whilst rotating his upper body to the dominant side; Dom leg ND means that the subject stood on the dominant leg whilst rotating his upper body to the non-dominant side; Dom leg Dom means that the subject stood on the dominant leg whilst rotating his upper body to the dominant side

### 7.3.2.3 Lumbar pathology in cricketers with and without lower back pain

Figure 7.6 shows the percentage occurrence of disc, nerve and endplate pathology in cricket players with and without self-reported lower back pain. The cricketers with lower back pain had a total of 135 lumbar (L<sub>1</sub> to L<sub>5</sub>) intervertebral discs between them, whilst the cricketers without lower back pain have a total of 90 lumbar (L<sub>1</sub> to L<sub>5</sub>) intervertebral discs between them. The figure below shows the percentage of these intervertebral discs that had pathology. The cricketers without lower back pain had slightly more occurrence of endplate pathology (27%) compared to the group with lower back pain (24%). However, the group without lower back pain had slightly less occurrence of disc

tear (10%) nerve root pathology (3%) compared to the cricketers without lower back pain (16% and 9% respectively). Both groups had the same occurrence of disc degeneration, both grade I (90%) and above grade I (10%) severity.

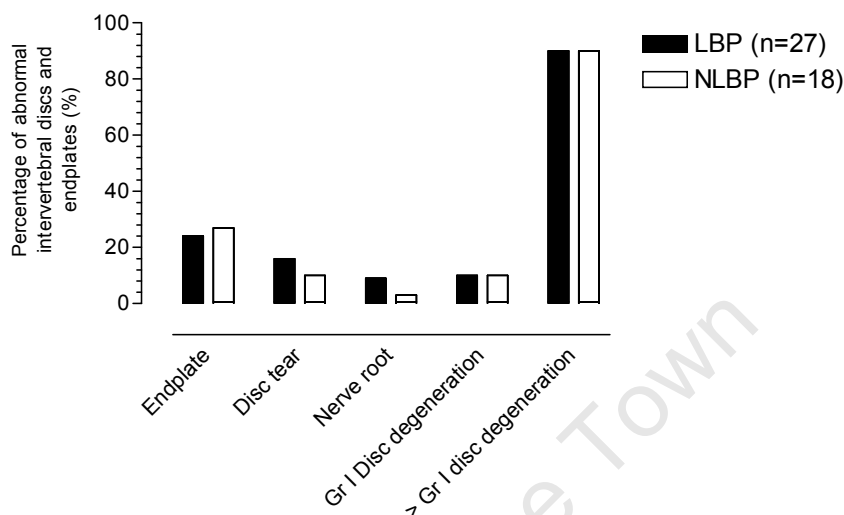


Figure 7.6: Percentage occurrence of abnormal intervertebral discs, nerves and endplates in cricketers with and without lower back pain

Abbreviations: LBP, lower back pain; NLBP, no lower back pain; Gr, grade

### 7.3.3 Baseline results separated by cricketing disciplines

#### 7.3.3.1 Clinical assessment results

Figure 7.7 shows results of the findings of a clinical assessment of the lumbar spine in cricketers with and without lower back pain and separated by cricketing discipline. There was a significant interaction for forward trunk flexion flexibility and cricketing discipline ( $F_{2,42}=3.28$ ;  $p=0.047$ ). Further analysis indicated that fast bowlers were less flexible in forward trunk flexion ( $1.5 \pm 2.7\text{cm}$ ) compared to batsmen ( $5.9 \pm 7.5\text{cm}$ ) ( $p=0.037$ ). Fast bowlers and spin bowlers complained of the most pain on palpation of the vertebrae (13%) compared to batsmen (6%).

The fast bowlers also complained more frequently of pain on both dominant (11%) and non-dominant ( $n=8$ ) paraspinal palpation compared to the spin bowlers (3% and 3% respectively) and batsmen (3% and 4% respectively). Fast bowlers also had the highest occurrence of positive (painful) single leg hyperextension rotation tests ( $n=10$ ) with the greatest pain produced by the test in which the cricketers stand on the non-

dominant leg and rotate the trunk to the dominant side (n=5), followed by the test in which the cricketer stands on the dominant leg and rotates the trunk to the dominant side (n=3).

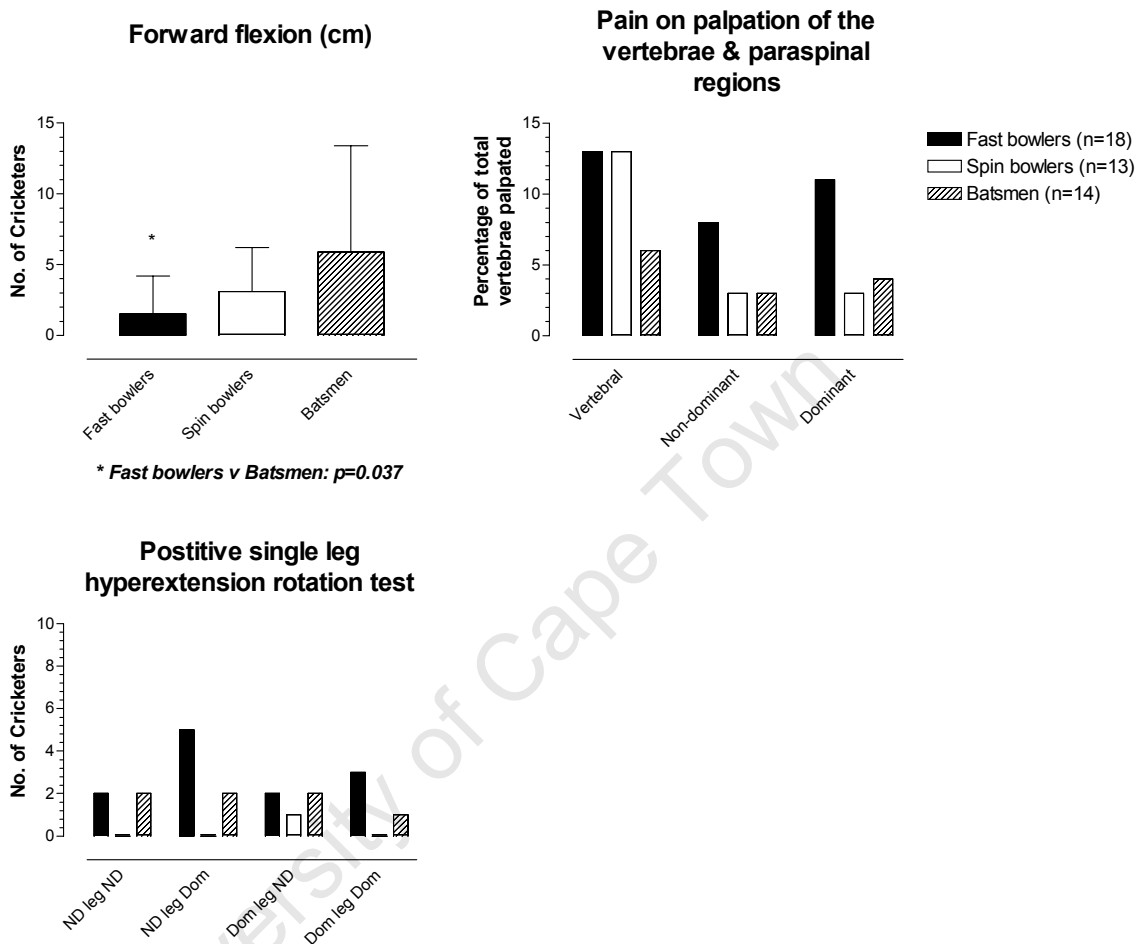


Figure 7.7: Number of cricketers and percentage vertebrae with pain during clinical assessments separated by cricketing discipline

Abbreviations: Dom, dominant; ND, non-dominant

Note that: ND leg ND means that the subject stood on the non-dominant leg whilst rotating his upper body to the non-dominant side; ND leg Dom means that the subject stood on the non-dominant leg whilst rotating his upper body to the dominant side; Dom leg ND means that the subject stood on the dominant leg whilst rotating his upper body to the non-dominant side; Dom leg Dom means that the subject stood on the dominant leg whilst rotating his upper body to the dominant side

### 7.3.4 Score of lumbar pathology assessment by cricketing disciplines

Figure 7.8 shows the mean pathology scores for cricketers separated by discipline. There were no significant differences between pathology score and discipline; nor were there differences between pathology score and each discipline separated into players with and without lower back pain.

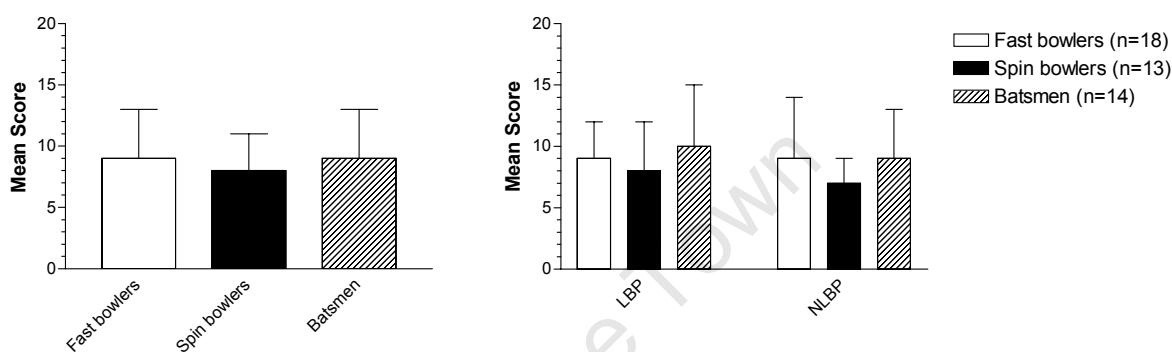


Figure 7.8: Mean pathology score on imaging for cricketers separated by discipline and with and without lower back pain

Abbreviations: LBP, lower back pain; NLBP, no lower back pain

#### 7.3.4.1 Lumbar pathology separated by cricketing disciplines

Fast bowlers had a total of 90 lumbar intervertebral discs between them, whilst spin bowlers and batsmen had 65 and 70 respectively. Figure 7.9 shows the percentage occurrence of specific pathology to the intervertebral discs, nerves and endplates in the lumbar spine comparing cricketing disciplines. Batsmen had the highest occurrence of abnormal endplates (29%) and abnormal nerve roots (10%), followed by fast bowlers (27% and 6% respectively) and spin bowlers (20% and 5% respectively). Fast bowlers had the highest occurrence of disc degeneration with greater than grade I severity (12%) in the lumbar spine, followed by spin bowlers (9%) and batsmen (7%). Both fast bowlers and batsmen had the highest occurrence of disc tear pathology in the lumbar spine (16%).

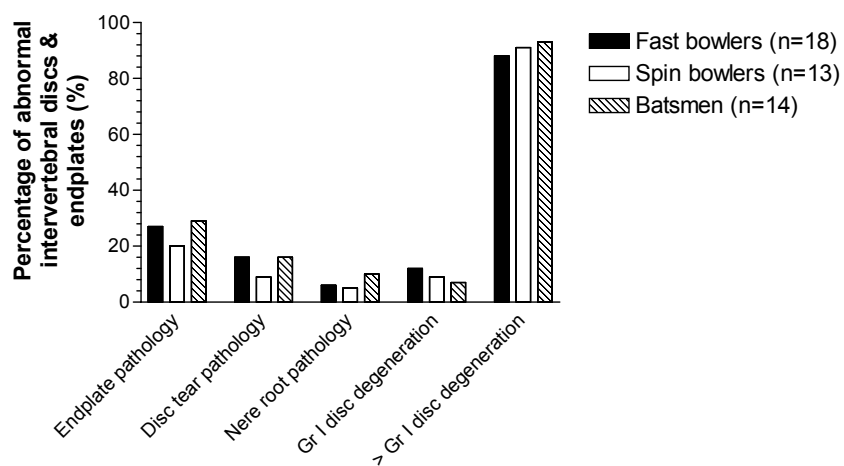


Figure 7.9: Percentage occurrence of intervertebral discs and endplates with abnormalities comparing the cricketing disciplines

Abbreviations: Gr, grade

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## 7.4 DISCUSSION

The findings of the clinical examination and MR imaging of the lumbar spine in a group of schoolboy cricketers with and without self-reported lower back pain were assessed in this chapter. These investigations were necessary as it was reported in Chapter 3 that 60% (n=27) of these schoolboy cricketers had self-reported lower back pain at the start of this study and that only 40% (n=18) were pain free.

The first important finding of this study was that the total pathology score for the group (n=45) was  $9 \pm 4$  out of a total of 125. Assessment of specific lumbar pathology on imaging studies revealed that all the cricketers assessed had a minimum of grade I disc degeneration at all lumbar vertebral levels. This occurrence is higher than previous reports of disc degeneration in cricketers<sup>13;14;16;25-27;54;55</sup>. However, unlike this investigation, those studies reported only on the occurrence of disc degeneration in fast bowlers and not across all the cricketing disciplines. Furthermore, the occurrence of disc degeneration in this study is higher than that of only 26% reported among 15 year olds in the non-cricketing population<sup>20</sup>. This further emphasizes that young cricketers are at risk of developing more advanced lumbar injuries due to the nature of the sport and the fact that young cricketers play throughout their growth period.

Other pathologies documented in these cricketers were endplate pathology, which had the second highest occurrence (56 endplate injuries in 45 cricketers) followed by 31 instances of disc tears and 15 instances of nerve root compressions in this study population. The majority of these pathologies occurred at the lower lumbar intervertebral disc levels of L<sub>4</sub> and L<sub>5</sub>. The pathology described in the cartilaginous endplates in this group of cricketers may be due to the high stresses on the lumbar spine during their rapid growth period. The cartilage is less resistant to the repetitive stresses, particularly during fast bowling, and complete ossification has not yet occurred<sup>27;57;58</sup>. Of special interest is that none of the cricketers studied demonstrated facet joint pathology or defects of the pars interarticularis on imaging studies at pre-season testing. These findings are unlike those of previous studies in which fast bowlers specifically were found to have a high occurrence of spondylolysis<sup>8;14;19;23;25-27;31;44;54;56;60;127;174</sup>. The probable reason for this was that the players were young. More exposure to cricket would probably have produced a greater number of more serious pathologies.

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A second important finding of this part of the study was the high number of positive clinical tests in this group of cricketers. Thirty-one of the 45 cricketers tested pre-intervention had either pain on lumbar extension (n=10), pain during single leg hyperextension rotation tests (n=20) or pain on vertebral (n=24) or paraspinal (n=21) palpation. The majority of pain during palpation was experienced from the 3<sup>rd</sup> to the 5<sup>th</sup> lumbar vertebral levels. Furthermore, the positive single leg hyperextension rotation test in which the cricketers stand on the non-dominant leg whilst rotating the trunk to the dominant side produced the greatest frequency of pain. It was also of interest that most of the pathology described above occurred at the lower lumbar intervertebral levels.

A third important finding was that a large number of cricketers with self-reported lower back pain had positive tests and experienced pain during clinical examination compared to cricketers without lower back pain. The cricketers with lower back pain were more likely to have pain on lumbar extension and during single leg hyperextension rotation tests compared to players who did not report lower back pain. Furthermore, the players with lower back pain also experienced the greatest frequency of pain on vertebral and paraspinal palpation. Surprisingly, even though cricketers with lower back pain had a greater occurrence of positive clinical tests, they did not necessarily have more severe pathology identified by the imaging studies.

A further important finding was that there were no significant differences for mean pathology scores between cricketers with ( $9 \pm 4$ ) and without ( $8 \pm 4$ ) self-reported lower back pain. This indicates that some cricketers without lower back pain showed significant abnormalities on MR imaging. One could perhaps infer that pain may in fact be a symptom that develops some time after the pathological can first be detected in the lumbar spine. Furthermore, cricketers with lower back pain may not always show abnormal imaging findings. This is important as it indicates a dissociation between lower back pain and the presence of pathology in the lumbar spine. This finding of dissociation between symptoms and pathology are consistent with previous studies<sup>40;175;176</sup>. Millson and colleagues assessed prospectively the diagnostic procedures used to detect lumbar pain and bone stress injuries in fast bowlers<sup>40</sup>. Their study reported a dissociation between reported lower back pain and the presence of spondylolysis. Previous studies have also attempted to relate Modic endplate changes with clinical symptoms of lower back pain, with some reporting a dissociation between

a history of lower back pain and Modic endplate changes at specific intervertebral disc levels<sup>175-179</sup>. Yet other studies have reported the opposite, specifically an association between lower back pain and pathologic changes of the lumbar spine<sup>25;26;62;63;180;181</sup>.

Since cricketers with and without lower back pain had similar mean pathology scores yet had varying clinical findings, it is important to assess the relationship of the mean pathology and clinical features. Cricketers with a mean pathology score of greater than 10 out of 125 had more positive tests for lumbar extension and single leg hyperextension with rotation. These players also experienced more pain on vertebral and non-dominant paraspinal palpation. However, players with a lower pathology score had more pain on dominant paraspinal palpation. It appears that cricketers with a higher mean pathology score have more clinical findings; however, there still appears to be dissociation between the presence of pathology shown on imaging and the presence of lower back pain. This type of analysis may have implications for clinicians and therefore further research is required to determine associations between mean pathology score and clinical findings assessing a larger sample group. Furthermore, previous studies have only assessed individual pathologies and not combined pathologies to give a total pathology score. This type of clinical analysis is novel to this thesis.

With respect to the assessment of specific radiological abnormalities identified by imaging studies, cricketers with lower back pain had a higher occurrence of nerve root and disc tear pathology compared to players without lower back pain. As the sample groups were too small, statistical analysis could not be performed on the data. Therefore these findings between the groups with and without lower back pain are not statistically significant and merely indicate possible trends. Further research should be conducted with larger sample groups to investigate the occurrence of lumbar pathology in schoolboy cricketers with and without lower back pain.

Findings in Chapter 3 showed that fast bowlers had the highest occurrence of self-reported lower back pain (29%) compared to the spin bowlers (23%) and batsmen (14%). One would therefore assume that the fast bowlers would have a higher occurrence of clinical abnormalities and lumbar pathology. However, there were no significant differences in mean pathology score between the disciplines. This again indicates a dissociation between the occurrence of lumbar pathology and lower back

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pain. Even though there was no significant difference between disciplines for mean pathology score, fast bowlers had the highest occurrence of more severe disc degeneration compared to spin bowlers and batsmen. However, the batsmen had the highest occurrence of endplate and nerve root pathology, whilst fast bowlers and batsmen had the same occurrence of disc tear pathology. Previous studies have shown a high rate of structural abnormalities in both vertebrae and intervertebral discs have been found among fast bowlers using various imaging techniques to diagnose lumbar pathology<sup>13</sup>. However, these previous studies did not assess the occurrence of these pathologies in batsmen and spin bowlers. This could be because young fast bowlers may be predisposed to this injury, as complete ossification has not yet occurred and their cartilage is less resistant to the repetitive stresses of bowling<sup>27;57;58</sup>. However, statistics could not be performed on the small sample groups. Therefore, these findings indicate only trends between disciplines. Spin bowlers and batsmen also presented with lumbar pathology and had a high occurrence of disc degeneration, which is surprising given the lower stresses to which their spines are exposed during cricket. These findings have not previously been reported as previous studies have only assessed the occurrence of intervertebral disc degeneration and pars interarticularis defects in fast bowlers<sup>13;14;16;25;27;40;43;55;127</sup>. These findings, however, clearly indicate that there is a need for future research to include an assessment of back pathology in spin bowlers and batsmen.

Findings of clinical features between disciplines indicate that the fast bowlers have the highest frequency of pain on vertebral and paraspinal palpation. Furthermore, fast bowlers had the greatest frequency of positive single leg hyperextension rotation tests when standing on the non-dominant leg rotating the trunk to the dominant side and standing on the dominant leg rotating the trunk to the dominant side. The latter test is of interest since at back foot impact, the fast bowlers land on his dominant leg and rotate their upper body to the dominant side and maintain this position until after front foot impact. One could postulate that fast bowlers with a higher degree of shoulder counter-rotation during this period would be likely to experience a positive clinical test.

It appears that cricketers have a greater degree of flexibility of the lumbar spine as compared to a non-sporting population. The total groups' mean lumbar extension was  $42 \pm 7.8^\circ$ , dominant lateral rotation  $47 \pm 19^\circ$  and non-dominant lateral rotation  $46 \pm 18^\circ$ , compared to  $20-35^\circ$  for lumbar extension and  $15$  to  $20^\circ$  for lateral rotation in the general population<sup>182</sup>. The batsmen also had a higher degree of flexibility with respect

to forward trunk flexion compared to the fast bowlers. Only one study has previously reported findings of lumbar flexibility in fast bowlers<sup>18</sup>. However, the results of that study (see Chapter 1) differ from the present study possibly due to the differences in measurement of trunk flexibility. A previous study reported no correlation between lumbar flexibility in wrestlers, gymnasts and soccer players and the presence of lower back pain<sup>183</sup>. Abnormal flexibility of the lumbar segments, specifically increased axial rotation, lateral bending, lumbar flexion and lumbar extension have previously been linked to the occurrence of disc degeneration<sup>184</sup>. However, that study assessed discs from cadavers with the lumbar segments being thawed to assess their biomechanical characteristics. Therefore, this finding may not be the case in live subjects when the sport and the muscles are taken into account. No studies appear to have assessed pathology and flexibility nor have they assessed spin bowlers and batsmen and cricketers with and without lower back pain. Therefore, these analyses are novel to this thesis.

## 7.5 CONCLUSION

The findings in this study indicate that the occurrence of grade I disc degeneration in the lumbar spine in these cricketers is higher than that reported in previous studies. All cricketers in this study, independent of pain and cricketing discipline had a minimum of grade I disc degeneration. Furthermore, there was no significant difference between mean pathology score and the presence of lower back pain, indicating a dissociation between the occurrence of pathology in the lumbar spine and self-reported lower back pain in young cricketers. However, cricketers with a higher mean pathology score (> 10) had a greater occurrence of positive clinical tests. Furthermore, there were a high number of positive clinical tests demonstrated particularly among the fast bowlers and cricketers with lower back pain. Fast bowlers also demonstrated the highest occurrence of more severe disc degeneration.

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## CHAPTER 8

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### **Clinical Evaluation and MR Imaging of the Lumbar Spine: Effects of a Lumbar Stabilisation Intervention**

#### **8.1 INTRODUCTION**

In Chapter 7 baseline clinical evaluation and baseline features of lumbar pathology as seen on MR imaging, were assessed in a group of young cricketers. Cricketers with self-reported lower back pain and fast bowlers had the highest occurrence of abnormal clinical and MR imaging findings. It was established in Chapter 3, that the lumbar stabilisation intervention program (as described in Chapter 2) was successful in decreasing the occurrence of self-reported lower back pain. This chapter will now assess the effects of the cricket-specific lumbar stabilisation exercise intervention on the clinical and imaging findings in this group of schoolboy cricketers.

Previous intervention studies in cricket have assessed changes in fast bowling technique with respect to shoulder counter-rotation and progression of disc degeneration through a coaching intervention and the use of a bowling harness<sup>28;55</sup>. Elliott and Khangure (2002) found that cricketers who decreased their shoulder counter-rotation over time did not show progression with respect to degeneration in the lumbar intervertebral discs<sup>55</sup>. Indeed, disc degeneration is more likely to progress in those fast bowlers who continue to bowl with a mixed action. However, to date no studies have evaluated the effects of a lumbar stabilisation exercise intervention on clinical findings on examination and lumbar pathology on imaging, across all cricketing disciplines.

The aim of this part of the study was therefore to determine the effect of a cricket specific lumbar stabilisation exercise intervention on the occurrence of adverse clinical signs and symptoms related to the lumbar spine and lumbar pathology as seen on MRI, in a group of elite, male, schoolboy cricketers.

## **8.2 METHODS**

### **8.2.1 Study design**

This was an intervention study of 39 elite male schoolboy cricketers (mean age of 16.7 ± 0.8 years) to determine the effect of a lumbar stabilisation program on pathologic features on MR imaging and clinical examination findings of the lumbar spine in cricketers. The effect of the intervention on these variables was also assessed to determine changes in the cricketers who continued to complain of pain in the lower back pain and cricketers whose lower back pain resolved during the intervention.

### **8.2.2 Investigations**

#### **8.2.2.1 Lower back pain**

Lower back pain was defined as self-reported pain in the lumbar region. For the purposes of accurate analysis the cricketers were divided into two groups to assess the effect of the intervention on change in lower back pain status. The first group was defined as cricketers without lower back pain or whose lower back pain resolved during the intervention period. The second group included cricketers who either had continued to complain of lower back pain or who developed new onset of lower back pain during the course of the study.

#### **8.2.2.2 Clinical assessment of the lumbar spine**

A clinical examination of the lumbar spine was performed by a sports physician to assess the lower back and trunk as outlined in Chapter 2.

#### **8.2.2.3 Magnetic resonance imaging of the lumbar spine**

MR imaging assessments included standard sagittal T2-weighted and STIR (short tau inversion recovery) and axial T1 sequences sequences of the lumbar spine performed pre and post-intervention. An additional sagittal DESS sequence was added post-intervention. MR imaging was specifically used to determine disc degeneration, nerve root compression, endplate and disc tear pathology, bone stress injury and facet joint pathology. MRI results were reported by radiologists with specific interest in musculoskeletal imaging.

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### **8.2.3 Intervention program**

An 8-week cricket specific progressive lumbar stabilization program was performed pre-season. As mentioned this program consisted of the cognitive, associative and autonomous phases. A detailed description of the intervention can be found in Chapter 2. The intervention and control groups were assessed pre-intervention and post-season to determine whether the intervention had any effect on clinical and imaging features of the lumbar spine. During the 8-week intervention the control group performed traditional pre-season cricket training, with no training occurring during the cricket season. The results are presented as comparisons between intervention and control groups.

### **8.2.4 Statistical analysis**

No statistics could be performed on some of the data as the sample groups were too small to achieve meaningful statistical power. In these instances the results were assessed descriptively by comparing the changes in the occurrence of positive single leg hyperextension rotation tests pre- and post-intervention, as well as the percentage of total lumbar vertebral levels with respect to pain on palpation and the occurrence of pathology of the lumbar spine pre- and post-intervention. Therefore, in the intervention group (n=21) there was a total of 105 lumbar vertebrae assessed and in the control group (n=18) a total of 90 lumbar vertebrae assessed. This was also calculated for the cricketing disciplines and lower back pain status. Statistical analysis was, however, performed using analysis of variance (ANOVA) to determine change over time in trunk flexibility between the intervention and control groups.

## 8.3 RESULTS

### **8.3.1 Changes in clinical assessments pre- and post-intervention**

#### **8.3.1.1 Comparisons of clinical assessments following the intervention period between all cricketers in the intervention and control groups**

There was no change in lumbar flexibility when comparing the cricketers in the intervention and control groups following the intervention program.<sup>xvi</sup>

Figure 8.1 shows the occurrence of pain during clinical tests pre- and post-intervention. The intervention group had increased the number of positive single leg hyperextension rotation test post-intervention (n=7 to n=14), whilst 3 players in the control group reported normal tests post-intervention (n=14 to n=11). There was little change in the percentage occurrence of pain on palpation of the vertebrae (10% to 9%) and dominant (8% to 10%) and non-dominant paraspinal (4% to 7%) sides in the intervention group following the intervention. However, the control group had a decrease in the percentage occurrence of pain on palpation of both the lumbar vertebrae (15% to 5%) and non-dominant paraspinal side (8% to 3%).

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<sup>xvi</sup> See Appendix K Table K31 for the results of change in lumbar flexibility post-intervention

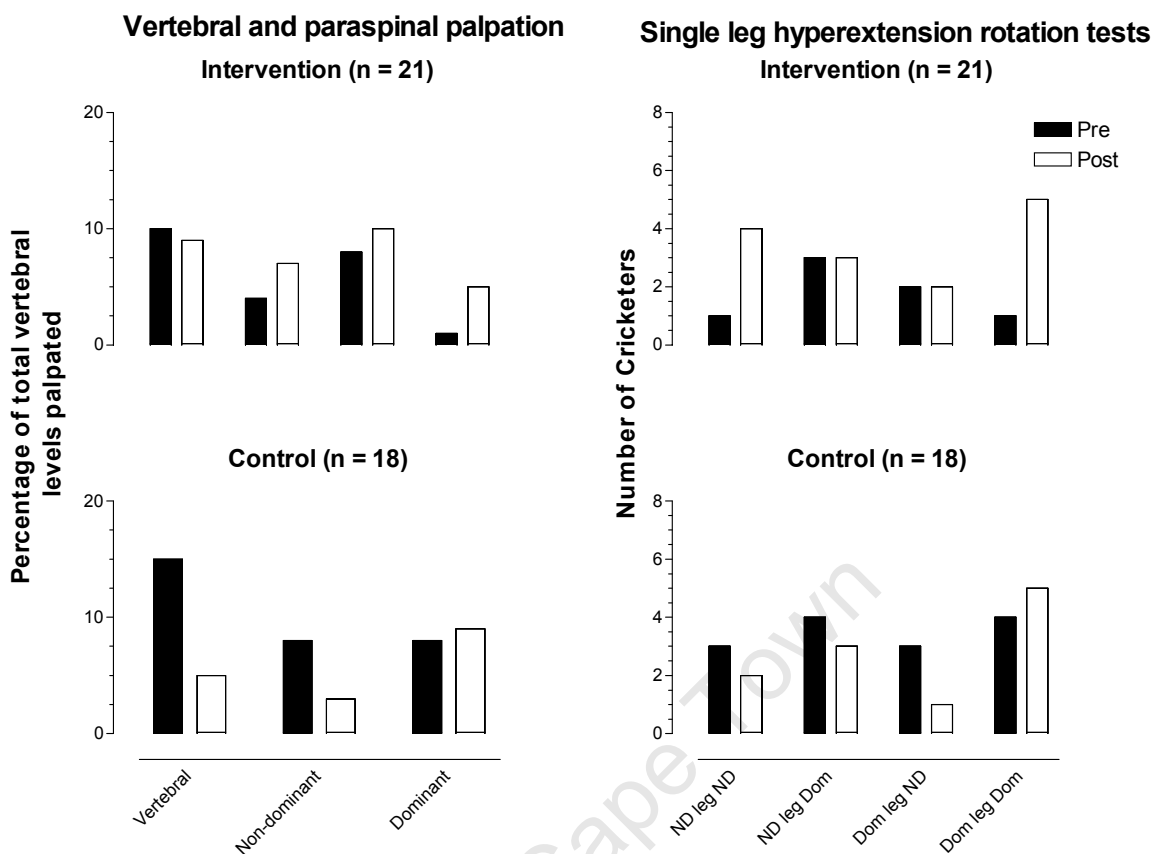


Figure 8.1: Cricketers with positive clinical tests pre- and post-intervention

Abbreviations: ND, non-dominant; Dom, dominant; Pre, pre-intervention; Post, post-intervention

Note that: ND leg ND means that the subject stood on the non-dominant leg whilst rotating his upper body to the non-dominant side; ND leg Dom means that the subject stood on the non-dominant leg whilst rotating his upper body to the dominant side; Dom leg ND means that the subject stood on the dominant leg whilst rotating his upper body to the non-dominant side; Dom leg Dom means that the subject stood on the dominant leg whilst rotating his upper body to the dominant side

### 8.3.1.2 Comparisons of clinical assessments following the intervention period between cricketing disciplines in the intervention and control groups

It is important to note that when separating the cricketers in the intervention and control groups into their separate cricketing disciplines the sample numbers are fairly small. Therefore, the occurrence of clinical signs and symptoms and pathology detected in imaging of the lumbar spine, are presented in the appendix and should be interpreted with caution.

There was no change in lumbar flexibility when comparing the different cricketing disciplines in the intervention and control groups following the intervention program. This has also been presented in the appendix due to the small groups. <sup>XVII</sup>

Figure 8.2 shows the change in occurrence of positive single leg hyperextension rotation tests (SLHR) across the cricketing disciplines following the intervention program. The fast bowlers (n=3), spin bowlers (n=1) and batsmen (n=3) in the intervention group all increased their occurrence of positive SLHR tests following the intervention program (fast bowlers: n=4, spin bowlers: n=6, batsmen: n=4). This is compared to the fast bowlers (n=7), in the control group who marginally decreased their occurrence of positive SLHR tests (n=5). Amongst the spin bowlers (n=0) and batsmen (n=4) in the control group, one other developed a positive SLHR test during the study.

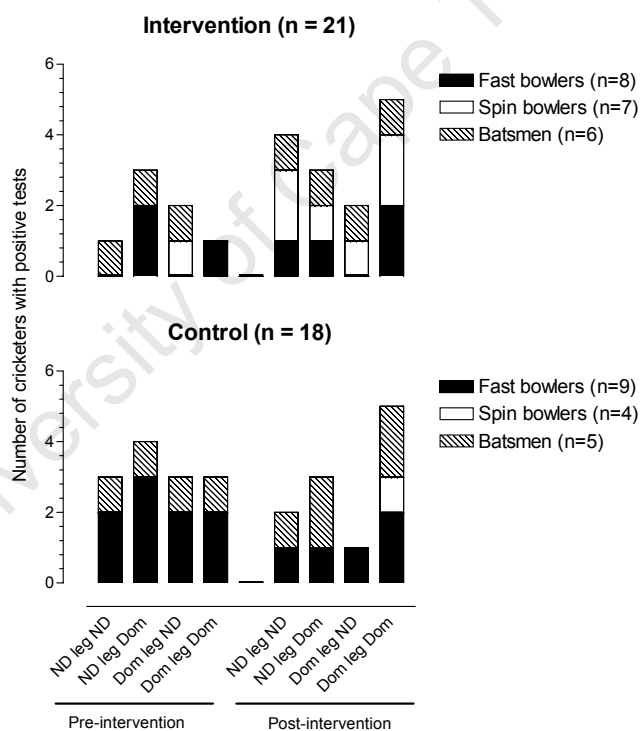


Figure 8.2: Cricketers with positive single leg hyperextension rotation tests pre- and post-intervention

Abbreviations: Dom, dominant; ND, non-dominant

Note that: ND leg ND means that the subject stood on the non-dominant leg whilst rotating his upper body to the non-dominant side; ND leg Dom means that the subject stood on the non-dominant leg whilst rotating his upper body to the dominant side; Dom leg ND means that the subject stood on the dominant leg whilst rotating his upper body to the non-dominant side; Dom leg Dom means that the subject stood on the dominant leg whilst rotating his upper body to the dominant side

<sup>XVII</sup> See Appendix K Table K32 for the results of change in lumbar flexibility post-intervention

Figure 8.3 shows the change in the percentage occurrence of pain on palpation of the vertebrae and paraspinal regions across cricketing disciplines following the intervention program. Intervention group fast bowlers (n=8) had a total of 40 lumbar vertebral levels palpated between them, whilst the spin bowlers (n=7) and batsmen (n=6) had a total of 35 and 30 lumbar vertebral levels palpated. The control group fast bowlers (n=9) had a total of 45 lumbar vertebral levels palpated, whilst the spin bowlers (n=4) and batsmen (n=5) had a total of 20 and 25 vertebral levels palpated.

Fast bowlers (15%) and spin bowlers (10%) in the intervention group both decreased their frequency of pain on vertebral palpation following the intervention program (fast bowlers: 6%, spin bowlers: 5%). However, the batsmen (6%) in the intervention group increased the occurrence of pain on palpation of the lumbar vertebrae (17%) following the intervention. These results are compared to the fast bowlers (13%), spin bowlers (25%) and batsmen (10) in the control group who all decreased their occurrence of pain on palpation of the lumbar vertebrae over the same time period (fast bowlers: 7%, spin bowlers: 4%, batsmen: 0%). Fast bowlers in the intervention group had little change in their frequency of pain on palpation of the non-dominant (5% to 5%) and dominant paraspinal (10% to 8%) regions following the intervention. This was also the case for palpation of the dominant side in spin bowlers in the intervention group (6% to 6%), however, they decreased their frequency of pain on palpation of the non-dominant region following the intervention (6% to 3%). In comparison the batsmen in the intervention group increased their frequency of pain on palpation of both the non-dominant (0% to 13%) and dominant (7% to 17%) sides following the intervention program. The fast bowlers and spin bowlers in the control group decreased their frequency of pain on palpation of both the non-dominant and dominant sides during the intervention period.

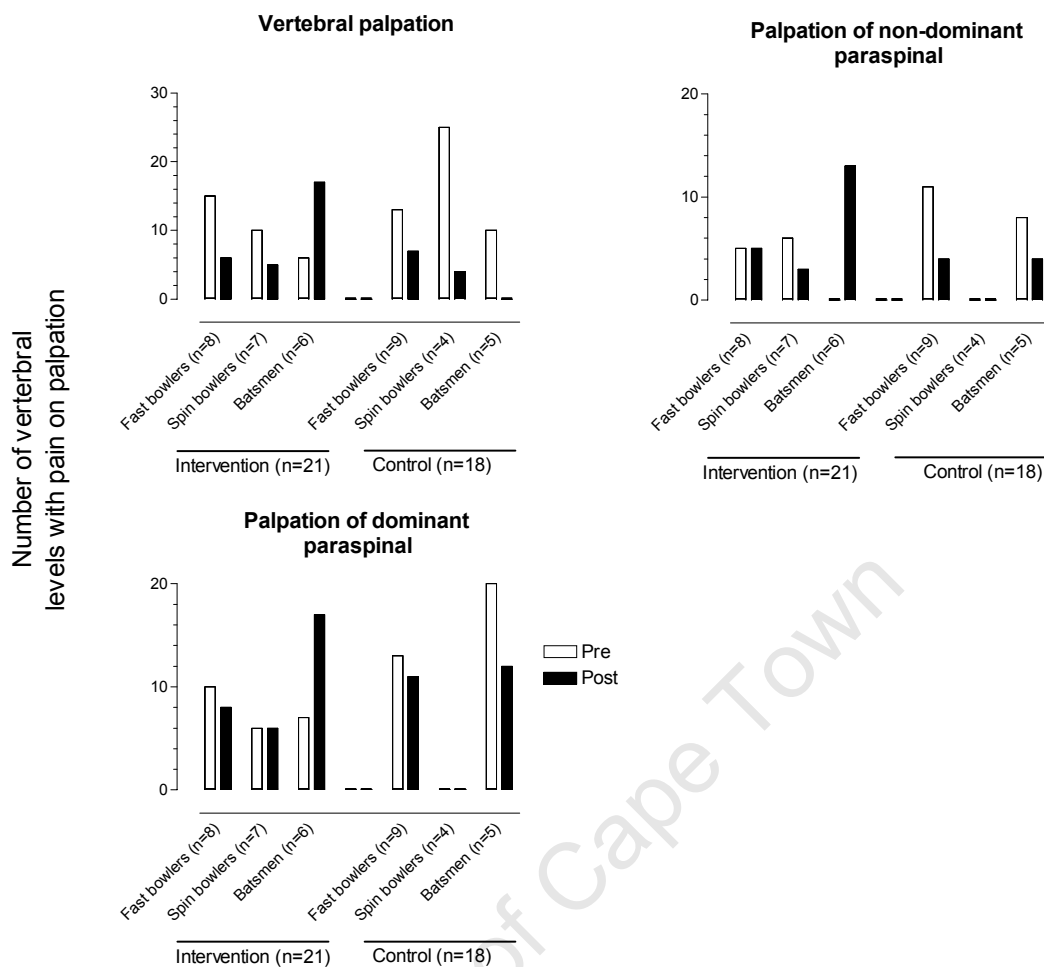


Figure 8.3: Percentage of total vertebral levels with pain on palpation of the lumbar vertebrae and non-dominant and dominant paraspinal regions pre- and post-intervention

Abbreviations: Pre, pre-intervention; Post, post-intervention

**8.3.1.3 Comparisons of clinical findings following the intervention period between all cricketers with and without lower back pain in the intervention and control groups**

There was no change in lumbar flexibility when comparing the cricketers with and without lower back pain in the intervention and control groups following the intervention program.<sup>XVIII</sup>

For the purpose of analysis in the change of positive clinical tests during the intervention period, the cricketers were separated into two clusters, the first included cricketers who did not experience lower back pain during the intervention period or

<sup>XVIII</sup> See Appendix K Table K33 for the results of change in lumbar flexibility post-intervention

whose lower back pain resolved during this period and the second included cricketers who either developed lower back pain or who continued to complain of lower back pain during the intervention period. There was little change demonstrated in the overall frequency of pain during single leg hyperextension rotation tests in cricketers in both the intervention and control groups with respect to change in lower back pain status.<sup>xix</sup> There was also little change in the percentage occurrence in frequency of pain on palpation of the vertebrae and non-dominant and dominant paraspinal regions separated by lower back pain status following the intervention program.<sup>xx</sup> However, it must be noted that these results included small groups (cricketers in the intervention group with lower back pain: n=3; cricketers in the control group without lower back pain: n=4) and thus should be interpreted with caution.

### **8.3.2 Changes in lumbar imaging pathology pre- and post-intervention**

#### **8.3.2.1 Change in mean lumbar pathology scores following the intervention**

Table 8.1 shows the mean imaging pathology scores pre- and post-intervention. There was no significant change between the control and intervention groups over time.

**Table 8.1: Mean pathology scores out of 125 for cricketers pre and post-intervention**

		Intervention (n=21)	Control (n=18)
Pre-intervention	Mean score	8 ± 3	10 ± 4
	95% Confidence intervals	7 – 10	8 – 12
Post-intervention	Mean score	8 ± 3	10 ± 4
	95% Confidence intervals	6 - 9	8 – 12

Table 8.2 shows the change in total pathology score in cricketers in the intervention and control group with respect to change in lower back pain status during the intervention period. There were no significant changes in total pathology score between the intervention and control groups over time when separating the cricketers into cricketers with respect to change in lower pain status. However, these findings need to be interpreted with caution due to the few cricketers in the intervention group

<sup>xix</sup> See Appendix K, Figure K3 for change in single leg hyperextension rotation test with respect to change in lower back pain status during the intervention period

<sup>xx</sup> See Appendix K, Figure K4 for change in percentage occurrence of pain on palpation of the vertebrae and paraspinal regions with respect to change in lower back pain status during the intervention period

who continued to complain of lower back pain (n=3) and cricketers in the control group without lower back pain (n=4).

**Table 8.2: Mean pathology score out of 125 for cricketers intervention and control group separated into cricketers with and without lower back pain**

		Intervention (n=21)		Control (n=18)	
		LBP (n=3)	NLBP (n=18)	LBP (n=14)	NLBP (n=4)
Pre-intervention	Mean score	12 ± 5	7 ± 3	10 ± 4	9 ± 3
	95% Confidence intervals	1 - 24	6 - 9	8 - 12	4 - 13
Post-intervention	Mean score	12 ± 5	7 ± 3	10 ± 4	10 ± 5
	95% Confidence intervals	1 - 24	6 - 9	7 - 12	2 - 17

**Abbreviations: LBP, lower back pain, NLBP, no lower back pain**

Table 8.3 shows the change in total pathology score during the intervention period in cricketers in the intervention and control group separated by cricketing discipline. There were no significant changes in total pathology score between the intervention and control groups over time when separating the cricketers into cricketing disciplines. However, these findings need to be interpreted with caution due to the small sample groups.

**Table 8.3: Mean pathology score out of 125 for cricketers in the intervention and control group by cricketing discipline**

Testing session		Intervention (n=21)			Control (n=18)		
		Fast bowlers (n=8)	Spin bowlers (n=7)	Batsmen (n=6)	Fast bowlers (n=9)	Spin bowlers (n=4)	Batsmen (n=5)
Pre-intervention	Mean score	7 ± 2	8 ± 4	10 ± 4	11 ± 4	8 ± 3	10 ± 4
	95% Confidence intervals	6 - 9	4 - 12	5 - 14	8 - 14	3 - 12	4 - 15
Post-intervention	Mean score	7 ± 2	8 ± 3	9 ± 5	12 ± 5	6 ± 1	9 ± 3
	95% Confidence intervals	6 - 9	5 - 11	4 - 14	8 - 16	4 - 7	5 - 12

### 8.3.2.2 Changes in lumbar pathology on MRI after the intervention in all cricketers

Figure 8.4 shows the change in number of lumbar intervertebral discs with disc, nerve and endplate pathology in all cricketers from pre- to post-intervention. There was little change in the total number of intervertebral discs, nerves and endplates with pathology or specific lumbar pathology in both the intervention and control groups during the intervention period.

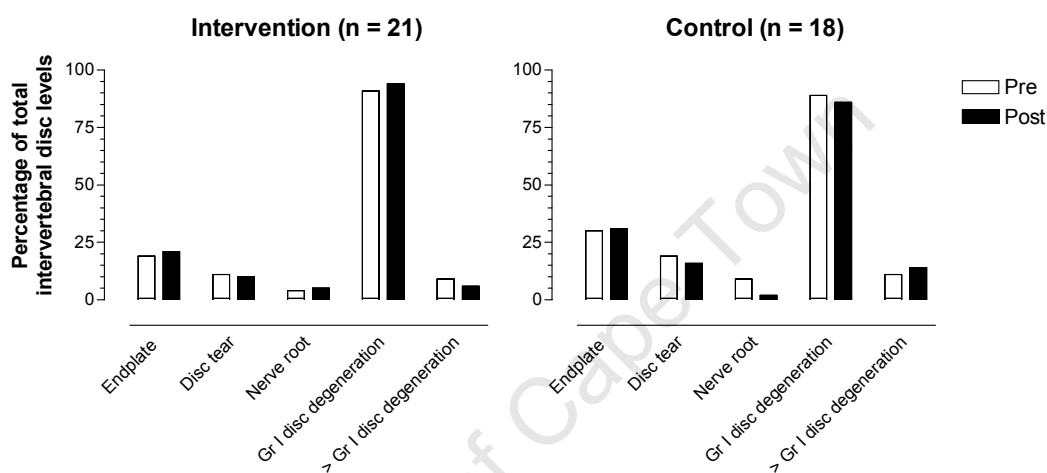


Figure 8.4: Percentage occurrence of lumbar disc, nerve root and endplate pathology in all cricketers pre- and post-intervention

### 8.3.3 Changes in lumbar pathology following an intervention by cricketing disciplines

Figure 8.5 shows the change percentage occurrence of disc and nerve root pathology of the lumbar spine across cricketing disciplines during the intervention period. There was little change in the percentage occurrence of intervertebral disc and nerve root pathology of the lumbar spine.

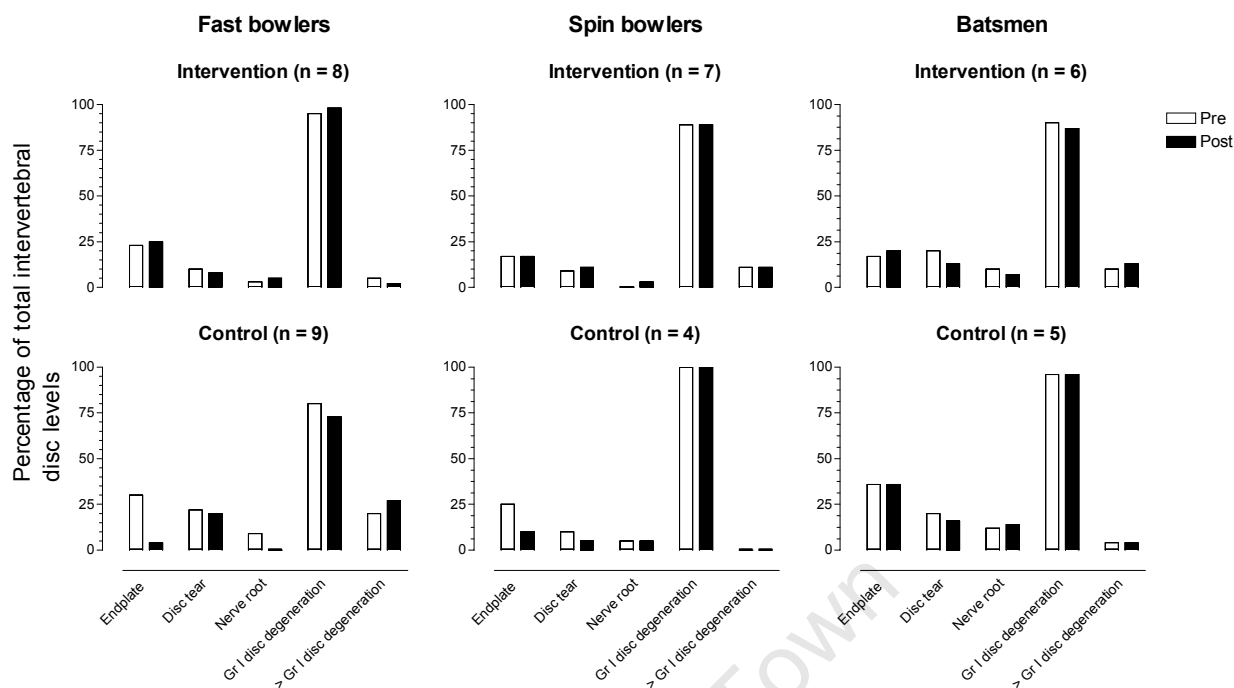


Figure 8.5: Percentage occurrence of lumbar disc, nerve root and endplate pathology across cricketing disciplines pre- and post-intervention

One bowler from the control group had a pars interarticularis grade III stress fracture, post-intervention. This may have developed during the season as it was only reported following the evaluation of a sagittal DESS MRI sequence (which is more sensitive to pars interarticularis abnormalities) performed post-intervention.

### 8.3.4 Lumbar pathologic changes in cricketers with and without lower back pain

The change in percentage occurrence of disc, nerve and endplate pathology of the lumbar spine in cricketers without lower back pain, namely those who resolved their lower back pain or were pain free (n=18) and cricketers who had lower back pain, namely those who continued to complain of pain or developed new onset of pain during the intervention period was assessed. There was little change in the percentage occurrence of disc and nerve root pathology in the lumbar spine in cricketers with or without lower back pain in the intervention and control groups during the intervention period.<sup>XXI</sup> There was also little change demonstrated in the presence of endplate pathology in cricketers with and without lower back pain in both the control and

<sup>XXI</sup> See Appendix K, Figure K5 for change in percentage occurrence of disc and nerve pathology during the intervention period

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intervention groups during the intervention period.<sup>xxii</sup> Once again these data should be interpreted with caution due to the few cricketers with lower back pain in the intervention group (n=3) and cricketers without lower back pain in the control group (n=4) following the intervention program.

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<sup>xxii</sup> See Appendix K, Figure K6 for change percentage occurrence of endplate pathology during the intervention period

## 8.4 DISCUSSION

To the best of my knowledge there is no other research regarding the effects of a progressive lumbar stabilisation exercise intervention on findings of clinical assessment and specific lumbar pathology in cricket players, with and without lower back pain. However, one study on the non-sporting population with lower back pain has previously assessed changes in lumbar range of motion following a stability exercise program<sup>98</sup>. In Chapter 3 it was discussed that 14 cricketers in the intervention group reported lower back pain pre-intervention, whilst only 1 cricketer still complained of pain post-intervention and 3 reported lower back pain post-season. This is compared to the control group who did not have a decrease in the occurrence of self-reported lower back pain. With this in mind it was necessary to assess whether there was a concurrent decrease in the occurrence of positive clinical and pathological features on MR imaging following the exercise intervention.

The first finding of this part of the study was that there were no differences in change of range of motion between the intervention and control groups following the intervention program. This finding was also the case when cricketers were separated into disciplines and the cricketers with and without lower back pain. This means that the lumbar stabilisation intervention had no effect on change of lumbar range of motion regardless of resolution of lower back pain. This finding is consistent with the findings of O'Sullivan et. al., (1997) who reported no change in range of motion of the lumbar spine in the groups that underwent conservative or stability exercise interventions<sup>98</sup>.

The cricketers were assessed as the entire group (n=39) and then separated into their respective cricketing disciplines to assess the change in occurrence of positive clinical tests following the lumbar stabilisation intervention. In both instances there appears to be no change in the occurrence of pain experienced during pain on palpation of the vertebrae and paraspinal regions and pain during single leg hyperextension rotation tests following the lumbar stabilisation intervention program. Due to the lack of statistical power and low occurrence of positive clinical tests, it was not possible to perform a statistical analysis. Therefore, only trends and not statistical results have been identified. A possible reason why the intervention program did not decrease the occurrence of pain during clinical examination is because the program was administered to the whole group. Rather it may need to be supervised on an individual basis especially during the first phase of the program. That phase involved the

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cricketers learning how to correctly activate the transverse abdominis muscle independently of the activation of the internal and external oblique muscles. As mentioned in Chapter 3, there was a significant decrease in the occurrence of self-reported lower back pain in the intervention group following the intervention. The symptoms of pain in the lower back region may therefore resolve first and pain during clinical tests only resolving later. Therefore, future intervention programs of this nature may need to be of longer duration.

In assessing the change in occurrence of pain during the clinical examination with respect to cricketers with and without lower back pain, the cricketers were separated into two groups. This was necessary to compare how the cricketers whose self-reported lower back pain resolved following the intervention and those cricketers who developed lower back pain during the cricket season responded to the intervention program. Therefore, cricketers whose lower back pain resolved or who were pain free during the intervention period were grouped together as those without lower back pain and cricketers who continued to complain of lower back pain or developed new onset of pain were grouped into cricketers with lower back pain. However, due to the few cricketers in the intervention group with lower back pain ( $n=3$ ) during the intervention and cricketers in the control group without lower back pain ( $n=4$ ) these comparisons should be interpreted with caution. Therefore, it was not possible to perform statistics on the small sample group, therefore the results are merely trends. It is important, however, that the majority of cricketers in the intervention group resolved their lower back pain, whilst the majority of cricketers in the control group continued to complain of lower back pain (see Chapter 3). It appeared that there was little change in the frequency of pain during single leg hyperextension rotation tests in both the intervention and control group cricketers with and without lower back pain. Furthermore, there was also little change in the frequency of pain on palpation of the vertebrae and paraspinal regions in cricketers in the intervention group without lower back pain. In contrast, it appears that cricketers in the intervention group with lower back pain tended to increase their frequency of pain on palpation during the intervention period. Furthermore, the control group players with lower back pain appeared to decrease their frequency of pain on palpation of the vertebrae and non-dominant paraspinal region. This seemingly anomalous result could be due to the fact that more players who complained of lower back pain in the control group ( $n=49$ ) had clinical symptoms pre-intervention compared to those in the intervention ( $n=10$ ). Alternatively it can support the earlier interpretation, namely, that lower back pain

resolves first and clinical symptoms possibly resolve later on. Or possibly that clinical symptoms may resolve independently of a lumbar stabilisation exercise intervention. There is therefore a need for these types of intervention programs to focus on the individual, specifically during the early phase of the lumbar stabilisation program. However, this needs further research with a larger sample group where it is firstly possible to perform a proper statistical analysis and secondly encompasses a longer intervention study to determine whether clinical signs and symptoms do resolve over a longer time period following the resolution of self-reported lower back pain.

A novel aspect of this study is the assessment of a pathology score, incorporating all the pathology that occurred to the lumbar spine. By calculating a pathology score it was possible to assess the overall severity of injury to the lumbar spine in cricketers. No differences were found in the pathology score for the intervention group following the intervention program. Neither was there any difference across disciplines or between cricketers with and without lower back pain in the intervention group. Similarly, there was no change in the pathology score for the cricketers in the control group. Therefore, there appears to be no effect of a lumbar stabilisation exercise intervention on the lumbar pathology score in cricketers with and without lower back pain or across cricketing disciplines. A possible reason for this may be due to a lack of sensitivity in this method of analysis or that changes in lumbar pathology may take longer as found by Elliott and Khangure (2002)<sup>55</sup> so that the intervention program needs to be implemented over a longer time period. A further possible reason for the lack of change may be due to the small sample size, the sensitivity of the scoring method or the lack of more advanced pathology in the lumbar spine. Therefore, further research using lumbar pathology scores to test the effect of this type of an intervention over a longer period and in a group with more severe lumbar pathology needs to be performed. Alternatively it might be argued that more severe pathology would be less likely to resolve with an intervention program.

It was difficult to compare the results of this part of the study with previous research because, as previously mentioned to the best of my knowledge no previous studies have assessed the effects of a lumbar stabilisation intervention on the occurrence of lumbar pathology. Review of the literature produced no studies which evaluated changes in these types of lumbar pathology with respect to the implementation of an exercise intervention<sup>185</sup>. However, Burnett et. al., (1996) used an educational intervention for cricketers during the first year of their 4 years study in an attempt to

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reduce the occurrence of lower back injuries and modify fast bowling technique<sup>16</sup>. Elliott and Khangure (2002) investigated the effect of a coaching intervention for fast bowlers over a 4 year period on the change in degree of shoulder counter-rotation and subsequent change in the occurrence of disc degeneration<sup>55</sup>. The authors, however, reported an increase in lumbar disc degeneration during years 1 and 2 of their study, therefore, this study showed that the coaching intervention needed to be more than 1 year to be viable. However, years 2 to 4 had a decrease in disc degeneration in the bowlers who decreased their shoulder counter-rotation. Progression of the number of degenerative discs or the severity of the disc degeneration was only observed in fast bowlers who continued to bowl with a mixed bowling technique.

Other pathologies including spondylolysis and spondylolithesis have been assessed with respect to the effect of bracing of the lumbar spine on recovery of these pathologies in patients with lower back pain<sup>186-189</sup>. A brace was worn around the lumbar spine to limit lumbar lordosis for several months. All of the studies reported good to excellent results in the resolution of spondylolysis and spondylolithesis. However, only one of these studies incorporated physical therapy focused on spinal flexion exercises combined with spinal bracing. A study by Moller and Hedlund (2000) assessed changes in spondylolithesis following 2.5-4 weeks of stretching, coordination exercise, abdominal and extension strengthening<sup>190</sup>. It reported no radiographic changes after 4-7 months follow-up. Furthermore, previous studies in cricket have reported on the occurrence of disc degeneration and spondylolysis in fast bowlers<sup>13;14;16;25;27;40;43;55;127</sup>, these and other pathologies have not been assessed post-lumbar stabilisation intervention for this discipline or indeed for cricketers in general. Intervention studies in cricket have involved coaching and lumbar bracing and have focused on changes in bowling technique in fast bowlers<sup>28;55</sup>. Therefore, a lumbar stabilisation intervention and analysis is unique in assessing cricketers with and without lower back pain and across all disciplines.

A further finding when assessing overall pathology of the lumbar spine following the exercise intervention was that there was little change in the total number of intervertebral discs, nerve roots or endplates with pathology. Furthermore, there was little change in specific pathology in the total group of cricketers following the intervention period. These findings appear to suggest that a decrease in lower back pain in this group of cricketers may occur prior to lumbar pathologic changes. However, as mentioned the intervention may require a longer duration and more one-

on-one training in the early phase, as well as further research with a larger population group for statistical power.

When the total study group was separated into their respective cricketing disciplines or by change in lower back pain status, it appeared that there was no change in the occurrence of individual pathologies to the lumbar spine. However, once again due to the lack of statistical power these findings could not be statistically analysed. These data should be interpreted with caution due to the few cricketers in some of the groups. Of interest is that even though cricketers resolved their lower back pain in the intervention group during the intervention period, they still had the presence of pathology on MR imaging. Thus it further appears to strengthen the case for a dissociation between lower back pain and the presence of pathology on MRI. Therefore, it is of importance to the clinician, that cricketers whose symptoms of pain in the lumbar region resolve does not necessarily indicate that their pathology in the lumbar spine has also resolved. Thus further research is suggested to determine whether a lumbar stabilisation intervention of longer duration is able to decrease this pathology following the resolution of lower back pain.

The effect of the lumbar stabilisation intervention on change in spondylolysis or spondylolithesis was not possible due to only one of the fast bowler in the control group, who complained of pain pre-season and post-season, presenting with grade III pars interarticularis pathology at L<sub>5</sub> during post-season imaging assessments. This is unlike previous studies that have reported a high occurrence of pars interarticularis defects in this age group due to the repetitive loading of the lumbar spine during fast bowling<sup>8;14;19;23;25-27;31;44;54;56;60;127;174</sup>. Young fast bowlers may also be predisposed to this injury as complete ossification has not yet occurred and their cartilage is less resistant to the repetitive stresses<sup>27;58;191</sup>. As pain reported is normally localized, being aggravated by lumbar extension, lateral deviation to one or both sides, spondylolysis is mostly easily identified in a clinical assessment by performing the one-legged hyperextension test<sup>8;54;56</sup>. This fast bowler, however, had a normal hyperextension test during the study. During post-season imaging, a high resolution Dual Echo Steady State (DESS) MR sequence using a slice thickness of 1mm was performed. This type of sequence is more sensitive in detecting pars interarticularis defects, as it did in this instance. As the DESS was not done pre-season, it is possible, indeed perhaps probable, that the defect may have been present but undetected pre-season.

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## 8.5 CONCLUSION

The findings of this study indicate that there was little change in the frequency of pain elicited during clinical examination in the entire group of cricketers or when separated into cricketing disciplines or change in lower back pain status following the intervention. Furthermore, there was no change in total pathology score and change in the percentage occurrence of disc, nerve and endplate pathology following the intervention period. Indeed, this was demonstrated in the entire group of cricketers and after subdivision into cricketing disciplines or change in lower back pain status during the intervention period. Furthermore, there is an apparent dissociation between self-reported lower back pain and pathological findings on MRI of the lumbar spine. Even though symptoms of lower back pain resolve in some of the cricketers, there is still the presence of pathology detected on MR imaging of the lumbar spine. This is important for clinicians as it indicates that they should rather treat each cricketer individually and not solely according to the pathology as viewed on MR imaging.

## SECTION 4

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In this section I will investigate muscle thickness dimensions (Chapter 9), clinical findings and lumbar pathology (Chapter 10) in the group of fast bowlers to correlate variables with shoulder counter-rotation pre- and post-intervention.

Chapters in this section:

- Chapter 9: Shoulder counter-rotation and muscle symmetry, pain and pathology on MRI of the lumbar spine in elite schoolboy fast bowlers
- Chapter 10: The effects of a lumbar stabilisation intervention on shoulder counter-rotation in elite schoolboy fast bowlers

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## CHAPTER 9

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### **Shoulder Counter-Rotation and Muscle Symmetry, Pain and Pathology on MRI of the Lumbar Spine in Elite Schoolboy Fast Bowlers**

#### **9.1 INTRODUCTION**

As investigated in Chapter 3 and described in other studies, fast bowlers have a higher occurrence of lower back pain than other cricketing disciplines<sup>5,6</sup>. It has previously been proposed that a combination of poor physical preparation, overuse and the incorrect mechanics of the bowling technique predispose fast bowlers to lower back injury<sup>10</sup>. Schoolboy fast bowlers in particular are prone to injury, due to their immature musculoskeletal structures which are immature and unable to absorb the high forces associated with fast bowling<sup>20</sup>. An incorrect technique has been identified (in Chapter 1) as a mixed bowling action which involves the counter-rotation of the shoulders in the transverse plane<sup>10;25</sup>. During this bowling action, the bowler adopts a front-on bowling action at the time of back foot impact followed by the realignment of the shoulders to a more side-on bowling action during the delivery stride (see Figures 1.1 and 1.2 in Chapter 1)<sup>10;25;28;29</sup>. Specifically, a mixed fast bowling technique which involves a large degree of lumbar axial rotation, extension, flexion and lateral flexion of the lumbar spine has been linked to abnormal radiological features associated with injury of the lumbar spine<sup>10;14;20;25</sup>.

Shoulder counter-rotation was originally considered to be harmful between back foot and front foot impact when it exceeded an angle of 40°<sup>10</sup>. This greater degree of shoulder counter-rotation has been associated with a greater occurrence of bony and disc pathology in the lumbar vertebrae<sup>10</sup>. More recent studies have found that a lower degree of shoulder counter-rotation, of between 20° and 30°, also predisposed fast bowlers to lower back injuries<sup>16;25;28</sup>. As there is no consensus as to the degree of shoulder counter-rotation that is in fact harmful to fast bowlers, it was decided to further investigate specific clinical signs and symptoms of lumbar injury and the

occurrence of lumbar pathology using MR imaging techniques in this group of young fast bowlers.

Furthermore, asymmetry of the quadratus lumborum muscle is related to bone stress injury of the pars interarticularis on the contralateral side to the bowling arm at the level of the 4<sup>th</sup> lumbar vertebra<sup>109</sup>. It has been suggested that the asymmetrical nature of the bowling technique causes unilateral muscle hypertrophy of quadratus lumborum. As this muscle's primary function is to facilitate lateral flexion of the trunk specifically around front foot impact<sup>110</sup>, it is possible this action could cause an increase in bone stress injury of the pars interarticularis on the non-dominant side of the fast bowler's spine. Therefore, muscle asymmetry is thought to be associated with both overuse and poor technique. Indeed asymmetry of quadratus lumborum may occur more frequently in fast bowlers with a greater degree of shoulder counter-rotation which in turn might predispose these bowlers to lumbar pathology<sup>108</sup>. However, no previous studies have investigated the relationship between the degree of shoulder counter-rotation and lumbar muscle symmetry. This part of the thesis, therefore, assessed the possible association between these two variables.

The symmetry of the abdominal muscles needs to also be better understood. During fast bowling, the movements of trunk flexion, extension and rotation produce periods of high acceleration and deceleration<sup>67;106</sup>. The muscles specifically associated with these rotational trunk movements in this action are internal and external oblique. This is in contrast to the transverse abdominis muscle which stabilises the lumbar spine by resisting these rotational forces on the motion segment<sup>87;88</sup>. This is especially important during these periods of acceleration and deceleration when injury is most likely to occur. Furthermore, coordinated co-contraction of the lumbar paraspinal muscles with the muscles of the lateral abdominal wall is important to stabilise the lumbar spinal segments<sup>64-66</sup>. Therefore, it is also necessary to investigate the morphometry of the lateral abdominal muscles in these fast bowlers.

The aims of this study were to measure the degree of shoulder counter-rotation using validated 2-dimensional video analysis in a group of elite schoolboy fast bowlers and to relate these data to abdominal and spinal muscle morphometry and self-reported lower back pain, clinical signs and symptoms and lumbar pathology, as detected on imaging studies, in this group.

## 9.2 METHODS

### 9.2.1 Study design

This was a descriptive study of 18 elite, male, schoolboy pace bowlers comparing those with and without the presence of self-reported lower back pain. Bowling dominance was recorded in order to assess muscle symmetry and clinical symptoms.

### 9.2.2 Measurements and calculations

#### 9.2.2.1 Lower back pain

Lower back pain (as described in Chapter 3) was defined as a self reported complaint of pain in the lumbar region. Participants were divided into two groups being those with and without lower back pain..

#### 9.2.2.1 Clinical assessment of the lumbar spine

Clinical assessment of the lumbar spine was performed to assess signs and symptoms. (see Chapter 2).

#### 9.2.2.2 Assessment of shoulder counter-rotation

In order to investigate the relationship between degree of shoulder counter-rotation and muscle symmetry, clinical signs and symptoms and pathology as seen on MR imaging, the fast bowlers were divided into two groups. The first group included fast bowlers who counter-rotated their shoulders between 20 and 40° and the second group included fast bowlers who counter-rotated their shoulders greater than 40°. Only one bowler counter-rotated less than 20° and therefore was excluded from the analysis.

#### 9.2.2.2 Measurement of antero-lateral abdominal wall thickness using high resolution soft tissue ultrasound imaging

The following calculations of muscle thickness were measured at rest to determine absolute muscle thickness (mm), relative muscle thickness (%), total lateral

abdominal wall thickness (mm) and percentage difference between dominant and non-dominant sides relative to the dominant side(%) and during abdominal hollowing to determine change in muscle thickness from rest to contraction ( $\Delta$ mm).

#### 9.2.2.3 Measurement of MR imaging

Muscle morphometry of psoas, quadratus lumborum, multifidus, longissimus and iliocostalis are expressed as relative cross-sectional area (cm<sup>2</sup>) and percentage difference between dominant and non-dominant sides relative to the dominant side (%) at the level of the 4<sup>th</sup> lumbar vertebra. MR imaging was also recorded to determine endplate, nerve root and disc tear pathology, disc degeneration, bone stress injury and facet joint pathology and total pathology score as described in Chapter 6.

#### 9.2.2.4 Statistical analysis

Statistical analysis was performed using Levene's t-test to determine differences between fast bowlers in the group who counter-rotated their shoulders above and the group of fast bowlers who counter-rotated their shoulders between 20° and 40°. A post-hoc power analysis was performed on significant data to determine the power of the study.

## 9.3 RESULTS

### 9.3.1 Subject characteristics

Fourteen out of the 18 male fast bowlers complained of lower back pain at the time of the evaluation, whilst only 4 experienced no pain. Participants had a mean age of  $16.7 \pm 0.8$  years; a mean weight of  $65.9 \pm 7.6$ kg and a mean body fat percentage of  $15.1 \pm 3.8\%$ .

### 9.3.2 Assessment of shoulder angles in all fast bowlers

Table 9.1 shows the mean maximum and minimum shoulder angles and the resultant shoulder counter-rotation angle for each fast bowler during pre-season testing. Of the 18 fast bowlers who were tested pre-intervention, 11 had shoulder counter-rotation greater than  $40^\circ$ , six had shoulder counter-rotation between  $20^\circ$  and  $40^\circ$  and one fast bowler counter-rotated his shoulders below  $20^\circ$ .

Table 9.1: Pre-season shoulder angles ( $^\circ$ ) for all fast bowlers involved in the study

Subject	Maximum shoulder angle ( $^\circ$ )	Minimum shoulder angle ( $^\circ$ )	Shoulder counter-rotation ( $^\circ$ )
1	$224 \pm 4$	$197 \pm 3$	$18 \pm 6$
2	$221 \pm 4$	$198 \pm 1$	$23 \pm 3$
3	$243 \pm 6$	$214 \pm 2$	$29 \pm 7$
4	$217 \pm 5$	$184 \pm 2$	$33 \pm 3$
5	$224 \pm 1$	$187 \pm 1$	$36 \pm 0$
6	$219 \pm 3$	$182 \pm 1$	$37 \pm 2$
7	$242 \pm 2$	$203 \pm 3$	$39 \pm 4$
8	$274 \pm 3$	$230 \pm 4$	$41 \pm 9$
9	$227 \pm 5$	$184 \pm 1$	$43 \pm 6$
10	$249 \pm 7$	$200 \pm 2$	$49 \pm 8$
11	$248 \pm 5$	$196 \pm 2$	$52 \pm 4$
12	$261 \pm 3$	$197 \pm 2$	$53 \pm 5$
13	$244 \pm 2$	$188 \pm 1$	$57 \pm 2$
14	$276 \pm 1$	$218 \pm 8$	$58 \pm 8$
15	$265 \pm 2$	$207 \pm 3$	$58 \pm 4$
16	$253 \pm 7$	$192 \pm 4$	$61 \pm 8$
17	$252 \pm 3$	$186 \pm 2$	$67 \pm 5$
18	$267 \pm 1$	$195 \pm 1$	$72 \pm 0$
<b>Mean angles</b>	<b><math>245 \pm 4</math></b>	<b><math>198 \pm 2</math></b>	<b><math>46 \pm 5</math></b>

Table 9.2 shows the maximum shoulder angle for the two groups of fast bowlers who bowl with a shoulder counter-rotation of greater than 40° or between 20° and 40°. Fast bowlers who counter-rotated their shoulders above 40° had a significantly greater ( $p=0.0008$ ) maximum shoulder angle ( $256 \pm 14^\circ$ ) at back foot impact, compared to the group of fast bowlers who had a shoulder counter-rotation of between 20° and 40° and had a lower maximum shoulder angle ( $227 \pm 12^\circ$ ) at back foot impact. A post-hoc power analysis between the two groups for the maximum shoulder angle was 99%. There was no difference between the two groups for minimum shoulder angle around front foot impact. Therefore, the high degree of shoulder counter-rotation in the group above 40° is due to the higher maximum shoulder angle at back foot impact.

**Table 9.2: Maximum and minimum shoulder angles comparing two groups of fast bowlers who either counter-rotated their shoulders above or below 40°**

Shoulder angle	20-40° (n=6)	> 40° (n=11)
Maximum shoulder angle (°) *	227 ± 12°	256 ± 14°
95% confidence intervals (°)	215 - 240°	246 - 265°
Minimum shoulder angle (°)	195 ± 12°	200 ± 14°
95% confidence intervals (°)	182 - 206°	191 - 210°

\* *Maximum shoulder angle, 20-40° verse > 40°:  $p=0.0008$*

Of the 18 fast bowlers assessed pre-intervention, 14 complained of lower back pain and only four were pain free. When assessing the degree of shoulder counter-rotation in young fast bowlers with and without lower back pain, there were no differences found between the bowlers with lower back pain or without lower back pain.<sup>xxiii</sup> The mean shoulder counter-rotation was above 40° for both groups of fast bowlers independent of self-reported lower back pain. The fast bowlers with and without lower back pain were also not different in the amount of maximum or minimum shoulder angle produced the resultant shoulder counter-rotation angle. The lack of significance may be due to the few number of fast bowlers without lower back pain ( $n=4$ ). The range of shoulder counter-rotation in each group, as shown by the 95% confidence limits, however, indicates that the majority of fast bowlers with lower

<sup>xxiii</sup> See Appendix K, Table K34 for results for degree of shoulder counter-rotation in fast bowlers with and without lower back pain

back pain bowled with a shoulder counter-rotation of between 37° and 55°, therefore the majority bowled with a shoulder counter-rotation of greater than 40°.

### **9.3.3 Assessment of shoulder counter-rotation and lateral abdominal and posterior lumbar musculature in fast bowlers**

The fast bowlers were divided into two groups, being bowlers who counter-rotated their shoulders above 40° and bowlers who had a shoulder counter-rotation between 20° and 40°. Comparison of lateral abdominal muscle thickness between these two groups of fast bowlers showed no significant differences for total resting abdominal wall muscle thickness, absolute resting muscle thickness (mm), percentage difference between dominant and non-dominant sides and relative resting (%) muscle thickness between the fast bowlers who counter-rotated their shoulders greater or less than 40°. <sup>XXIV</sup>

Table 9.3 shows the change in thickness from rest to contraction during abdominal hollowing of the internal oblique and transverse abdominis muscles comparing differences between the two groups of fast bowlers, being bowlers who counter-rotated their shoulders above and bowlers who counter-rotated their shoulders below 40°. TrA muscle function on both the dominant ( $p=0.028$ ) and non-dominant ( $p=0.018$ ) sides was significantly greater in the group of fast bowlers who counter-rotated their shoulders less than 40° compared to the group of fast bowlers with a shoulder counter-rotation of greater than 40°. A post-hoc power calculation between the groups for change in TrA muscle thickness was 77% and 76% for dominant and non-dominant sides respectively. There was no difference between the groups for change in OI muscle thickness during abdominal hollowing.

<sup>XXIV</sup> See Appendix K Tables K35 to K38 showing absolute, relative and percentage difference muscle thickness results.

**Table 9.3: Change in muscle thickness ( $\Delta$ mm) from rest to contraction during abdominal hollowing comparing degree of shoulder counter-rotation in fast bowlers**

Muscle	Side	20-40° (n=6)	> 40° (n=11)
OI	Dom	0.9 ± 1.0	1.2 ± 1.3
	ND	1.3 ± 1.5	1.0 ± 0.7
TrA	Dom *	<b>2.5 ± 0.4</b>	<b>1.8 ± 0.7</b>
	ND #	<b>2.9 ± 1.5</b>	<b>1.4 ± 0.9</b>

**Abbreviations:** OE, external oblique; OI, internal oblique; TrA, transverse abdominis; Dom, dominant; ND, non-dominant

\* Dominant TrA: 20-40° v > 40°:  $p = 0.028$

# Non-dominant TrA: 20-40° v > 40°:  $p = 0.018$

Table 9.4 shows the cross-sectional area of the lumbar musculature comparing the two groups of fast bowlers, being bowlers who counter-rotated their shoulders above and bowlers who counter-rotated their shoulders below 40°. Fast bowlers who counter-rotate their shoulders during the delivery stride less than 40° have a greater quadratus lumborum muscle cross-sectional area on the dominant side compared to bowlers who bowl with greater than 40° shoulder counter-rotation. Seventy-five percent power was found between the two groups for dominant quadratus lumborum when performing a post-hoc power analysis. However, there were no differences between the groups for the other posterior lumbar muscle cross-sectional areas.

**Table 9.4: Cross-sectional area (cm<sup>2</sup>) of the lumbar musculature comparing two groups of fast bowlers who either counter-rotated their shoulders above or below 40°**

Muscle	Side	20-40° (n=6)	> 40° (n=11)
Psoas (cm <sup>2</sup> )	Dom	19.1 ± 4.0	21.6 ± 2.2
	ND	19.1 ± 4.0	21.5 ± 2.6
Quadratus Lumborum (cm <sup>2</sup> )	Dom *	<b>9.5 ± 1.4</b>	<b>7.9 ± 1.2</b>
	ND	8.5 ± 1.0	7.6 ± 1.6
Multifidus (cm <sup>2</sup> )	Dom	7.4 ± 2.0	6.4 ± 1.1
	ND	7.2 ± 2.1	6.7 ± 1.3
Longissimus (cm <sup>2</sup> )	Dom	6.8 ± 1.0	6.8 ± 1.0
	ND	5.9 ± 0.9	6.5 ± 1.0
Iliocostalis (cm <sup>2</sup> )	Dom	11.2 ± 1.0	13.5 ± 3.2
	ND	12.0 ± 1.9	13.5 ± 2.8

**Abbreviations:** ND, non-dominant; Dom, dominant

\* Dom Quadratus Lumborum: 20-40° v > 40°:  $p = 0.024$

There were no significant differences for percentage differences between cross-sectional area of individual posterior muscles comparing fast bowlers who counter-rotated their shoulders between 20-40° and greater than 40°. <sup>xxv</sup>

### 9.3.4 Degree of shoulder counter-rotation and occurrence of clinical findings

Figure 9.1 shows the occurrence of positive (pain elicited during movement) clinical tests comparing the two groups of fast bowlers, being bowlers who counter-rotated their shoulders above and bowlers who counter-rotated their shoulders below 40°. The group of fast bowlers who had a shoulder counter-rotation of greater than 40° appeared to experience a greater frequency of pain during lumbar extension (n=5) compared to only one bowler in the group of fast bowlers who counter-rotated their shoulders between 20 and 40°. One bowler who counter-rotated his shoulders greater than 40° had pain on dominant trunk rotation compared to no bowlers who had a shoulder counter-rotation between 20 and 40°. Furthermore, the frequency of pain during single leg hyperextension rotation (SLHR) tests was higher in the group of fast bowlers who counter-rotated their shoulders greater than 40° (n=12), compared to no SLHR positive tests in the group of fast bowlers who counter-rotated their shoulders between 20 and 40°.

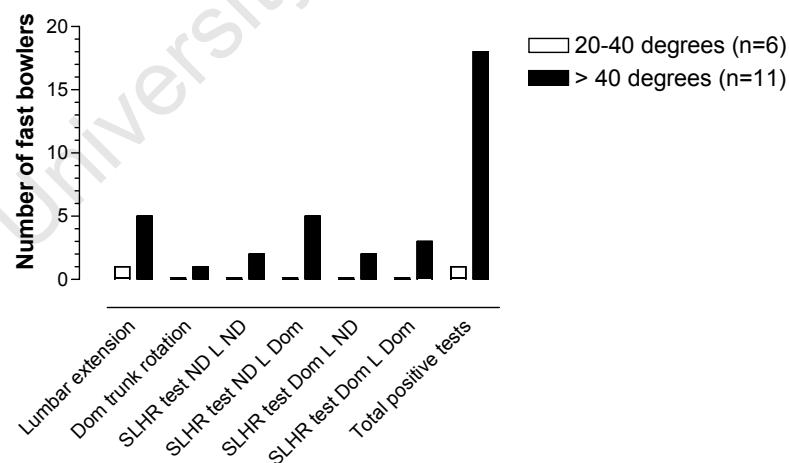


Figure 9.1: Fast bowlers with abnormal clinical tests by degree of shoulder counter-rotation (°)

Figure 9.2 shows the percentage occurrence of pain on palpation of the vertebrae and non-dominant and dominant paraspinal regions of the lumbar spine comparing

<sup>xxv</sup> See Appendix K Tables K39 for results of lumbar muscle percentage difference between groups

the two groups of fast bowlers, being bowlers who counter-rotated their shoulders above and bowlers who counter-rotated their shoulders below 40°. The group of fast bowlers who counter-rotated their shoulders greater than 40° complained of more frequency of pain on palpation of the vertebrae (17%) compared to pain experienced on vertebral palpation in only 6% in the group of fast bowlers who had shoulder counter-rotation between 20 and 40°. No fast bowlers in the group who counter-rotated their shoulders less than 40° complained of pain on palpation of the non-dominant paraspinal side, compared to 13% of the group of fast bowlers who complained of pain on palpation of the non-dominant paraspinal region in the group who counter-rotated their shoulders greater than 40°. Furthermore, fast bowlers in the group with a shoulder counter-rotation greater than 40° had more frequency of pain on palpation of the dominant paraspinal (15%) side compared to the group of fast bowlers who counter-rotated their shoulders between 20 and 40° (7%).

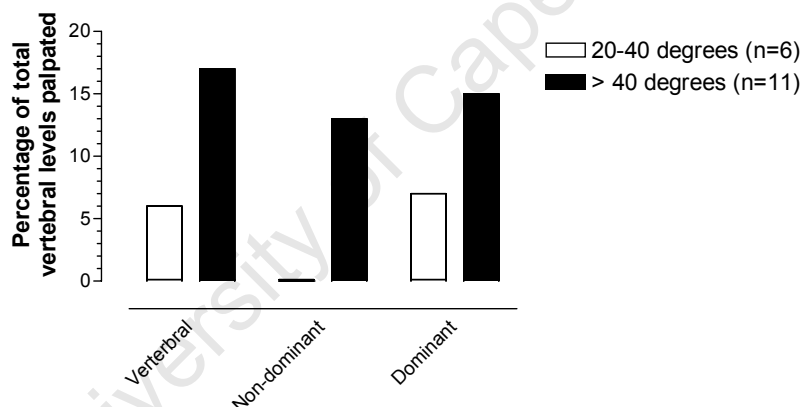


Figure 9.2: Percentage of total vertebral levels with pain on palpation of the vertebrae and non-dominant and dominant paraspinal regions, comparing groups of fast bowlers with a greater or less than 40° of shoulder counter-rotation

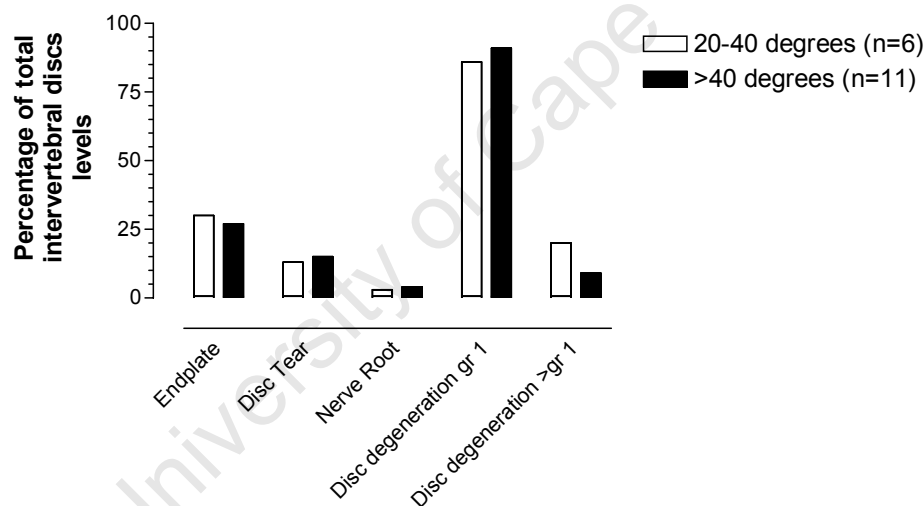
### **9.3.5 Influence of degree of shoulder counter-rotation on occurrence of clinical symptoms and pathology**

Table 9.5 shows the mean pathology score and mean number of abnormal intervertebral discs comparing two groups of fast bowlers with either a degree of shoulder counter-rotation greater than or less than 40°. There was no difference between the groups for total pathology score of the lumbar spine.

**Table 9.5: Total pathology score as detected on imaging studies comparing two groups of fast bowlers with shoulder counter-rotation either above 40° or between 20 and 40°**

	20-40° (n=6)	>40° (n=11)
Total pathology score	10 ± 4	8 ± 3
95% confidence limits	5 - 14	6 - 11

The total number of intervertebral discs and nerve roots with pathology were separated into specific lumbar pathologies and assessed with respect to the degree of shoulder counter-rotation (Figure 9.3). Fast bowlers with a shoulder counter-rotation of greater than 40° had a smaller percentage occurrence of intervertebral discs with greater than grade II severity (9%) compared to the bowlers who counter-rotated their shoulders between 20 and 40° (20%). However, the two groups were similar when assessing the percentage occurrence of endplate, nerve root and disc tear pathology and grade I intervertebral disc degeneration.



**Figure 9.3: Percentage occurrence of disc and nerve pathology comparing two groups of fast bowlers who counter-rotated their shoulders either above or below 40°**

The total number of endplates with pathology were separated into specific lumbar pathologies and assessed with respect to the degree of shoulder counter-rotation (Figure 9.4). The two groups were similar when assessing the percentage occurrence of endplate pathology.

SHOULDER COUNTER-ROTATION AND MUSCLE SYMMETRY, PAIN AND PATHOLOGY ON MRI OF THE LUMBAR SPINE IN ELITE SCHOOLBOY FAST BOWLERS

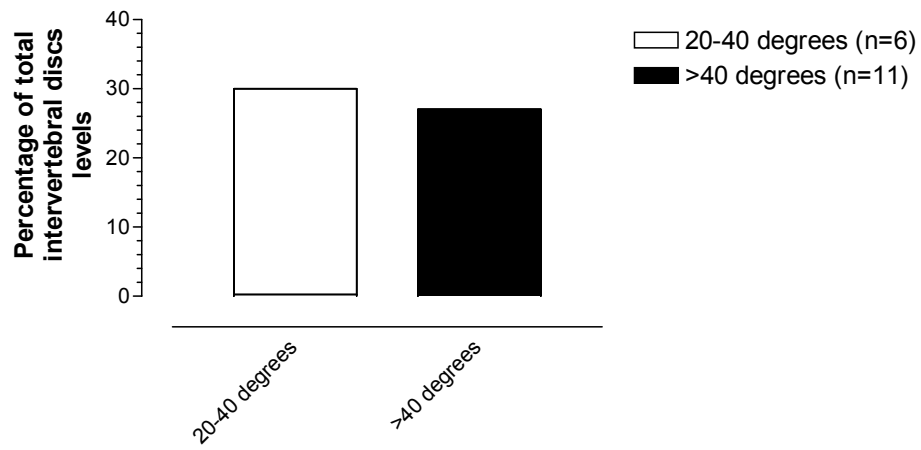


Figure 9.4: Percentage occurrence of endplate pathology comparing two groups of fast bowlers who counter-rotated their shoulders either above or below 40°

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## 9.4 DISCUSSION

Earlier studies have shown that the spine is rotated and hyperextended at front foot impact during the bowling action when the ground reaction forces are high<sup>10;25;27;28;126</sup>. Therefore, a high degree of shoulder counter-rotation could predispose bowlers to lumbar spine injury. In this thesis, Chapter 3 showed that fast bowlers have the highest occurrence of self-reported lower back pain. Furthermore, Chapter 4, showed that fast bowlers were more asymmetrical with respect to specific muscles when comparing fast bowlers to the other cricketing disciplines. Chapter 7, also showed that fast bowlers had more frequency of pain on vertebral and dominant and non-dominant paraspinal palpation as well as positive single leg hyperextension rotation tests compared to spin bowlers and batsmen. Fast bowlers also had a greater occurrence of disc tear and endplate pathology as well as grade II and above disc degeneration compared to spin bowlers and batsmen. Furthermore there is no consensus as to what degree of shoulder counter-rotation is harmful to the fast bowler<sup>10;25;28</sup>. It is important, therefore, to further analyze the fast bowlers, specifically the effect of shoulder counter-rotation on self-reported lower back pain, abdominal and lumbar musculature, clinical signs and symptoms and lumbar pathology as detected on imaging studies.

An important finding of this thesis is that of the 18 fast bowlers assessed pre-intervention, 11 had a shoulder counter-rotation of greater than 40° and 7 fast bowlers counter-rotated their shoulders less than 40°. Therefore, it appears that a mixed bowling technique is the most prevalent type of bowling action among this group of schoolboy cricketers. The group of bowlers who had greater than 40° of shoulder counter-rotation, also had a significantly greater maximum shoulder angle at back foot impact compared to the bowlers who had less degree of shoulder counter-rotation. Furthermore, there was no difference between the two groups for minimum shoulder angle around front foot impact. Therefore, it appears that a greater maximum shoulder angle is the cause of a higher degree of shoulder counter-rotation during the delivery phase of the bowling action. One may postulate that in order to decrease their shoulder counter-rotation and adopt a more front-on or side-on bowling technique, bowlers may need to decrease their maximum shoulder angle at back foot impact.

Due to the majority of fast bowlers who present with a mixed bowling technique, one could expect that the majority of the fast bowlers would also have self-reported lower back pain and radiological abnormalities on their MRI investigations. However, a further important finding was that 14 fast bowlers reported the presence of lower back pain during testing whilst only 4 bowlers were pain free. Of the fast bowlers with lower back pain, 9 were in the group who counter-rotated above 40° and 5 in the group with less counter-rotation. Furthermore, there was no difference between the groups when assessing the mean shoulder counter-rotation for fast bowlers with and without lower back pain, with both groups having a mean shoulder counter-rotation above 40°. However, one should be cautious in interpreting this lack of significance between the two groups due to the few bowlers (n=4) in the pain free group. Further research may be required with a larger sample group to determine whether there is an association between the degree of shoulder counter-rotation and the presence of self-reported lower back pain. Yet it may be possible that the presence of lower back pain occurs independently and is caused by factors other than the degree of shoulder counter-rotation.

Furthermore, lower back pain is associated with impaired function of the transverse abdominis muscle as seen by the lack of change in TrA muscle thickness during abdominal hollowing<sup>88;89</sup>. Considering both groups of fast bowlers with and without lower back pain had the same degree of shoulder counter-rotation it may be expected that shoulder counter-rotation would not be associated with an impaired function of the TrA muscle. However, the degree of pain experienced in the lower back region of these bowlers was not measured. When TrA muscle function was analysed comparing the degree of shoulder counter-rotation, it was found that both dominant and non-dominant TrA muscle function was less in fast bowlers who counter-rotated their shoulders above 40° compared to bowlers whose counter-rotation was less than 40°. Therefore, it appears that fast bowlers who bowl with a greater degree of shoulder counter-rotation are likely to have impaired TrA muscle function and therefore a decreased ability of TrA to effectively stabilise the lumbar spine<sup>67;71;89</sup> during the activity of fast bowling. This is likely to increase the risk of injury to the lower back. Therefore, one may postulate that an increase in shoulder counter-rotation may be a catalyst in impairing TrA muscle function and might be a risk factor for injuries to the lumbar spine. Therefore, by retraining TrA muscle

function through a lumbar stabilisation intervention, one may likely decrease shoulder counter-rotation and subsequently the occurrence of injuries to the lumbar spine.

The possible influence of degree of shoulder counter-rotation on the cross-sectional area of the posterior lumbar muscles has not been previously investigated. Fast bowlers with a shoulder counter-rotation of above 40° were found to have a smaller quadratus lumborum muscle on the dominant side compared to the bowlers who had less shoulder counter-rotation. Quadratus lumborum is activated in a range of trunk movements, including extension, axial rotation and lateral flexion, therefore asymmetric activation during the strenuous loading phase of the delivery action may be a stimulus for hypertrophy on the bowling arm side<sup>59</sup>. However, the mixed fast bowling technique involves a greater degree of lumbar axial rotation, trunk extension and forward and lateral trunk flexion compared to the side-on and front-on techniques<sup>10;25</sup>. Therefore, it would in fact be expected that the fast bowlers who adopt a mixed bowling action with a greater degree of shoulder counter-rotation, would have a greater quadratus lumborum on the dominant side compared to bowlers who counter-rotate their shoulders less. Quadratus lumborum is also known to play an important role in the intrinsic stabilisation of the lumbar spine<sup>89</sup>, therefore the group who counter-rotate their shoulders less than 40° may have a better ability to stabilise the lumbar spine. However, this current study did not assess the function of quadratus lumborum. Furthermore, previous studies reported that substantial shoulder counter-rotation, of greater than 20 to 40°, was consistently associated with pars interarticularis lesions in bowlers and may play a role in quadratus lumborum asymmetry<sup>10;111</sup>. However, in the current study quadratus lumborum was found not to be asymmetrical and no fast bowlers had the presence of pars interarticularis lesions. Reasons for the lack of asymmetry in this muscle may be due to the analysis of the cross-sectional area of this muscle and not the muscle volume as assessed previously. The MRI scans in the current study were only performed on the lumbar spine and thus did not include the entire muscle to calculate quadratus lumborum muscle height. Future studies need to therefore further assess the association between quadratus lumborum cross-sectional area and the degree of shoulder counter-rotation in a larger group of fast bowlers.

To the best of my knowledge a specific, lumbar clinical assessment of this nature has not been previously been done, therefore, there are no comparative data to set these findings against. Having a shoulder counter-rotation greater than 40° is more likely to predispose a fast bowler to experience pain on palpation of the lumbar vertebrae at

multiple levels. Fast bowlers with a higher degree of shoulder counter-rotation are also more likely to experience pain on palpation of the dominant and non-dominant lumbar paraspinal regions. In this study, it has also been found that players who have a shoulder counter-rotation greater than  $40^{\circ}$  are more likely to have positive single leg hyperextension rotation tests, whereas those who have less counter-rotation do not have any positive tests. The majority of the positive hyperextension rotation tests were found to occur when the bowler was standing on the non-dominant leg and rotating the upper body to the dominant side followed by the test where the bowler stands on the dominant leg and rotating the upper body to the dominant side. Of interest to note is that at back foot impact (BFI) the bowler lands on his dominant leg and rotates his upper body to the dominant side and at front foot impact (FFI) the bowler lands on his non-dominant leg still rotating his upper body to the dominant side. During the delivery stride (BFI to FFI) is where shoulder counter-rotation occurs. Fast bowling involves the combination of compression and shear forces. These forces are transmitted during back foot and front foot landing during the delivery phase of the bowling action and increase the loading on the lumbar spine<sup>3;4;7;8;10-15</sup>. At front-foot impact the ground reaction forces transmitted through the bowler's body are about 5 times the body weight<sup>9</sup>. Absorption by the body of these ground reaction forces creates a load which, if excessive, may cause pain and injury in the lumbar region<sup>8-11;18;19</sup>. Furthermore, besides axial loading of the spine, during the phase of front foot impact the lumbar spine also undergoes hyperextension, lateral flexion, rotation and forward flexion in order for the fast bowler to achieve maximum power. The combination of these forces and movements predispose the fast bowler to injury of the lumbar spine. Therefore, the occurrence of these positive single leg hyperextension tests may in fact be a clinical indication of the presence of injury to the lumbar spine caused specifically at these two points during the fast bowling action. As discussed earlier, the maximum shoulder angle at back foot impact was greater in the fast bowlers who counter-rotated their shoulders more than  $40^{\circ}$ , thus one postulates that this factor, coupled with its role in the high degree of counter-rotation, may predispose fast bowlers to lumbar injuries. Furthermore, these positive tests may be an important indication of pathology as established in Chapter 7. This association is between the severity of disc degeneration L<sub>5</sub> and these positive hyperextension rotation tests. Interestingly enough, the fast bowlers with a higher degree of shoulder counter-rotation have more severe disc degeneration especially those who bowl with this type of action over a longer period of time.

The total pathology score documented in Chapter 7, was not found to be different between the cricketing disciplines, nor was it different between cricketers with and without lower back pain. To add to this new information is that fast bowlers who counter-rotate their shoulders above 40° do not have a significantly greater total pathology score compared to the fast bowlers with less shoulder counter-rotation. However, this method of analysis may not be sensitive enough to identify changes in subtle pathology. Thus using this method to determine severity of pathology in the lumbar spine may require that a larger group of fast bowlers be assessed with a spectrum of injury including more severe lumbar pathology.

All fast bowlers independent of degree of shoulder counter-rotation had a minimum of grade I disc degeneration at all intervertebral disc levels. This is higher than previous studies of fast bowlers showing the occurrence of disc degeneration in approximately 65% of 17-18 year old cricketers and up to 70% of retired fast bowlers<sup>25;27</sup>. Elliott et al., (1993), also found that 21% of fast bowlers who had an MRI scan had disc degeneration at L<sub>1</sub>-L<sub>2</sub> to L<sub>5</sub>-S<sub>1</sub> and demonstrated an increased shoulder counter-rotation<sup>14</sup>. Furthermore, Walker et. al., (1996) studied the occurrence of disc degeneration in 13 to 17 year old fast bowlers showing that disc degeneration increased with age<sup>13</sup>. The under 13 bowlers had 15%, under 15 bowlers had 30% and under 17 group had 40% disc degeneration in the respective groups. A further study showed a close association between disc degeneration and bowling technique with 69% of all fast bowlers with disc degeneration having bowled with a mixed bowling technique<sup>54</sup>. Similarly, a study of young fast bowlers (mean age of 13.7 years) found that all of the bowlers with disc degeneration used a mixed bowling technique<sup>14</sup>. This high occurrence of disc degeneration indicates a need for the fast bowlers to alter their bowling technique by decreasing their shoulder counter-rotation in order to decrease their risk of progression in the occurrence and severity of disc degeneration. This was shown in a study by Elliott and Khangure (2002) who found that fast bowlers who decreased their shoulder counter-rotation using coaching intervention had less progression in severity of disc degeneration<sup>55</sup>.

These new findings emphasize the importance of the degree of shoulder counter-rotation in lumbar pathology and lower back pain among schoolboy fast bowlers. It is clear that their technique needs to be corrected so that players adopt a bowling action that involves a degree of shoulder counter-rotation of less than 40° if injury and pain is to be reduced.

## 9.5 CONCLUSION

The findings in this study are important firstly as they show the high occurrence of increased shoulder counter-rotation above  $40^{\circ}$  in elite schoolboy fast bowlers. Secondly, fast bowlers with a shoulder counter-rotation above  $40^{\circ}$  also have a greater maximum shoulder angle at back foot impact. Therefore, a greater maximum angle at back foot impact causes a high degree of shoulder counter-rotation during the delivery stride. Further, findings of this study show that fast bowlers with a greater than  $40^{\circ}$  of shoulder counter-rotation have less transverse abdominis muscle function. There also appears to be a possible relationship between a shoulder counter-rotation of greater than  $40^{\circ}$  and a greater frequency of pain during lumbar palpation and single leg hyperextension rotation tests. Importantly, there was no difference in total pathology score between bowlers who counter-rotated their shoulders above  $40^{\circ}$  or between  $20^{\circ}$  and  $40^{\circ}$ . The finding that young fast bowlers have a high occurrence of self-reported lower back pain and coupled with a high degree of shoulder counter-rotation indicates the need for the education and correction of their bowling technique and the implementation of successful injury prevention strategies, such as a lumbar stabilisation intervention in schoolboy fast bowlers.

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## CHAPTER 10

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### **The Effects of a Lumbar Stabilisation Intervention on Shoulder Counter-Rotation in Elite Schoolboy Fast Bowlers**

*An abstract for this chapter has been accepted for presentation at the 2<sup>nd</sup> World Sports Injury Conference, Norway, June 2008*

#### **10.1 INTRODUCTION**

As highlighted in Chapter 9, there is a high occurrence of increased shoulder counter-rotation (above 40°) among schoolboy fast bowlers. This high degree of shoulder counter-rotation was also found to possibly be associated with a greater frequency of pain during palpation of the lumbar spine and single leg hyperextension rotation tests with all fast bowlers having disc degeneration. Previous research showed an association between a high degree of shoulder counter-rotation and injury to the lumbar spine<sup>10</sup>. Chapter 9 also showed that fast bowlers with a shoulder counter-rotation above 40° are likely to have impaired function of the transverse abdominis muscle. Therefore, these findings highlight a need for successful injury prevention strategies that encompass not only the retraining of transverse abdominis function in this group of fast bowlers, but also the decrease in shoulder counter-rotation.

Intervention studies in cricket have previously sought to change mixed technique bowlers by decreasing the amount of shoulder counter-rotation either through a coaching intervention or by the use of a harness while bowling<sup>28;55</sup>. Elliott and Khangure (2002) found that fast bowlers who decreased their shoulder counter-rotation, over a three year period from 35.4° to 21.3°, as a result of the coaching intervention did not show progression in lumbar disc degeneration<sup>55</sup>. However, the fast bowlers who continued to bowl with a mixed bowling technique were more likely to have progression of disc degeneration. The greatest limitation of this study was that the population changed over the study period. In the first year there were 41 participants and by the fourth year only 21 remained. Wallis et. al., (2002) studied the

effect of a bowling harness aimed at restricting the movement of the shoulders during the delivery stride <sup>28</sup>. One group received a coaching intervention that emphasized correct shoulder and hip alignment whilst bowling and the second group wore the harness while bowling and were given verbal and visual guidance regarding their bowling. However, there was no significant decrease in the shoulder counter-rotation angle in either group after the 8 weeks of intervention.

Besides these abovementioned studies there are no published studies that have investigated the influence of specific exercise interventions on fast bowlers. It was decided, therefore, to conduct a lumbar stabilisation intervention and investigate the effects of this program on shoulder counter-rotation, muscle morphometry, clinical signs and symptoms and the presence of pathology of the lumbar spine using MR imaging techniques.

Therefore the aim of this chapter was to assess the effect of a pre-season cricket-specific progressive lumbar stabilisation intervention on change in shoulder counter-rotation in schoolboy fast bowlers. A further aim of this part of this study was to subsequently assess the effect of any change in shoulder counter-rotation on abdominal and lumbar muscle morphometry, clinical signs and symptoms and spinal pathology as seen on MR imaging of the lumbar spine.

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## 10.2 METHODS

### 10.2.1 Study design

This was an intervention study of 15 elite, male, schoolboy fast bowlers (mean age of  $16.7 \pm 0.8$  years) to determine the effect of a lumbar stabilisation program on change in shoulder-counter-rotation. The 15 fast bowlers were divided into bowlers who took part in the pre-season intervention program (n=7) and bowlers who did traditional pre-season cricket training (n=8).

### 10.2.2 Intervention program

An 8-week cricket-specific, progressive lumbar stabilization exercise program was performed pre-season (see Chapter 2 for a detailed description).

### 10.2.3 Lower back pain

Lower back pain was defined as a self-reported symptom of pain in the lumbar region at the time of testing. On the basis of these symptoms, participants were divided into cricketers with and without lower back pain.

### 10.2.4 Measurements and calculations

#### 10.2.4.1 Clinical assessment of the lumbar spine

Clinical assessment of the lumbar spine was performed to assess pain during specific clinical tests. (see Chapter 2).

#### 10.2.4.2 Shoulder counter-rotation

The degree of shoulder counter-rotation was measured using two-dimensional video analysis (see Chapter 2 for a detailed description). Fast bowlers were assessed pre-intervention and immediately following the 8-week intervention (post-intervention) to

assess changes as a result of the program. Fast bowlers were further assessed post-season to determine whether the in-season maintenance exercise classes of the intervention had resulted in any further changes in shoulder counter-rotation. The results are presented as intervention and control groups to assess differences in shoulder counter-rotation.

The following equations were used to analyze changes pre- and post-intervention:

*Change in SCR immediately after the 8-week intervention = pre-intervention – post-intervention*

*Change in SCR from pre-intervention to post-season = pre-intervention – post-season*

*Change in SCR from post-intervention to post-season = post-intervention – post-season*

#### 10.2.4.3 Measurement of antero-lateral abdominal wall thickness using high resolution soft tissue ultrasound imaging

The following measurements of muscle thickness were calculated at rest to determine absolute muscle thickness (mm), relative muscle thickness (%), total lateral abdominal wall thickness (mm) and percentage difference between dominant and non-dominant sides relative to the dominant side (%) and during abdominal hollowing to determine change in muscle thickness from rest to contraction ( $\Delta$ mm).

#### 10.2.4.4 Measurement of MR imaging

Muscle morphometry of psoas, quadratus lumborum, multifidus, longissimus and iliocostalis are expressed as relative cross-sectional area (cm<sup>2</sup>) and percentage difference between dominant and non-dominant sides relative to the dominant side (%) at the level of the 4<sup>th</sup> lumbar vertebra. MR imaging was also recorded to determine endplate, nerve root and disc tear pathology, disc degeneration, bone stress injury and facet joint pathology.

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#### 10.2.4.5 Statistical analysis

Statistical analysis was performed using analysis of variance (ANOVA) to determine differences between the intervention and control groups following the intervention program. Significant interactions were further analysed using and Tukeys HSD post-hoc test to determine where the specific significant differences existed. Statistical significance was accepted at  $p < 0.05$ . All descriptive statistics were expressed as the means  $\pm$  SD. In the case of small sample groups, statistical analysis was not possible. Thus these data have been presented as either number of fast bowlers with positive clinical tests or percentage occurrence of pain on palpation of the lumbar spine and percentage occurrence of pathology as seen on MRI of the lumbar spine. A post-hoc power analysis was performed on significant data to determine the power of the results.

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## 10.3 RESULTS

### ***10.3.1 Changes in shoulder angles following the intervention***

Table 10.1 shows the change in shoulder counter-rotation of each fast bowler over time. Of the 15 fast bowlers who completed all three testing sessions, eight had a pre-intervention shoulder counter-rotation greater than 40°, six had shoulder counter-rotation between 20° and 40° and one was below 20°.

Six out of 7 fast bowlers decreased their shoulder counter-rotation in the intervention group, with one bowler's angle remaining constant following the 8-week intervention program. During the in-season 5 bowlers in this group who initially decreased their shoulder counter-rotation angle, increased this angle by post-season, however, the angle still remained below the pre-intervention value. Only 2 fast bowlers in the intervention group increased their angle by post-season to above pre-intervention values.

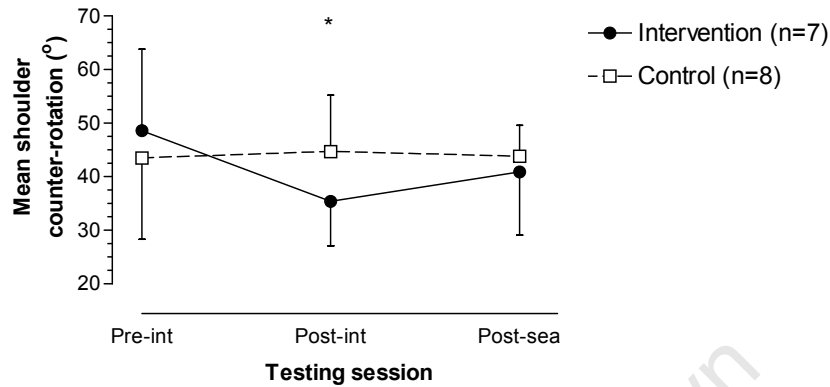
Seven out of 8 fast bowlers in the control group increased their shoulder counter-rotation angle following the intervention and one bowler decreased his angle. By post-season, 4 bowlers in this group had decreased their shoulder counter-rotation angle, however, 3 were still above the pre-intervention value. Three fast bowlers, continued to increase their shoulder counter-rotation by post-season. The fast bowler who decreased his shoulder counter-rotation post-intervention marginally increased this angle by post-season.

**Table 10.1: Shoulder counter-rotation ( $^{\circ}$ ) recorded over three testing sessions for all fast bowlers separated into control and intervention groups**

Subject	Groups	Pre-intervention SCR ( $^{\circ}$ )	Post-intervention SCR ( $^{\circ}$ )	Post season SCR ( $^{\circ}$ )
1	Intervention	72 $\pm$ 0	34 $\pm$ 10	65 $\pm$ 6
2		61 $\pm$ 8	42 $\pm$ 10	38 $\pm$ 7
3		58 $\pm$ 4	37 $\pm$ 8	38 $\pm$ 2
4		53 $\pm$ 5	47 $\pm$ 4	44 $\pm$ 3
5		41 $\pm$ 9	28 $\pm$ 5	31 $\pm$ 3
6		39 $\pm$ 4	29 $\pm$ 7	42 $\pm$ 4
7		23 $\pm$ 3	24 $\pm$ 3	29 $\pm$ 3
8	Control	58 $\pm$ 8	41 $\pm$ 7	42 $\pm$ 4
9		52 $\pm$ 4	55 $\pm$ 3	56 $\pm$ 7
10		49 $\pm$ 8	50 $\pm$ 1	40 $\pm$ 6
11		37 $\pm$ 2	50 $\pm$ 5	39 $\pm$ 7
12		36 $\pm$ 0	53 $\pm$ 1	47 $\pm$ 5
13		33 $\pm$ 3	41 $\pm$ 7	40 $\pm$ 7
14		29 $\pm$ 7	35 $\pm$ 4	41 $\pm$ 2
15		18 $\pm$ 6	24 $\pm$ 6	40 $\pm$ 4

Figure 10.1 shows the mean change in the degree of shoulder counter-rotation in the intervention and control groups following the intervention program. There was a significant interaction for change in degree of shoulder counter-rotation between the groups over time ( $F_{2,26}=6.19$ ;  $p = 0.006$ ). Thus the fast bowlers in the intervention group significantly decreased their degree of shoulder counter-rotation by  $15^{\circ}$  from  $49 \pm 16^{\circ}$  to  $35 \pm 8^{\circ}$  during the 8-week intervention program ( $p=0.014$ ). Furthermore, there was no significant difference in shoulder counter-rotation angle in the fast bowlers in the intervention group over the 7 month period between post-intervention and post-season. Thus the intervention group fast bowlers were able to maintain their initial decrease in shoulder counter-rotation. There is a sharp contrast between the results of the intervention group and control group, as the control group fast bowlers' degree of shoulder counter-rotation increased during the 8-week period ( $44 \pm 15^{\circ}$  to  $45 \pm 11^{\circ}$ ) and this increase was maintained during the 7 in-season months ( $44 \pm 6^{\circ}$ ). The result of a post-hoc power analysis between the intervention and control groups for the

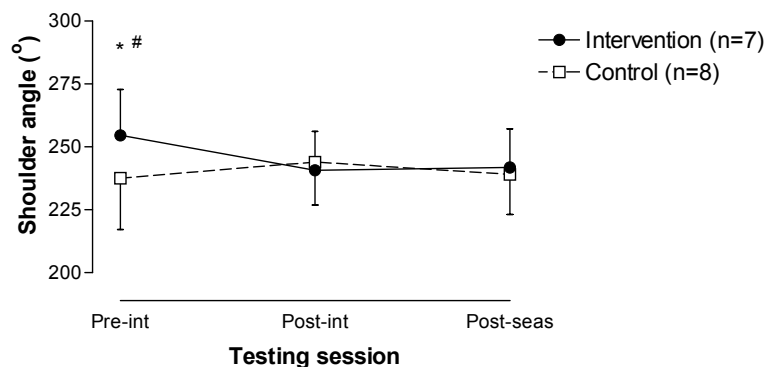
change in shoulder counter-rotation between pre-intervention and post-intervention was 99%.



**Figure 10.1: Mean shoulder counter-rotation for the intervention and control groups pre and post-intervention**  
**Abbreviations: Pre-int, pre-intervention; Post-int, post-intervention; Post-sea, post-season**

**\* Intervention group (pre-intervention v post-intervention):  $p=0.014$**

Figure 10.2 shows the change in maximum shoulder angle at back foot impact in the intervention and control groups' fast bowlers over time. There was a significant main effect for change in maximum shoulder angle between the intervention and control groups over time ( $F_{2,26}=9.19$ ;  $p=0.0009$ ). Thus the maximum shoulder angle at back foot impact significantly decreased in the intervention group immediately following the intervention program ( $255 \pm 18^\circ$  to  $241 \pm 14^\circ$ ) ( $p=0.007$ ). There was also a significant decrease in overall maximum shoulder angle between pre-intervention and post-season ( $242 \pm 15^\circ$ ) ( $p=0.015$ ). In comparison there were no differences in maximum shoulder angle in the control group over time ( $238 \pm 20^\circ$  to  $244 \pm 12^\circ$  to  $239 \pm 16^\circ$ ). A post-hoc power analysis of this data was 82% between the intervention and control groups for change in maximum shoulder angle over time.

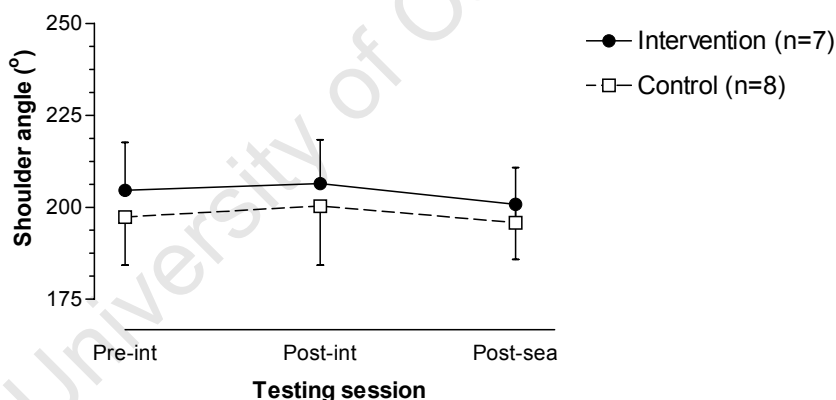


**Figure 10.2: Mean maximum shoulder angle for the intervention and control groups pre and post-intervention**  
**Abbreviations: Pre-int, pre-intervention; Post-int, post-intervention; Post-sea, post-season**

\* *Intervention group: (pre-intervention v post-intervention):  $p=0.007$*

# *Intervention group: (pre-intervention v post-season):  $p=0.015$*

There were no significant changes in minimum shoulder angle in either group during the study (Figure 10.3). Therefore, the significant change in shoulder counter-rotation angle in the intervention group's fast bowlers can be attributed to the decrease in maximum shoulder angle.

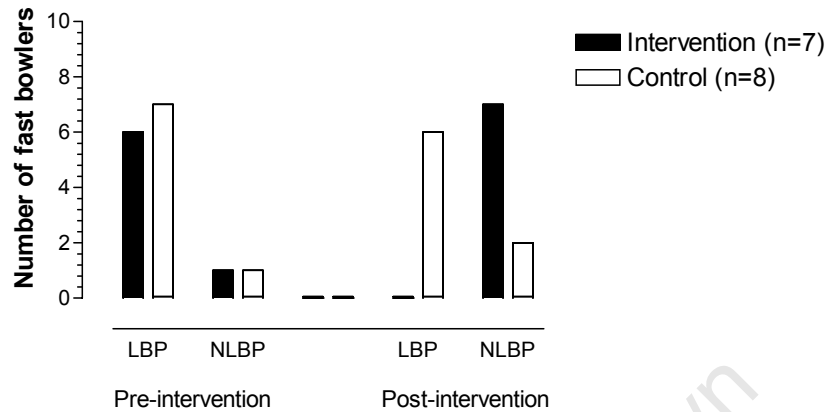


**Figure 10.3: Mean minimum shoulder angle for the intervention and control groups pre and post-intervention**  
**Abbreviations: Pre-int, pre-intervention; Post-int, post-intervention; Post-sea, post-season**

### **10.3.2 Influence of change of shoulder counter-rotation on lower back pain**

Figure 10.4 shows the change in self-reported lower back pain status comparing the intervention and control group fast bowlers following the intervention program. At the start of the study 6 and 7 fast bowlers in the intervention and control groups respectively complained of lower back pain. Only one player in each group were pain free pre-intervention. However, following the intervention program no fast bowlers in

the intervention group complained of lower back pain, whilst 6 bowlers in the control group continued to complain of lower back pain.



**Figure 10.4: Change in self-reported lower back pain status comparing intervention and control groups pre and post-intervention**

**Abbreviations: LBP, lower back pain; NLBP, no lower back pain**

Figure 10.5 shows the comparison between change in the status with respect to lower back pain and change in shoulder counter-rotation in the intervention and control groups following the 8-week intervention program. None of the fast bowlers in the intervention group reported the presence of lower back pain following the 8-week intervention program and significantly decreased their degree of shoulder counter-rotation ( $15 \pm 12^\circ$ ). In comparison, 6 fast bowlers in the control group continued to complain of lower back pain and increased their shoulder counter-rotation during the same period ( $4 \pm 12^\circ$ ). Furthermore, two fast bowlers in the control group resolved their lower back pain, yet increased their shoulder counter-rotation ( $7 \pm 2^\circ$ ). However, due to the few bowlers in these groups and thus the lack of statistical power, no statistical analysis was performed.

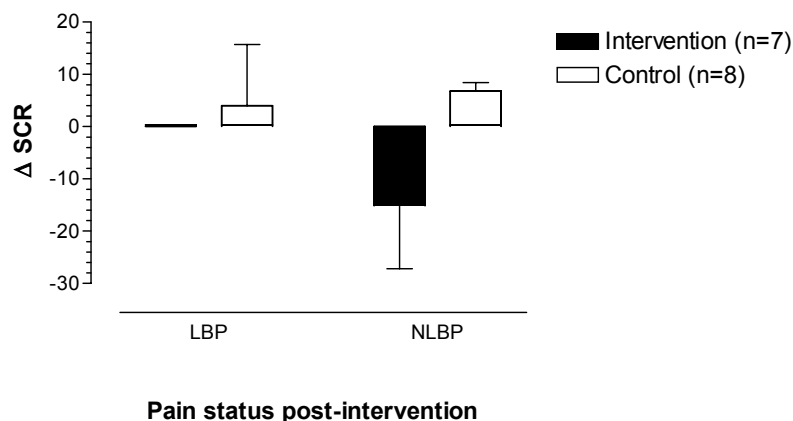


Figure 10.5: Comparison of change in lower back pain status and change in degree of shoulder counter-rotation following the 8-week intervention program

Abbreviations: SCR, shoulder counter-rotation; LBP, lower back pain; NLBP, no lower back pain

### **10.3.3 Influence of change of shoulder counter-rotation on abdominal and lumbar morphometry and clinical and imaging findings**

#### **10.3.3.1 Lateral abdominal musculature**

Analysis of data indicated that there was no difference in the change in total abdominal wall thickness, absolute and relative resting muscle thickness and percentage difference between dominant and non-dominant sides, between the fast bowlers in the intervention group who decreased their degree of shoulder counter-rotation following the implementation of a lumbar stabilisation intervention program and the fast bowlers in the control group who increased their shoulder counter-rotation during the same period.<sup>xxvi</sup> Furthermore, there were no significant differences in the change in transverse abdominis and internal oblique muscle thickness change during abdominal hollowing between groups.<sup>xxvii</sup>

#### **10.3.3.2 Posterior lumbar musculature**

Analysis of the posterior lumbar musculature cross-sectional area and percentage difference between dominant and non-dominant sides showed no significant

<sup>xxvi</sup> See Appendix K Tables K40 to K43 for tables of resting muscle thickness data pre- and post-intervention

<sup>xxvii</sup> See Appendix K Tables K44 for change in TrA and Oi muscle thickness during abdominal hollowing in fast bowlers during the intervention period

differences between the fast bowlers who decreased (intervention group) or increased (control group) their degree of shoulder counter-rotation.<sup>xxviii</sup>

### 10.3.3.3 Change in clinical findings during the intervention period

There was little change demonstrated in the occurrence of positive single leg hyperextension rotation tests and frequency of pain on palpation of the vertebrae and dominant and non-dominant paraspinal regions in both the intervention and control groups during the intervention period.<sup>xxix</sup>

### 10.3.3.4 Change in lumbar pathology during the intervention period

Table 10.2 shows the total pathology score comparing all the fast bowlers in the intervention and control groups following the intervention program. There were no significant differences between the intervention and control groups for change in total pathology score following the intervention program. However, the fast bowlers in the intervention group did not change their total pathology score and the fast bowlers in the control group appear to have increased their total pathology score during the intervention period.

**Table 10.2: Total pathology score comparing the all the fast bowlers in the intervention and control groups following the intervention program**

		Intervention (n=7)	Control (n=8)
Pre-intervention	Pathology score	7 ± 2	11 ± 4
	95% CI	5 - 9	8 - 14
Post-intervention	Pathology score	7 ± 2	12 ± 5
	95% CI	5 - 8	8 - 16

**Abbreviations: CI, confidence intervals**

Figure 10.6 shows the changes in percentage occurrence of total intervertebral discs and nerve roots with pathology viewed on imaging comparing the fast bowlers in the intervention control group during the intervention period. There was little change in the

<sup>xxviii</sup> See Appendix K Tables K45 and K46 for change in posterior lumbar musculature during the intervention period

<sup>xxix</sup> See Appendix K Figures K7 and K8 for changes in positive clinical tests during the intervention period

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occurrence of disc degeneration, disc tear and nerve root pathology in both the intervention and control groups during the intervention period.<sup>xxx</sup> There was also little change demonstrated in the percentage occurrence of endplate pathology, as seen on MR imaging, in both the intervention and control group fast bowlers during the intervention period.<sup>xxxI</sup> Due to the few fast bowlers and thus a lack of statistical power, statistical analysis was not performed.

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<sup>xxx</sup> See Appendix K, Figure K9 for change in disc degeneration, disc tear and nerve root pathology during the intervention period

<sup>xxxI</sup> See Appendix K, Figure K10 for change in endplate pathology during the intervention period

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## 10.4 DISCUSSION

As established in this thesis, schoolboy fast bowlers have a high occurrence of lower back pain (Chapter 3) and a high degree of shoulder counter-rotation (Chapter 9). Furthermore, all fast bowlers have a minimum of grade I disc degeneration in their lumbar intervertebral discs (Chapter 7). These factors combined with the fact that they continue to bowl throughout their growth period and with pain, place these young fast bowlers at risk of progressing in the severity of their injuries. Therefore, education and successful injury prevention strategies are required.

As indicated, previous interventions studies, have focused only on changing the degree of shoulder counter-rotation using a coaching intervention or bowling harness<sup>28;55</sup>. The intervention strategies implemented in this study specifically targeted the retraining of TrA muscle function combined with sport-specific strengthening to decrease the occurrence of lower back pain and degree of shoulder counter-rotation. With respect to the treatment of lower back pain there is sufficient scientific evidence in favour of intervention programs that incorporate strength training, flexibility and cardiovascular fitness<sup>131;133;133</sup>. It has therefore, been suggested that rehabilitation should focus on retraining stability (segmental control), strength and neuromuscular function through the precise co-contraction of the deep trunk muscles (transverses abdominis and lumbar multifidus) in order to decrease pain, increase stability and improve functional ability<sup>64;65;137;138</sup>. Spinal stability is achieved through an appropriate interaction between the abdominal and trunk muscles of rectus abdominis and external oblique and those abdominal muscles which control lumbar spine stability (deep multifidus, transverse abdominis, quadratus lumborum and psoas major)<sup>19;98</sup>. It is postulated that few athletes with an adequate amount of abdominal and posterior muscle strength experience injuries related to hyperlordotic movement such as fast bowling<sup>10</sup>. The transverse abdominis muscle (TrA) combined with the other abdominal muscles (internal (OI) and external oblique (OE)), pelvic floor, lumbar paraspinal muscles and the diaphragm work in a coordinated way to form a muscular corset that stabilises the spine<sup>73</sup>. Strengthening the core muscles is therefore advocated as a means of preventing and rehabilitating lower back pain<sup>73</sup>. Furthermore, it is important to retrain TrA independently in the early phase of a rehabilitation program as TrA contributes to spinal control and this muscle is reported to be dysfunctional in patients with LBP<sup>82;83;85;86;88;139</sup>.

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A lumbar stabilisation exercise intervention is a novel approach in a group of fast bowlers. It was established in Chapter 3 that this type of intervention significantly decreases the occurrence of self-reported lower back pain. The first important finding of this part of the thesis was that fast bowlers who took part in the pre-season lumbar stabilisation intervention significantly decreased their shoulder counter-rotation angle ( $49.4 \pm 16.2^\circ$  to  $34.3 \pm 8.4^\circ$ ) during the 8-week intervention. These fast bowlers were also able to maintain their initial significant decrease in shoulder counter-rotation when tested 6 months later post-season. This maintenance was likely due to the intervention group fast bowlers taking part in the in-season maintenance exercise intervention program. By contrast, the control group fast bowlers who performed traditional fitness training pre-season seemed to increase their shoulder counter-rotation when assessed post-intervention and post-season.

A further finding was that the maximum shoulder angle occurring at the time of back foot impact significantly decreased in the intervention group during the intervention program. However, there was no change in the minimum shoulder angle recorded near front foot impact in the intervention group. These findings suggest that the decrease in the maximum shoulder angle is therefore responsible for the decrease in shoulder counter-rotation in the intervention group. Therefore, an intervention program focused on the retraining of the abdominal and lumbar muscles that assists in stabilising and protecting the lumbar spine from lower back injury, has been found to be successful on its own, without the aid of a coaching intervention to alter bowling technique. These results prove the value of a cricket-specific lumbar stabilisation intervention in significantly reducing the degree of shoulder counter-rotation and thereby changing a potentially harmful fast bowling technique.

As shown in Chapter 3, the intervention program also had a significant positive effect on players' lower back pain. At the commencement of the study 6 fast bowlers in the intervention group ( $n=7$ ) complained of lower back pain, however, following the intervention program no fast bowlers in the intervention group continued to complain of lower back pain. Of these 6 bowlers who decreased, their occurrence of lower back pain, 5 decreased their shoulder counter-rotation and 1 bowlers' counter-rotation remained unchanged. In comparison, 7 of the 8 fast bowlers in the control group complained of lower back pain pre-intervention. Following the 8-weeks, 6 fast bowlers continued to complain of lower back pain, of which 5 increased degree of their

shoulder counter-rotation and only 1 decreased his degree of shoulder counter-rotation. Therefore, it appears that there may be an association between the decrease in shoulder counter-rotation and the resolution of lower back pain in fast bowlers. However, further research, with a larger group of subjects, needs to investigate this possible association.

Changes in the lateral abdominal and posterior lumbar musculature with respect to the decrease in shoulder counter-rotation in the intervention group or increase in shoulder counter-rotation in the control group were analysed. There were no significant differences found between these two groups suggesting that a change in the degree of shoulder counter-rotation may not be responsible for the change in muscle morphometry. It may, however, be postulated that a change in shoulder counter-rotation occurs first and it takes a longer period of time for the musculature to change in thickness or cross-sectional area. The change in the morphometry of the abdominal and lumbar muscles may occur as an adaptation over time to change in bowling action. As mentioned in Chapter 6, a lack of muscle hypertrophy<sup>158</sup> may be due to the fact that strength training is mostly a neural adaptation for the first 6 weeks of training and only thereafter does muscle hypertrophy tend to become evident<sup>159;160</sup>. As the main intervention program only lasted 8 weeks and focused more on stability than strength training it is possible that more time is required for these muscles to significantly hypertrophy. A further limitation of the program was that it was a group-based program due to the fact it involved working with a team and thus it is difficult to cater for the individual, however, the program may have proved more successful had the first phase of the intervention been conducted on a one-on-one basis. This individual attention may have allowed for the cricketers to be better monitored in the phase where they were required to achieve isolated contraction of transverse abdominis.

A further important finding of this chapter was that there were no changes in total pathology score of the fast bowlers in both the intervention and control groups during the intervention period. The lack of change in total pathology score may be due to its lack of sensitivity in picking up subtle changes in pathology. Further research should investigate the total pathology score in a larger group of fast bowlers who have more severe lumbar pathology on MRI.

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There was little change in the percentage occurrence of intervertebral disc degeneration in the fast bowlers in the intervention group who decreased their degree of shoulder counter-rotation during the intervention period. However, the fast bowlers in the control group who increased their degree of shoulder counter-rotation, appeared to slightly progress in severity of disc degeneration during the intervention period. Due to the small sample size, it was not possible to perform statistical analysis. However, this finding is consistent with earlier research which reported that all bowlers who continued to counter-rotate their shoulders at a high degree showed the development of a new degenerative disc or progression in the severity of their existing pathology<sup>55</sup>. In this previous study, Elliott and Khangure (2002), reported that fast bowlers who attended coaching clinics over a 4 year period, initially reported an increase in lumbar disc degeneration between years 1 and 2 with no initial significant decrease in the degree of shoulder counter-rotation (year 1 = 35.4° to year 2 = 31.1°). The authors, therefore, concluded that the intervention needed more than one year of coaching intervention to be effective. When the bowlers were tested at year 3 and year 4, their shoulder counter-rotation had significantly decreased to 24.8° and 21.3° respectively. This decrease in shoulder counter-rotation was reported in 67% of the fast bowlers. Therefore, the important finding of this thesis is that the implementation of a lumbar stabilisation program is effective in not only reducing the degree of shoulder counter-rotation after only 8-weeks and maintaining this decrease 7 months later, but of possibly also reducing the progression in severity of pathology to the lumbar spine over a 10-month period. Thus this intervention appears to be more successful than a coaching intervention which takes longer to see a reduction in both shoulder counter-rotation and progression of disc degeneration.

Of interest is the little change in the occurrence of positive clinical tests and percentage occurrence of disc degeneration, disc tear, nerve root and endplate pathology of the lumbar spine in both the intervention and control groups during the intervention period. These findings are consistent with the findings in Chapter 8. These findings further indicate that lower back pain resolves first, with clinical symptoms and the presence of pathology on MRI possibly only resolving later on. An intervention program of longer duration and focused more on the individual may be more effective in resolving clinical symptoms and lumbar pathology. However, this needs further research with a larger sample group and possibly with more severe pathology.

Limitations of this study and the analysis thereof include the small sample size which limited the possibility of statistical analysis. The intervention program also did not focus on the individual as it was performed as a group. A further limitation of this study was compliance of the participants, specifically those in the intervention group. Thus the lack of an individualized intervention and the variation in compliance of participants may have affected the outcome of the intervention program.

## **10.5 CONCLUSION**

A cricket-specific progressive, lumbar stabilisation intervention program in schoolboy fast bowlers is effective in not only decreasing the occurrence of self-reported lower back pain, but also in significantly decreasing the degree of shoulder counter-rotation by decreasing the maximum shoulder angle at back foot impact. Importantly, the lumbar stabilisation intervention is successful in maintaining the decrease in the degree of shoulder counter-rotation in young fast bowlers at a 6 month follow-up. There was no change, however, in abdominal and posterior muscle morphometry, occurrence of pain during clinical examination and percentage occurrence of disc, nerve and endplate pathology as seen on MR imaging of the lumbar spine.

## SECTION 5

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In this section I will summarize the most important findings and discuss their clinical implications.

Chapters in this section:

- Chapter 11: Summary and conclusions
- References
- Appendices

## CHAPTER 11

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### Summary and Conclusions

#### 11.1 OVERVIEW

The aim of this thesis is to investigate the effect of a pre-season cricket specific progressive lumbar stabilisation intervention and its subsequent in-season maintenance on morphometric changes in the abdominal and lumbar musculature, clinical findings, imaging features as determined using MRI, and shoulder counter-rotation in a group of male schoolboy cricketers.

The overall hypothesis of this thesis was that the pre-season cricket-specific progressive lumbar stabilisation exercise intervention would reduce the occurrence of self-reported lower back pain, improve muscle morphometry asymmetry, reduce pain on clinical examination and the presence of pathology on imaging of the lumbar spine of schoolboy cricketers with and without lower back pain and decrease the degree of shoulder counter-rotation in young fast bowlers.

#### **Section 2: Lower back pain and abdominal and lumbar muscle morphometry in schoolboy cricketers**

#### **Chapter 3**

*The hypothesis was that schoolboy cricketers have a high occurrence of self-reported lower back pain and that this occurrence can be reduced with the implementation of a pre-season cricket-specific progressive lumbar stabilisation program and maintained during the cricket season for a 6 month period.*

The hypothesis of this chapter was supported. Adolescent schoolboy cricketers do sustain a high occurrence of self-reported lower back pain. This finding was particularly demonstrated in the group of young fast bowlers. Spin bowlers and batsmen also

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sustain injuries resulting in lower back pain, however, the occurrence in these cricketing disciplines was less than in the fast bowlers. Furthermore, the majority of all injuries were sustained during cricket matches, particularly at the beginning and end of the cricket season. The second part of the hypothesis was also supported as the implementation of a cricket-specific lumbar stabilisation program did significantly decrease the occurrence of lower back pain. Importantly, the maintenance of the intervention program was shown to assist in preventing the recurrence of lower back pain when cricketers were tested at a 6-month follow-up. Compliance for both the 8-week intervention and maintenance period was 71%. Two further findings of this chapter, were that the consensus definition of injury for cricketers needs to be redefined for this specific age group as schoolboy cricketers tend to play with pain and are unlikely to miss a match or practice session due to injury. Secondly, the failure to report and monitor their symptoms of pain or injury, as well as inadequate access to pain or injury management may increase the occurrence and progression of injury in this age group. Therefore, access to adequate injury management is important in reducing the occurrence and progression of injuries.

#### **Chapter 4**

*The hypothesis was that there is asymmetry in the lateral abdominal and posterior lumbar musculature in a group of schoolboy cricketers and that lower back pain in cricketers is associated with muscle symmetry.*

The hypothesis that asymmetry in the lateral abdominal musculature indeed occurs in cricketers, was supported. This finding was demonstrated when combining all cricketing disciplines and found in the total abdominal wall muscle thickness and resting absolute internal oblique muscle thickness, with both being thicker on the non-dominant side. Furthermore, cricketers without lower back pain had asymmetry of the total abdominal wall muscle thickness and resting TrA muscle thickness with the non-dominant side being thicker. Cricketers without lower back pain also had less function of the OI and TrA muscles as measured by change in muscle thickness during abdominal hollowing, compared to those with lower back pain. Furthermore, fast bowlers specifically, demonstrated asymmetry of resting absolute internal oblique muscle thickness, with the non-dominant side being thicker than the dominant side. The second part of the hypothesis that asymmetry is present in the posterior lumbar musculature in cricketers, was proved to be correct in the cross-sectional area of the

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longissimus muscle, where the dominant side was greater than the non-dominant side in the combined group of cricketers. However, this hypothesis was found to be incorrect for the other lumbar muscles including, psoas, quadratus lumborum, multifidus and iliocostalis. There were also no asymmetries in the lumbar muscles when separating the cricketers into cricketing discipline and with respect to the presence or absence of lower back pain. A further finding of this chapter was that, dominant quadratus lumborum was found to have a greater cross-sectional area in cricketers with lower back pain compared to those without lower back pain.

### **Chapter 5**

*The hypothesis of Chapter 5 was that a lumbar stabilisation intervention can reduce muscle asymmetry and improve transversus abdominus muscle function in schoolboy cricketers with and without lower back.*

Indeed a progressive, 8-week cricket-specific lumbar stabilisation intervention program is able to increase the total abdominal wall and internal oblique muscle thickness on the dominant side in combined cricketing disciplines. Furthermore, these increases in total wall and internal oblique muscle thickness on the dominant side assisted in decreasing the pre-intervention asymmetry in these muscles. Importantly, the 6-month in-season maintenance program was able to maintain these changes in muscle symmetry. The second part of the hypothesis that TrA muscle function improves with the implementation of a lumbar stabilisation intervention, was not found to be the case. There was also no change in abdominal muscle morphometry with respect to change in lower back pain status. Furthermore, there was no change in cross-sectional area of the individual lumbar musculature. This lack of change in lumbar muscle hypertrophy may require further research involving a program of longer duration, more frequent exercise sessions with an increase in focus on sport-specific strengthening exercises.

### **Section 3: Clinical and Imaging Features as determined by MRI in cricketers of different disciplines with and without lower back pain**

### **Chapter 6**

*The hypothesis was that a new MRI scoring system is reliable and repeatable in assessing lumbar pathology of the lumber spine.*

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Indeed this novel MRI scoring system was reliable for both inter- and intra-observer agreement for pathology scored at various intervertebral disc levels and for different types of lumbar pathology. The small sample size, however, affected the ability to calculate the level of agreement for all types of pathology. Furthermore, radiologists were able to reliably distinguish between severity of disc degeneration at the different lumbar intervertebral disc levels. A further finding of this chapter was that this new MRI classification system is comprehensive since it assesses a variety of anatomical structures of the lumbar spine. Furthermore, it allows for the calculation of a total pathology score to assist in assessment of the overall severity of injury to the lumbar spine and evaluate the effects of an intervention on the pathological features described in the latter chapters of this thesis.

### **Chapter 7**

*The hypothesis of this chapter was firstly that there is a high occurrence of positive clinical tests and pathology as detected on MRI in the lumbar spine.*

Indeed there is a high occurrence of positive clinical tests and pathology as seen on MRI of the lumbar spine. There were a high number of positive clinical tests demonstrated particularly among the fast bowlers and cricketers with lower back pain. The occurrence of disc degeneration in the lumbar spine of these cricketers is higher than reported in previous studies, with all cricketers in this study, independent of pain and cricketing discipline having a minimum of grade I disc degeneration. Fast bowlers, in particular, demonstrated the highest occurrence of more severe disc degeneration, whilst batsmen demonstrated the highest occurrence of endplate and nerve root pathology. Furthermore, there was no significant difference in total pathology score between cricketers with and without lower back pain. This finding indicates a dissociation between the occurrence of pathology in the lumbar spine and self-reported lower back pain in young cricketers. However, cricketers with a higher mean pathology score (> 10) appeared to have a greater occurrence of positive clinical tests.

**Chapter 8**

*The hypothesis of this chapter was that a lumbar stabilisation intervention can decrease the occurrence of positive clinical tests and imaging features of lumbar spine pathology in a group of schoolboy cricket players.*

The hypothesis for this chapter was not supported as there was little change in the frequency of pain elicited during clinical examination in the entire group of cricketers, when separated into cricketing disciplines or by change in lower back pain status during the intervention period. Furthermore, there was no change in total pathology score, change in percentage occurrence of disc, nerve and endplate pathology following the intervention period. Indeed, this was demonstrated in the entire group of cricketers, when separated into cricketing disciplines or by change in lower back pain status during the intervention period. Therefore, it is suggested that both the occurrence of positive clinical findings and pathology seen on MRI of the lumbar spine may take longer to regress following resolution of lower back pain with the aid of a lumbar stabilisation intervention. Furthermore, there is an apparent dissociation between self-reported lower back pain and pathological findings of an MRI of the lumbar spine. Even though symptoms of lower back pain resolve in some cricketers, there is still the presence of disc, nerve and endplate pathology detected on MR imaging.

**Section 4: Morphometry, Clinical and Imaging features and Shoulder counter-rotation in the group of fast bowlers****Chapter 9**

*The hypothesis of this chapter was that the degree of shoulder counter-rotation in fast bowlers is associated with thickness changes of the lateral abdominal and posterior lumbar musculature and findings on clinical examination and imaging studies in schoolboy fast bowlers.*

The findings in this study are important firstly as they show the high occurrence of increased shoulder counter-rotation above 40° in elite schoolboy fast bowlers. Secondly, fast bowlers with a shoulder counter-rotation above 40° also have a greater maximum shoulder angle at back foot impact. Therefore, a greater maximum angle at

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back foot impact causes a high degree of shoulder counter-rotation during the delivery stride. The first part of this hypothesis was not supported as there were no differences in abdominal muscle thickness and lumbar muscle cross-sectional area found between the fast bowlers with a shoulder counter-rotation greater than  $40^\circ$  and fast bowlers with a lower degree of shoulder counter-rotation. However, the fast bowlers with a shoulder counter-rotation of greater than  $40^\circ$  had lower transverse abdominis muscle function during abdominal hollowing compared to fast bowlers with a lower degree of shoulder counter-rotation. There also appears to be a possible relationship between a shoulder counter-rotation of greater than  $40^\circ$  and a greater frequency of pain during lumbar palpation and single leg hyperextension rotation tests. Importantly, there was no difference in total pathology score between bowlers who counter-rotated their shoulders above  $40^\circ$  or between  $20^\circ$  and  $40^\circ$ . The finding that young fast bowlers have a high occurrence of self-reported lower back pain and coupled with a high degree of shoulder counter-rotation indicates the need for the education and correction of their bowling technique and the implementation of successful injury prevention strategies for this age group.

### **Chapter 10**

*The hypothesis was that a cricket-specific lumbar stabilisation intervention is effective in decreasing the degree of shoulder counter-rotation in a group of schoolboy fast bowlers. A further hypothesis of this chapter was that the intervention will cause thickness changes of the abdominal and lumbar muscle morphometry and decrease the occurrence of positive clinical findings and imaging features of pathology to the lumbar spine in schoolboy fast bowlers.*

Indeed a cricket-specific progressive, lumbar stabilisation intervention program in schoolboy fast bowlers was effective in significantly decreasing the degree of shoulder counter-rotation. This decrease in shoulder counter-rotation appears to have occurred due to the significant decrease in the maximum shoulder angle at back foot impact. Importantly, the lumbar stabilisation intervention is successful in maintaining the decrease in the degree of shoulder counter-rotation in young fast bowlers at a 6-month follow-up. The second part of the hypothesis was not supported as there was little change in abdominal and lumbar morphometry in the group of fast bowlers who decreased their shoulder counter-rotation. There was also little change in the occurrence of positive clinical tests following the intervention and subsequent

decreased in shoulder counter-rotation. There was no change in the percentage occurrence of disc degeneration, disc tear, nerve root and endplate pathology as seen on MR imaging of the lumbar spine.

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## 11.2 LIMITATIONS OF THIS THESIS

- 11.2.1 A limitation of the intervention part of this study was that it relied on the commitment from both the cricketers and their parents (to provide transport). Therefore, due to the large amount of time they were required to commit to, some participants were unable to attend all exercise intervention classes. Therefore this may have had an impact on the results in Chapter 3, 5, 8 and 10. However, in saying this, the overall attendance for both the 8-week intervention and maintenance period was 71%.
- 11.2.2 A limitation of the study in Chapter 3 was that many players could not recall all previous injuries in the years preceding this study. Therefore, the occurrence of injuries analysed may not have included all of their previous injuries. Furthermore, the majority of cricketers had not had their previous injuries diagnosed by a clinician, therefore, injuries were described as a symptom of pain in each anatomical region.
- 11.2.3 A further limitation is the use of a new injury definition in Chapter 3. This thesis commenced prior to the publication of a standardized injury definition by Orchard et al (2005). However, the consensus definition of injury established by Orchard et al (2005), states “a medical condition that causes a player to not be fully available for selection in a match”, it is possible that in fact the players in our study may have continued to play matches, however, they may have been limited in their specific cricketing discipline, such as bowling and thus played as a batsmen. Therefore, it is a possibility that our definition may fit in very loosely with Orchard et al (2005) definition of injury. The majority of injuries incurred by the participants in this study may have limited full participation but did not preclude it.
- 11.2.4 A limitation of this study is that the presence of absence of lower back pain is recorded using a binary classification whilst the MRI severity and clinical findings do not use binary classifications. Therefore, caution should be taken when assessing comparisons of these variables.

- 11.2.5 A limitation of the studies in Chapters 4 and 5 was that posterior lumbar muscle cross-sectional area and not muscle volume was assessed. This was due to the expense of MRI scanning and therefore only the lumbar spine was scanned which did not include the entire length of certain lumbar muscles. This could be a limitation as previous studies have shown asymmetries in muscle volume to be prevalent in fast bowlers.
- 11.2.6 A limitation to the studies presented in Chapters 4, 5, 8 and 10 was that there were relatively small sample sizes specifically for players without lower back pain and fast bowlers with less than 20° of shoulder counter-rotation. Therefore, the data were interpreted with caution. In Chapters 5, 8 and 10, by subdividing the group into cricketers whose lower back pain status changed during the intervention period caused the creation of small groups with low statistical power. Furthermore, in Chapters 5 and 8 only changes in the separate cricketing disciplines in the intervention and control groups were assessed and the disciplines were not separated further into players with and without lower back pain as the sample sizes would have been too small.
- 11.2.7 A limitation to the MRI classification described in Chapter 6 was that specialist radiologists were required to read the MRI scans and due to the fact that each scan required a minimum of 20 minutes to score, it was only possible to assess the inter- and intra-observer reliability of 13 scans. This small sample size and subtle pathology made it impossible to assess the reliability of some of the lumbar pathologies.
- 11.2.8 A further limitation of this study was that due to time constraints and the size of the entire study it was not possible to assess the interaction between muscle symmetry and lumbar pathology. Previous studies have however, shown a link between quadratus lumborum muscle volume asymmetry and the presence of pars interarticularis defects at the 4<sup>th</sup> lumbar intervertebral disc level in fast bowlers.
- 11.2.9 The greater time spent exercising by the intervention group compared to the control group may have influenced the results. The intervention was required to attend exercise sessions 3 times per week for 8-weeks during the initial intervention. This group was further required to attend maintenance exercise

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sessions once every two weeks during the season. In comparison the control group was only required to attend traditional cricket fitness training once a week for 8 weeks during the 8-week intervention period.

- 11.2.10 Furthermore due to time constraints it was not possible to perform phase one of the intervention program on an individual basis and rather it was performed as a group. In a clinical setting it is best to work on an individual basis with patients to train them to isolate TrA through abdominal hollowing. However, throughout phase one and subsequent phases of the intervention the cricketers were regularly checked to make sure that players were correctly activating TrA and were performing the exercises correctly.

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### 11.3 FUTURE RESEARCH

- The definition of an injury needs to be more specific to the cricketing group. This study documented that the consensus definition does not apply to schoolboy cricketers, as schoolboy cricketers tend to play with pain or injury. It appears that unless their injury is totally debilitating they continue to play. Very often their coaches are not even aware of the fact that the cricketer is injured or playing with pain.
- Future research should explore the effect of more individualized exercise interventions. It should also investigate the effect of a lumbar stabilisation intervention that is of longer duration and incorporates more frequent sessions during the maintenance phase as well as an increased focus on the strengthening exercises. This type of intervention may show changes in muscle hypertrophy of the lumbar and abdominal musculature, it may also show changes in positive clinical tests and changes in pathology as seen on MRI of the lumbar spine.
- Further research is required to investigate lumbar muscle cross-sectional area at multiple lumbar vertebral levels to determine whether there is a link between lower back pain in cricketers and asymmetry of the muscle's cross-sectional area. The findings in this study showed few asymmetries when assessing cross-sectional area of the individual lumbar muscles only at the 4<sup>th</sup> lumbar vertebral level.
- The MRI classification system developed for this study needs to be further researched with respect to more severe pathology and a wider variation of lumbar pathology in a larger sample group of cricketers. This classification also needs to be validated for other population groups. Future research should explore total pathology scores in a larger group of cricketers with and without lower back pain, among cricketers with more severe pathology to establish clinical guidelines. The total pathology score also needs to be validated for other population groups, sporting and non-sporting. This research could assist in establishing clinical guidelines for overall severity of pathology in the lumbar spine.
- The degree of pain using a pain scale was not measured in this study, therefore, future research that assesses lower back pain with respect to

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pathology, clinical assessments, shoulder counter-rotation in fast bowlers and muscle symmetry should include the degree of pain of all participants.

- The occurrence of pathology and lower back pain in spin bowlers and batsmen needs to be further investigated as few studies have previously assessed spin bowlers and batsmen. The findings of this study indicate that these cricketing disciplines are also at risk of developing lower back pain and the presence of pathology in the lumbar spine.
- The relationship between the degree of shoulder counter-rotation in fast bowlers, lower back pain, abdominal and lumbar muscle morphometry, and the regression or progression of positive clinical signs and pathology on MRI of the lumbar spine needs further investigation. Furthermore, the relationship between the change in shoulder counter-rotation and the above variables also needs to be further researched with respect to a lumbar stabilisation intervention period.

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## 11.4 CLINICAL IMPLICATIONS

The success of a cricket-specific lumbar stabilisation intervention program is important, as shown in this group of young cricketers. Overall, cricketers of all age groups and levels of participation incur a high occurrence of lower back injuries, particularly in fast bowlers. Some of these injuries have been so severe that they have cut short cricketers careers. However, as seen in this thesis, spin bowlers and batsmen also incur lower back injuries. The success of a lumbar stabilisation intervention implemented for all the cricketing disciplines at all levels of cricket participation, will assist in decreasing the occurrence of lower back pain. Therefore, it is recommended that this type of intervention be implemented to cricketers who are not only playing throughout their growth period, but also provincial and international cricketers who either suffer from lower back pain or are at risk of developing lower back pain.

The success of the lumbar stabilisation intervention program on the decrease in degree of shoulder counter-rotation is important for this age group. This is because there appears to be a lack of knowledge of coaches at school level and thus fast bowlers are bowling with a greater degree of shoulder counter-rotation and thus are more predisposed to injuries in the lumbar spine. Therefore, this intervention should be implemented specifically in young fast bowlers. The further success of this intervention was that the fast bowlers' degree of shoulder counter-rotation reduced after 8 weeks with no coaching intervention, whereas a previous coaching intervention only showed a significant decrease in shoulder counter-rotation after 3 years.

Lumbar stabilisation interventions need to include the three phases of progression. In the third phase, the strengthening exercises implemented should take into account the specific demands of the sport and the specific mechanisms of injury for that sport. It is also recommended that this intervention be performed not only as rehabilitation for players with lower back pain and other injuries, but also as a preventative intervention to avoid the risk of players developing lower back pain and other injuries. It is further recommended that phase one of the intervention be implemented on an individual basis. It is suggested that this phase not be taught to groups of greater than 3 or 4 participants. This will allow for adequate supervision in teaching the correct technique to isolate the transverse abdominis muscle and maintain this contraction throughout the first phase of exercises.

As shown in this thesis, the consensus definition of injury for cricketers should be revised to include schoolboy cricketers. This is necessary for future studies on schoolboy cricketers to have a consensus as to what the accepted definition of an injury is. As documented in this thesis, schoolboy cricketers continue to play throughout pain or injury and generally do not inform their coaches of any underlying pain or injury. The degree of pain, however, was not measured therefore it is possible that it was not debilitating enough to prevent participation. However, it was noticed that the occurrence of pain did prevent some players from performing the exercises correctly.

A further implication arising from young cricketers playing throughout pain or injury, is that school cricket coaches need to be educated in injury recognition and indeed prevention. School coaches need to be aware of when the players may be carrying an injury, as well as how to correct techniques that may be harmful and predispose a player to pain or injury.

The fact that there is a dissociation between the occurrence of lower back pain and pathology as seen on MRI of the lumbar spine, raises the problem that some cricketers may be playing with pathology that is undiagnosed and therefore untreated. The fact that lower back pain resolved following a lumbar stabilisation intervention, yet clinical symptoms and pathology was still present on MRI, further indicates this dissociation. It also highlights that even though symptoms of pain may have resolved, pathology may still be present in the lumbar spine. Furthermore, the fact that all of the young cricketers in this study had the presence of disc degeneration to the lumbar spine, highlights the need for players of this age group to be better monitored. As disc degeneration is reported to increase with age, it is a worrying factor that adolescent boys already have such a high occurrence of early disc degeneration. Had they not taken part in this study, the pathology present in the lumbar spine would likely still be undetected. A concerning finding in this thesis was that there is a lack of access to injury management among this age group. The fact that they were all representing their province at either under 17 or under 19 age group level and had little access to treatment, highlights the need for sporting bodies to allocate funds for these specific age groups. Sporting bodies should also have these young cricketers assessed by medical professionals as part of a routine pre-season assessment.

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Lastly, the creation of a total pathology score may assist clinicians in the future in diagnosing overall severity in pathology as seen on MR imaging to the lumbar spine. This is important as there appears to be a variety of different pathologies evident on MRI evaluation in these young cricketers. A total pathology score, after further research, may even have a role to play in return to sport guidelines and in the comparison with the occurrence of lower back pain and overall treatment of the individual. This study however, indicates possible dissociation between total pathology score and the presence of self-reported lower back pain in cricketers.

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## APPENDIX A: SUBJECT INFORMATION SHEET

UCT/MRC Research Unit for Exercise Science and Sports Medicine,  
Department of Human Biology, Faculty of Health Sciences, University of  
Cape Town



### CLINICAL AND IMAGING FEATURES OF THE LUMBAR SPINE IN ELITE MALE SCHOOLBOY CRICKETERS: THE EFFECT OF A PRE-SEASON LUMBAR STABILISATION INTERVENTION

#### Why is the study being done?

Lower back injury in cricket is a serious concern for young fast bowlers. There is currently a lot of research providing evidence that the deep muscle stabilisers of the lower back change their function as a result of lower back pain. As a result of this the stability of the spine is threatened and recurrence of the injury is more likely. This study aims to assess the effect of an intervention program on the abdominal musculature and injury profile of the lower back.

#### How will the study be done?

Subjects are required to be cricketers playing at representative level within their province and between the ages of 16 and 30 years. Cricketers with and without lower back pain are needed. They will be required to complete a short medical and injury questionnaire and a cricket training history. They will undergo a full medical examination by a medical professional to assess the lower back and trunk. The abdominal muscle asymmetry of the transverses abdominis, internal and external obliques, deep multifidus, quadratus lumborum and psoas major will be assessed using an ultrasound technique. This is a completely non-invasive, topical technique which causes no discomfort to the patient. It will be assessed pre-season both prior to and after intervention and again immediate post-season. MRI scanning will be performed pre- and post- season to assess the radiological aspects of the lumbar spine specifically looking for any disc degeneration, disc protrusion, bone stress injury or facet joint abnormality. This is a non-invasive technique which is safer than x-rays and is radiation free. The biomechanics of the bowler's technique will be assessed using a video camera pre-season both prior to and immediately after the intervention programme as well as immediate post-season. This is also a non-invasive technique. Subjects will then be randomly divided into two groups. One group will act as the control who will continue with their traditional pre-season and in-season training. The second group will be the intervention group who will undergo a pre-season 8 week lumbar stabilization intervention programme by attending classes two to three times per week for eight weeks at the UCT/MRC Research Unit ESSM. This intervention will be non-invasive and consist of a structured exercise programme. The maintenance of this programme will continue once every two weeks during the season with subjects attending stabilization classes.

**What are the benefits of participating in the study?**

The anticipated benefit for the subject is includes being part of the research process. The subjects will receive information on various aspects of their abdominal muscle and lumbar function and bowling technique. They will be taught the appropriate method for contracting the core stabilisers of the abdominal muscle responsible for spinal stability, which may or may not result in improvement of their condition. The effectiveness of this intervention will be assessed. The anticipated gain in knowledge is in establishing a lower back injury profile of cricketers with lower back pain and assessing the benefit of an education program in retraining the transversus abdominis. Should the intervention prove effective, the control group will be offered a similar intervention on completion of the analysis, performed in accordance with the principles of the Declaration of Helsinki (2004).

**Are there any risks involved in participating in this trial?**

There are no documented risks associated with the use of ultrasound or MRI scanning. A potential risk may include that which would be experienced during day-to-day cricket bowling. The 8-week intervention program will include time spent participating in gym work, thus there is an injury risk. However, all exercises will be supervised by a qualified biokineticist and clear instruction will be given. Should any of the subjects sustain an injury immediate medical attention will be provided by a qualified medical professional, who is a co-investigator. All film taken during the videoing of the biomechanical assessment will be overwritten or destroyed on completion of analysis confidentially.

**How will privacy be ensured?**

All information regarding subject information, records and results will be kept in a locked cabinet. Data will be stored in an unlinked fashion from the subject information. All individual data will be treated confidentially. The subject will have access to all their results.

**If you are interested or require further information on the study please contact \_\_\_\_\_ and the following number \_\_\_\_\_**



## APPENDIX B: INFORMED CONSENT



UCT/MRC Research Unit for Exercise Science and Sports Medicine,  
Department of Human Biology, Faculty of Health Sciences, University of  
Cape Town

### CLINICAL AND IMAGING FEATURES OF THE LUMBAR SPINE IN ELITE MALE SCHOOLBOY CRICKETERS: THE EFFECT OF A PRE-SEASON LUMBAR STABILISATION INTERVENTION

The aim of this study is to assess the effect of an 8-week pre-season abdominal rehabilitation and strength program on the low back injury profile of cricketers.

#### Testing procedure

The subject will be required to present to the laboratory for testing on two occasions 12 weeks pre-season. The subject will have their lumbar spine scanned using Magnetic resonance imaging (MRI), and their abdominal muscle symmetry assessed using an ultrasound machine. The biomechanical analysis will involve the videoing of the bowler from overhead and side-on during the delivery stride. A medical professional, who is a co-investigator, will perform a full medical assessment of the lumbar spine and trunk musculature on the subject. An anthropometrical assessment will be performed to assess height, weight and body fat percentage. Once the above tests have been performed the subjects will be randomly divided into two groups with one undergoing an 8-week intervention program and the other traditional training. During this stage intervention subjects will be required to present to the UCT/MRC Research Unit ESSM three times per week for the eight weeks.

Immediately following the intervention program (12 weeks), all subjects will be required to present to the laboratory for a further abdominal muscle ultrasound scan and biomechanical bowling analysis.

During the season intervention subjects are required to attend a stabilization class once every two weeks. Both groups of subjects will be required to keep a log book of the amount of overs bowled during net practices and matches, minutes spent batting in the nets and in matches and nature and duration of training sessions. Detailed injury reports will be required on any subject that may get injured during the season, this will be done by a qualified medical professional, who is a co-investigator.

Immediately post-season, all subjects will be required to present themselves to the laboratory for a repeat of the initial pre-season assessment, where MRI and ultrasound scanning, biomechanical bowling analysis, full medical assessment and anthropometrical analysis will be performed.

### **Benefits**

The anticipated benefit for the subject includes being part of the research process. The subjects will receive information on various aspects of their abdominal muscle and lumbar function. Intervention subjects will be taught the appropriate method for maximising the contraction of the abdominal muscle responsible for spinal stability. The effectiveness of this intervention will be assessed. Should the intervention prove effective, the control group will be offered a similar intervention on completion of the analysis, performed in accordance with the principles of the Declaration of Helsinki (2004).

### **Anticipated gain in knowledge**

The anticipated gain in knowledge is in establishing a low back injury profile of cricketers and assessing the benefit of a lumbar stabilization intervention on radiological imaging, muscle asymmetry, bowling technique and injury prevention.

### **Risks**

There are no documented risks associated with the use of either magnetic imaging resonance (MRI) or ultrasound. The 2 testing manoeuvres involve no effort on the part of the subject and provide no potential risk to the subject. A potential risk may include that which would be experienced during day-to-day cricket bowling. The 8-week intervention program will include time spent participating in gym work, thus there is an injury risk. However, all exercises will be supervised by a qualified biokineticist, who is the principal investigator, and clear instruction will be given. Should any of the subjects sustain an injury during testing, immediate medical attention will be provided by a qualified medical professional, who is a co-investigator. All film taken during the videoing of the biomechanical assessment will be overwritten or destroyed on completion of analysis confidentially.

### **Privacy**

All information regarding subject information, records and results will be kept in a locked cabinet. Data will be stored in an unlinked fashion from the subject information. All individual data will be treated confidentially. The subject will have access to all their results.

The subjects of this study will be registered with the UCT research insurance for this group. The University of Cape Town and its team of researchers will be responsible for any medical treatment arising from the participation in this research study.

I, \_\_\_\_\_ am aware that I will be free to withdraw from the study at any time and that will not be subjected to any pressure whatsoever to remain in the trial. I also understand that I have been required to give my assent to the trial and that my parent/guardian (if under 21 years) has given their consent. If I should not wish to give assent despite my parents consent I have been advised that my assent will override my parent's consent. I understand the implications of my consent and that questions have been answered to my satisfaction.

	Name	Signature	Date
<b>Subject (assent)</b>			
<b>Parent (consent)</b>			
<b>Researcher</b>			
<b>Witness</b>			

Researcher: Kerith Aginsky  
B.A Hons (Biokinetics)

Contact email: [kaginsk@sports.uct.ac.za](mailto:kaginsk@sports.uct.ac.za)

Contact number: 082 823 3670

Principal supervisor: Prof. Wayne Derman  
Sports physician

Contact email: [ewderman@iafrica.com](mailto:ewderman@iafrica.com)

**APPENDIX C: MEDICAL AND INJURY QUESTIONNAIRE**

Name: \_\_\_\_\_

Age: Number of years playing cricket: Number of years playing professional cricket: **1. Medical questionnaire**

Do you now have, or have you ever had, any of the following conditions? (Please tick)

		Current (last month)	1-12 months	> 12 months ago
1	Frequent headaches (1 per week)			
2	Fainting spells/ dizziness			
3	Frequent colds (1 per month)			
4	High Blood pressure (> 150mmHg)			
5	Allergies			
	Which type:			
6	Asthma/respiratory condition			
7	Weight loss/gain: (3kg either way)			
8	Indigestion/Heartburn			
9	Any other? Please state			

## 2. Injury Profile

### Current and previous injuries

Do you have, or have you ever had, any of the following conditions?

(Please tick the appropriate box)

		Current		Previous	
		Within the last month		1-12 months ago	>12 months ago
		Right / Left side	Right / Left side	Right / Left side	Right / Left side
1	Neck injuries				
2	Shoulder injuries				
3	Arm/wrist/hand injuries				
4	Ribcage injuries				
5	Lower back injuries				
6	Hip joint injuries				
7	Hip muscle injuries				
8	Groin injuries				
9	Thigh injuries				
10	Knee injuries				
11	Lower limb/shin splints				
12	Ankle injuries				
13	Foot injuries				
14	Toe injuries				
15	Muscle strains				
16	Tendon injuries				
17	Abdominal injuries				
18	Other (Specify below)				

Other injuries: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

**If you have currently (or previously) sustained an injury to your lower back, please complete the remainder of the questionnaire.**

1. During which activity did the injury occur (tick relevant box):

- a. Fast bowling
- b. Batting
- c. Fielding
- d. Wicket Keeping
- e. Other (specify) \_\_\_\_\_

2. Describe the onset of the injury:
- a. Slow and insidious
  - b. Acute onset
  - c. Acute on chronic injury
3. Diagnosis given: \_\_\_\_\_
4. Who gave diagnosis: \_\_\_\_\_
5. If unable to play, how long were you off for: \_\_\_\_\_
6. Treatment received:
- a. Medication
  - b. Physiotherapy
  - c. Strapping
  - d. Surgery
  - e. Rest
7. If physiotherapy was received, tick the relevant modalities used:
- a. Massage
  - b. Joint mobilisation
  - c. Electrotherapy
  - d. Acupuncture
  - e. Exercise rehabilitation
8. Did you receive any core stability rehabilitation post-injury?
- a. Yes
  - b. No
9. Have you achieved a complete recovery:
- Yes  No

## APPENDIX D: CRICKET HISTORY QUESTIONNAIRE

1. Name: \_\_\_\_\_
2. Age: \_\_\_\_\_
3. The level of cricket playing at present? (Tick appropriate box/s)
- |                        |                          |
|------------------------|--------------------------|
| Representative cricket | <input type="checkbox"/> |
| First team cricket     | <input type="checkbox"/> |
| A team cricket         | <input type="checkbox"/> |
| Club cricket           | <input type="checkbox"/> |
4. The highest level of cricket achieved? (Tick appropriate box)
- |                        |                          |
|------------------------|--------------------------|
| Representative cricket | <input type="checkbox"/> |
| First team cricket     | <input type="checkbox"/> |
| A team cricket         | <input type="checkbox"/> |
| Club cricket           | <input type="checkbox"/> |
5. Number of years playing cricket for your school:
6. Number of years playing cricket for your club:
7. (a) Number of years playing cricket for other teams:   
 (b) Specify which team: \_\_\_\_\_
8. Are you a bowler: Yes   
 No   
 Specify if slow or fast bowler: \_\_\_\_\_
9. If yes, Number of years as bowler for any cricket side:
10. Are you an wicketkeeper?
- |     |                          |
|-----|--------------------------|
| Yes | <input type="checkbox"/> |
| No  | <input type="checkbox"/> |
11. Are you a batsman?
- |     |                          |
|-----|--------------------------|
| Yes | <input type="checkbox"/> |
| No  | <input type="checkbox"/> |

APPENDICES

12. Total number of practises per week:

13. Length of the season:  months (including preseason).

14. Average number of cricket matches per season:

Bowlers and all-rounders to answer questions 15 to 18

15. (a) Average number of overs per practise:

(b) Average time spent bowling at a cricket practice:

hours

minutes

16. Average number of overs bowled in a game:

17. Number of spells per match:

18. What type of action do you feel or have been told you use?

Side-on

Front-on

Mixed

University of Cape Town

## APPENDIX E: OSWESTRY QUESTIONNAIRE

Name \_\_\_\_\_ Date \_\_\_\_\_

<p><b>1. Pain intensity</b></p> <ul style="list-style-type: none"> <li><input type="checkbox"/> I have no pain at the moment</li> <li><input type="checkbox"/> The pain is very mild at the moment</li> <li><input type="checkbox"/> The pain is moderate at the moment</li> <li><input type="checkbox"/> The pain is fairly severe at the moment</li> <li><input type="checkbox"/> The pain is very severe at the moment</li> <li><input type="checkbox"/> The pain is the worst imaginable at the moment</li> </ul>	<p><b>2. Walking</b></p> <ul style="list-style-type: none"> <li><input type="checkbox"/> Pain doesn't prevent me walking any distance</li> <li><input type="checkbox"/> Pain prevents me walking more than 2km</li> <li><input type="checkbox"/> Pain prevents me walking more than 1km</li> <li><input type="checkbox"/> Pain prevents me walking more than 500m</li> <li><input type="checkbox"/> I can only walk while using a stick or crutches</li> <li><input type="checkbox"/> I am in bed most of the time and have to crawl to the toilet</li> </ul>
<p><b>3. Personal care</b></p> <ul style="list-style-type: none"> <li><input type="checkbox"/> I can look after myself normally without causing extra pain</li> <li><input type="checkbox"/> I can look after myself normally but it is very painful</li> <li><input type="checkbox"/> It is painful to look after myself and I am slow and careful</li> <li><input type="checkbox"/> I need some help but manage most of my personal care</li> <li><input type="checkbox"/> I need help every day in most aspects of self-care</li> <li><input type="checkbox"/> I do not get dressed, wash with difficulty and stay in bed</li> </ul>	<p><b>4. Sitting</b></p> <ul style="list-style-type: none"> <li><input type="checkbox"/> I can sit in a chair as long as I like</li> <li><input type="checkbox"/> I can only sit in my favourite chair as long as I like</li> <li><input type="checkbox"/> Pain prevents me from sitting for longer than 1 hour</li> <li><input type="checkbox"/> Pain prevents me from sitting for longer than 30 minutes</li> <li><input type="checkbox"/> Pain prevents me from sitting for longer than 10 minutes</li> <li><input type="checkbox"/> Pain prevents me sitting at all</li> </ul>
<p><b>5. Lifting</b></p> <ul style="list-style-type: none"> <li><input type="checkbox"/> I can lift weights without extra pain</li> <li><input type="checkbox"/> I can lift heavy weights but it causes extra pain</li> <li><input type="checkbox"/> Pain prevents me from lifting heavy weights off the floor, but I can manage if they are conveniently positioned e.g. on a table</li> <li><input type="checkbox"/> Pain prevents me from lifting heavy weights but I can manage light to medium weights if they are conveniently positioned</li> <li><input type="checkbox"/> I can lift only very light weights</li> <li><input type="checkbox"/> I cannot lift or carry anything at all</li> </ul>	<p><b>6. Standing</b></p> <ul style="list-style-type: none"> <li><input type="checkbox"/> I can stand as long as I want without causing extra pain</li> <li><input type="checkbox"/> I can stand as long as I want but it gives me extra pain</li> <li><input type="checkbox"/> Pain prevents me from standing for more than 1 hour</li> <li><input type="checkbox"/> Pain prevents me from standing for more than 30 minutes</li> <li><input type="checkbox"/> Pain prevents me from standing for more than 10 minutes</li> <li><input type="checkbox"/> Pain prevents me from standing at all</li> </ul>

<p><b>7. Sleeping</b></p> <ul style="list-style-type: none"> <li><input type="checkbox"/> My sleep is never disturbed by pain</li> <li><input type="checkbox"/> My sleep is occasionally disturbed by pain</li> <li><input type="checkbox"/> Because of pain I have less than 6 hours sleep</li> <li><input type="checkbox"/> Because of pain I have less than 4 hours sleep</li> <li><input type="checkbox"/> Because of pain I have less than 2 hours sleep</li> <li><input type="checkbox"/> Pain prevents me from sleeping at all</li> </ul>	<p><b>8. Social life</b></p> <ul style="list-style-type: none"> <li><input type="checkbox"/> My social life is normal and causes me no extra pain</li> <li><input type="checkbox"/> My social life is normal but increases the degree of pain</li> <li><input type="checkbox"/> Pain has no significant effect on my social life apart from limiting my more energetic interests e.g. sports etc.</li> <li><input type="checkbox"/> Pain has restricted my social life and I do not go out as often</li> <li><input type="checkbox"/> Pain has restricted my social life to my home</li> <li><input type="checkbox"/> I have no social life because of pain</li> </ul>
<p><b>9. Employment/Homemaking</b></p> <ul style="list-style-type: none"> <li><input type="checkbox"/> My normal home making/job activities do not cause pain</li> <li><input type="checkbox"/> My normal homemaking/job activities increase my pain but I can still perform all that is required of me</li> <li><input type="checkbox"/> I can perform most of my normal homemaking/job duties but pain prevents me from performing more physically stressful activities (e.g. Lifting, vacuuming)</li> <li><input type="checkbox"/> Pain prevents me from doing anything but light duties</li> <li><input type="checkbox"/> Pain prevents me from doing even light duties</li> <li><input type="checkbox"/> Pain prevents me from doing any job or homemaking chores</li> </ul>	<p><b>10. Traveling</b></p> <ul style="list-style-type: none"> <li><input type="checkbox"/> I can travel anywhere without pain</li> <li><input type="checkbox"/> I can travel anywhere but it gives me extra pain</li> <li><input type="checkbox"/> Pain is bad but I manage journeys over 2 hours</li> <li><input type="checkbox"/> Pain restricts me to journeys of less than 1 hour</li> <li><input type="checkbox"/> Pain restricts me to short journeys under 30 minutes</li> <li><input type="checkbox"/> Pain prevents me from traveling except to receive treatment</li> </ul>

Please tick the appropriate response regarding your changing degree of pain

- My pain is rapidly getting better
- My pain fluctuates, but overall is definitely getting better
- My pain seems to be getting better, but improvement is slow at present
- My pain is neither getting better or worse
- My pain is gradually worsening
- My pain is rapidly worsening

**Signature** \_\_\_\_\_ **Date** \_\_\_\_\_

**APPENDIX F: ACCESS TO TREATMENT**

**Name:** \_\_\_\_\_ **Team:** \_\_\_\_\_

1. Do you have medical aid?  
Yes OR No
2. Does WP cover your medical costs should you get injured playing for them?  
Yes OR No
3. Do you have access to medical treatment, such as doctors or physiotherapists?  
Yes OR No
4. Are you involved in any program that pays for your medical costs or arranges treatment for you?  
Yes OR No  
If yes please state which program it is: \_\_\_\_\_  
\_\_\_\_\_
5. Do your parents cover your medical costs?  
Yes OR No

**APPENDIX G: ANTHROPOMETRY ASSESSMENT SHEET**

Name: \_\_\_\_\_

Age: \_\_\_\_\_

Date: \_\_\_\_\_

<b>Weight (kg)</b>	
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<b>Height (cm)</b>	
--------------------	--

<b>Skinfold (mm)</b>	<b>left</b>	<b>right</b>
Triceps		
Biceps		
Subscapular		
Suprailiac		
Calf		
Thigh		
Abdominal		

<b>Girths (mm)</b>	<b>left</b>	<b>right</b>
Forearm		
Mid-thigh		
Calf		

<b>Results</b>	
Sum of skinfolds (mm)	
% Body fat	
Fat mass (kg)	
Lean body mass (kg)	
Muscle mass (kg)	

**APPENDIX H: LOWER BACK MEDICAL EVALUATION FORM**

Name: \_\_\_\_\_

Date: \_\_\_\_\_

Lumbar spine: movement & inspection

Forward flexion	Abnormal	<input type="checkbox"/>	Normal	<input type="checkbox"/>	cm	_____
Extension	Abnormal	<input type="checkbox"/>	Normal	<input type="checkbox"/>	deg	_____
Rotation right	Abnormal	<input type="checkbox"/>	Normal	<input type="checkbox"/>	deg	_____
Rotation left	Abnormal	<input type="checkbox"/>	Normal	<input type="checkbox"/>	deg	_____
Lateral flexion right					cm	_____
Lateral flexion left					cm	_____
Stork test L leg Left	Abnormal	<input type="checkbox"/>	Normal	<input type="checkbox"/>		
Stork test L leg Right	Abnormal	<input type="checkbox"/>	Normal	<input type="checkbox"/>		
Stork test R leg Left	Abnormal	<input type="checkbox"/>	Normal	<input type="checkbox"/>		
Stork test R leg Right	Abnormal	<input type="checkbox"/>	Normal	<input type="checkbox"/>		

Other visible abnormalities: \_\_\_\_\_

Scoliosis	thoracic	yes	<input type="checkbox"/>	no	<input type="checkbox"/>
	lumbar	yes	<input type="checkbox"/>	no	<input type="checkbox"/>

Inspection standing

Visible asymmetries: \_\_\_\_\_

Lumbar spine: Supine evaluation

Straight leg raise Left deg \_\_\_\_\_

Straight leg raise Right deg \_\_\_\_\_

## Palpation:

T <sub>12</sub>	painful	<input type="checkbox"/>	no pain	<input type="checkbox"/>
L <sub>1</sub>	painful	<input type="checkbox"/>	no pain	<input type="checkbox"/>
L <sub>2</sub>	painful	<input type="checkbox"/>	no pain	<input type="checkbox"/>
L <sub>3</sub>	painful	<input type="checkbox"/>	no pain	<input type="checkbox"/>
L <sub>4</sub>	painful	<input type="checkbox"/>	no pain	<input type="checkbox"/>
L <sub>5</sub>	painful	<input type="checkbox"/>	no pain	<input type="checkbox"/>

Paraspinal:

	Left		Right	
L <sub>1</sub>	painful <input type="checkbox"/>	no pain <input type="checkbox"/>	painful <input type="checkbox"/>	no pain <input type="checkbox"/>
L <sub>2</sub>	painful <input type="checkbox"/>	no pain <input type="checkbox"/>	painful <input type="checkbox"/>	no pain <input type="checkbox"/>
L <sub>3</sub>	painful <input type="checkbox"/>	no pain <input type="checkbox"/>	painful <input type="checkbox"/>	no pain <input type="checkbox"/>
L <sub>4</sub>	painful <input type="checkbox"/>	no pain <input type="checkbox"/>	painful <input type="checkbox"/>	no pain <input type="checkbox"/>
L <sub>5</sub>	painful <input type="checkbox"/>	no pain <input type="checkbox"/>	painful <input type="checkbox"/>	no pain <input type="checkbox"/>

SI Joint      Left      painful       no pain

SI Joint      Right      painful       no pain

Iliac lumbar ligament      Left      painful       no pain

Iliac lumbar ligament      Right      painful       no pain

Gross neurological evaluation      abnormal       normal

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## APPENDIX I: INTERVENTION PROGRAM EXERCISES

## Phase One

**Common Aspects Which Apply To All Of The Exercises**

- ❑ What to do:
  - Perform each movement in a slow and controlled manner. (There is no rush and no race to see how quickly you can perform each exercise.)
  - Activate your Transversus Abdominus (TA) while performing the movements.
  - Draw in your pelvic floor muscles before each movement begins.
  - Keep your shoulders away from your ears by sliding your shoulder blades down.
  - Keep your chest open by drawing your shoulder blades together.
  - Keep your head and neck in a neutral position. [Avoid excessive flexion (jamming your chin toward your chest) or excessive extension (pointing your chin up toward the ceiling).]
  - Breathe into the back and sides of your ribcage.
  - Breathe continuously.

**TA Activation Prone**

- ❑ **Start:** Lie on your stomach with your abdominals relaxed.
- ❑ **Exhale:** Activate your TA to lift your lower abdominals away from the mat.
- ❑ **Inhale:** Relax
- ❑ **Advanced:** Reverse breathing
- ❑ **Tips:**
  - ❑ Try activate your pelvic floor first.
  - ❑ Draw in your abdominals as though you are trying to put on a tight pair of jeans.
  - ❑ Cough to feel your muscles work.

**TA Activation Supine**

- ❑ **Start:** Lie on your back with your legs spaced hip distance apart. Place two fingers from each hand at an angle running from the top of the hips toward the pubic bone.
- ❑ **Exhale:** Draw in the abdominal muscles below your belly button.
- ❑ **Inhale:** Relax.
- ❑ **Advanced:** Repeat the procedure with the breath phase reversed.
- ❑ **Tips:**
  - ❑ Try activate your pelvic floor first.
  - ❑ Draw in your abdominals as though you are trying to put on a tight pair of jeans.
  - ❑ Cough to feel your lower abdominal muscles work.

**TA Activation Standing**

- ❑ **Start:** Standing with your abdominals relaxed and with a neutral spine.
- ❑ **Exhale:** Activate your TA to draw your lower abdominals in and up toward your spine.
- ❑ **Inhale:** Relax.
- ❑ **Advanced:** Reverse breathing.
- ❑ **Tips:**
  - ❑ Try activate your pelvic floor first.
  - ❑ Draw in your abdominals as though you are trying to put on a tight pair of jeans.
  - ❑ Cough to feel your lower abdominal muscles work.

**Imprint and Neutral**

- ❑ **Start:** Lie on your back with your legs hip distance apart and your knees bent.
- ❑ **To find neutral:** Flatten your back against the floor by tilting your hips back towards you, then tilt your hips in the opposite direction, slightly arching your back. Neutral is located between these two positions.
- ❑ **Alternatively:** Straighten your legs. In this position your spine will align itself into your neutral position. Keep your spine in this position and return your legs to the bent position.
- ❑ **To find imprint:** Rock your hips back by contracting your abdominals until your lower back is touching the mat.

**Alternate Arm Lift**

- ❑ **Start:** Sitting with an upright posture (Neutral spine) while drawing in the TA. Your arms start by your side with your fingertips pointed toward the ground.
- ❑ **Exhale:** Lift one arm upward until your fingertips are pointed towards the ceiling.
- ❑ **Inhale:** Slowly lower your arm to the start position.
- ❑ (Alternate arms)
- ❑ **Incorrect:** Losing neutral spine (Rounding the back), losing TA activation, or lifting the shoulder up toward the ear.


**Pelvic Tilt**

- ❑ **Start:** Neutral spine with your legs bent and spaced hip distance apart
- ❑ **Exhale:** Contract your abdominals while rocking your pelvis backwards so that your lower back touches the mat
- ❑ **Inhale:** Return to neutral
- ❑ **Exhale:** Tilt your pelvis in the opposite direction so that your lower back is in a slight hyper extension
- ❑ **Inhale:** Return to neutral

**TA Activation Seated**

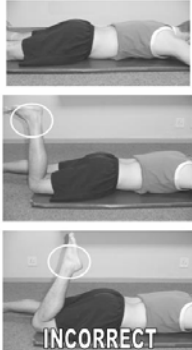
- ❑ **Start:** Sitting with your abdominals relaxed and with a neutral spine.
- ❑ **Exhale:** Activate your TA to draw your lower abdominals in and up toward your spine.
- ❑ **Inhale:** Relax.
- ❑ **Advanced:** Reverse breathing.
- ❑ **Tips:**
  - ❑ Try activate your pelvic floor first.
  - ❑ Draw in your abdominals as though you are trying to put on a tight pair of jeans.
  - ❑ Cough to feel your lower abdominal muscles work.

### TA Activation Kneeling




- **Start:** Your hands are underneath your shoulders and are placed shoulder width apart. Your knees are underneath your hips and are hip width apart. Your abdominals are relaxed.
- **Exhale:** Activate your TA to draw your lower abdominals in and up toward your spine.
- **Inhale:** Relax.
- **Advanced:** Reverse breathing.
- **Tips:**
  - Try activate your pelvic floor first.
  - Draw in your abdominals as though you are trying to put on a tight pair of jeans.
  - Cough to feel your lower abdominal muscles work.

### Prone Knee Flexion



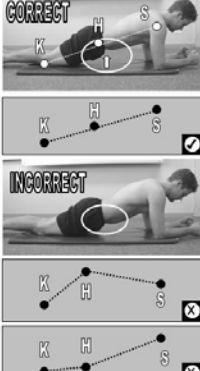
- **Start:** Lie on your stomach with your TA drawn in. Your head can rest on your hands if it is more comfortable.
- **Exhale:** Flex at the knee until your heel faces up toward the ceiling. Your foot should be kept in a neutral position. While moving your leg it is important to maintain TA activation.
- **Inhale:** Hold at the top position
- **Exhale:** Return to the start
- **Incorrect:**
  - If your foot is pointed.
  - If your lower back moves out of the neutral spine position.
  - Losing TA activation

### Prone Back Extension




- **Start:** Lie on your stomach with your arms by your side, your forehead on the mat and your TA drawn in.
- **Exhale:** Lift your shoulders and arms away from the mat.
- **Inhale:** Hold this position.
- **Exhale:** Return to the mat.
- **Incorrect:**
  - Losing TA activation.
  - Extending from the neck.

### Prone Knee Bridge




- **Start:** Your body is supported off the mat with your arms. There is a straight line between your knees and your shoulders. Your TA is activated.
- **Breathing:** Inhale and exhale while holding this position.
- **Incorrect:**
  - Losing TA activation.
  - Sinking into the shoulders.
  - Losing neutral spine.
    - Raising your hips up toward the ceiling.
    - Dropping your hips toward the floor.

### Forward Backward Rocking




- **Start:** Your hands are underneath your shoulders and are placed shoulder width apart. Your knees are underneath your hips and are hip width apart. Your TA is contracted.
- **Exhale:** Rock backwards, moving your hips towards your feet while maintaining neutral spine and TA activation.
- **Inhale:** Hold position.
- **Exhale:** Return to start position.
- **Incorrect:** Losing TA activation, or losing neutral spine by rounding your back.

### The Clam




- **Start:** Lie on your side with a neutral spine. One arm is used to support your head while your other arm helps with stabilization. Your hips and knees are flexed. Your TA is activated.
- **Exhale:** Separate your knees while keeping your feet together and maintaining your hips and shoulders one on top of the other.
- **Inhale:** Lower your leg so that your knees touch.
- **Incorrect:**
  - Losing TA activation.
  - Losing neutral spine.
  - Collapse forward or backward with your hips or shoulders (Rolling).

### Passive Segmental Bridging



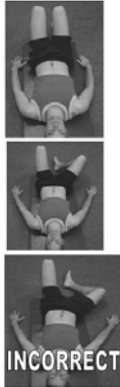
- **Start:** Kneeling with legs hip width apart. Your TA is drawn in and your arms are relaxed by your side with your forehead on the mat.
- **Exhale:** Start the movement from the top of your head sequentially extending your spine, lifting your upper body away from the mat until you have a neutral spine. Your hands remain by your side. Make sure that your legs remain in the start position.
- **Inhale:** Hold in this position.
- **Exhale:** Return to the start.

### Bilateral Fall-Out



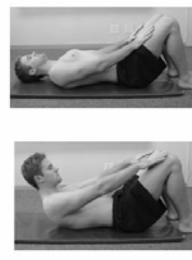
- **Start:** Lie on your back with your legs together. Your back is in neutral and your TA is activated. Ensure that your lower spine (sacrum) and coccyx stay on the mat throughout the entire exercise.
- **Exhale:** Lower both legs toward the right while maintaining TA activation.
- **Inhale:** Return to the start position.
- **Exhale:** Lower both legs toward the left while maintaining TA activation.
- **Inhale:** Return to the start position.
- **Incorrect:**
  - Losing TA activation.
  - Lifting your lower spine (sacrum) or coccyx off of the mat (Rolling).

### Unilateral Fall-Out



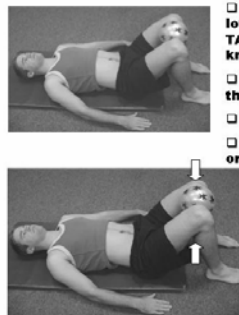
- **Start:** Lie on your back with your back in neutral spine. Your knees are bent and spaced hip width apart. Your TA is activated and your arms are relaxed by your side. Your lower spine (sacrum) and coccyx remain on the mat throughout the entire exercise.
- **Exhale:** Maintain your TA activation while controlling your leg as you lower it out to the side.
- **Inhale:** Control your leg back toward the midline. Return to the start position.
- **(Alternate legs)**
- **Incorrect:**
  - Losing TA activation.
  - Losing neutral spine.
  - Allowing your lower spine (sacrum) or coccyx to lift off of the mat (Rolling)

### Abdominal Crunch




- **Start:** Lie on your back with your knees bent. Your back is in neutral and your TA is activated. Your head is on the floor and your hands are resting on your thighs. Maintain neutral spine throughout the exercise.
- **Exhale:** Leading from the top of your head sequentially curl up so that your hands move up toward your knees and the top of your shoulders lift off of the mat. Make sure that your abdominals are drawn in and up. Keep your shoulders down and maintain a tennis ball space between your chin and chest (eyes on knees). Avoid rounding your shoulders by keeping them drawn back (Ensure that your chest remains "open").
- **Inhale:** Hold this position.
- **Exhale:** Return to the starting position.

### Ball Squeeze

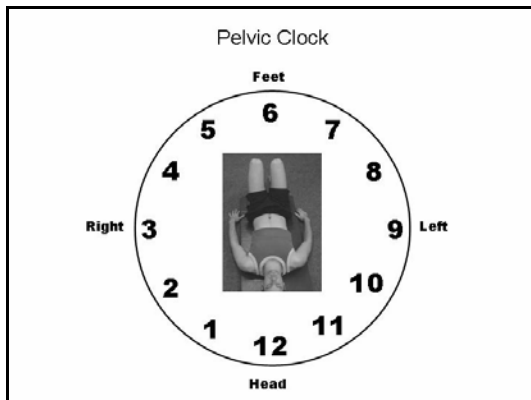


- **Start:** Lie on your back with your lower back in neutral. Activate your TA. Place the ball between your knees.
- **Exhale:** Bring your knees toward the midline as you squeeze the ball.
- **Inhale:** Relax.
- **Advanced:** Reverse the breath order.

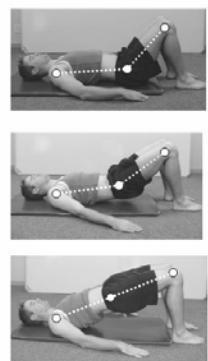
### Heel Slide On Floor



- **Start:** Lie on your back with your spine in neutral. Your TA is activated. Your knees bent and spaced hip distance apart.
- **Exhale:** Send one leg away from you along the floor, holding your foot in a neutral position.
- **Inhale:** Return your leg to the start position.
- **Incorrect:**
  - Losing neutral spine ("Popping" your rib cage toward the ceiling).
  - Losing TA activation.
  - Excessively pointing your foot.




### Segmental Bridging



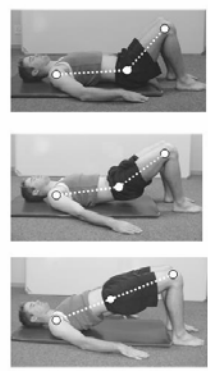
- **Start:** Lie on your back with your spine in neutral. Your knees bent and spaced hip distance apart. Your TA is activated.
- **Exhale:** Rock your hips back into imprint and continue to sequentially roll your spine up, vertebra by vertebra, starting at the coccyx ending when your shoulders, hips and knees are in a line.
- **Inhale:** Hold in this position.
- **Exhale:** Sequentially roll down and return to the starting position.
- **Focus:** The focus of this exercise is on segmental control and TA activation. The gluteals, hamstrings and quadriceps should only play an assistive (secondary) role as far as possible.

### Pelvic Clock




- **Start:** Lie on your back with your back in neutral spine. Your knees are bent and spaced hip width apart. Your TA is activated and your arms are relaxed by your side. Your lower spine (sacrum) remains on the mat throughout the entire exercise.
- **Exhale:** Move your pelvis back so that you imprint your spine (12 o'clock).
- **Inhale:** Return to the start.
- **Exhale:** Move your pelvis away from you (6 o'clock).
- **Inhale:** Return to the start.
- **Exhale:** Move your pelvis to the left (3 o'clock).
- **Inhale:** Return to the start.
- **Exhale:** Move your pelvis to the right (9 o'clock).
- **Inhale:** Return to the start.

### Pelvic Lift (Bridging)



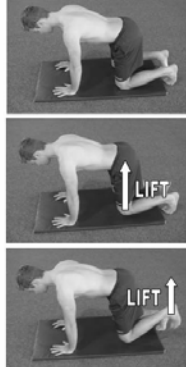
- **Start:** Lie on your back with your spine in neutral. Your knees bent and spaced hip distance apart. Your TA is activated.
- **Exhale:** Lift your pelvis directly off the mat without rolling through imprint. Ending when your shoulders, hips and knees are in a line.
- **Inhale:** Hold in this position.
- **Exhale:** Return to the starting position without passing through imprint.
- **Focus:** The focus of this exercise is on TA activation. The gluteals, hamstrings and quadriceps should only play an assistive (secondary) role as far as possible.

### Knee Lift



- ❑ **Start:** Your hands are underneath your shoulders and are placed shoulder width apart. Your knees are underneath your hips and are hip width apart. Your TA is contracted.
- ❑ **Exhale:** Lift your knees approximately 5cm off of the mat while maintaining neutral spine and TA activation.
- ❑ **Inhale:** Hold position.
- ❑ **Exhale:** Return to start position.
- ❑ **Incorrect:** Losing TA activation, or losing neutral spine by rounding your back.

### Knee And Foot Lift



- ❑ **Start:** Your hands are underneath your shoulders and are placed shoulder width apart. Your knees are underneath your hips and are hip width apart. Your TA is contracted.
- ❑ **Exhale:** Lift your knees approximately 5cm off of the mat while maintaining neutral spine and TA activation.
- ❑ **Inhale:** Hold position.
- ❑ **Exhale:** Lift your foot off of the mat.
- ❑ **Inhale:** Lower your foot to the mat.
- ❑ **(Alternate legs)**
- ❑ **Incorrect:** Losing TA activation, or losing neutral spine by rounding your back.

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## Phase Two Exercises

### Heel Slide Off Floor




- **Start:** Lie on your back with your spine in neutral. Your TA is activated. Your knees bent and spaced hip distance apart.
- **Exhale:** Send one leg away from you above the floor, holding your foot in a neutral position.
- **Inhale:** Return your leg to the start position.
- (Alternate)
- **Incorrect:**
  - Losing neutral spine ("Popping" your rib cage toward the ceiling).
  - Losing TA activation.
  - Excessively pointing your foot.

### Bridging With Leg Lift



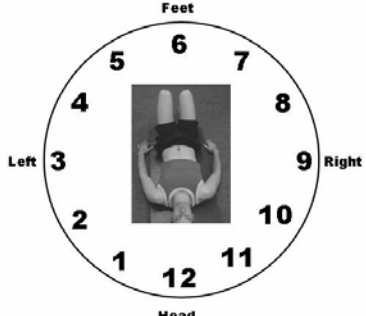
- **Start:** Using a pelvic lift get into the bridge position. Keep your TA activated. Your shoulders, hips and knees should be in a line. In this position your spine should be in a straight line.
- **Exhale:** Lift your leg off of the mat and straighten your knee, keeping your foot in a neutral position. At the top of the movement both thighs are parallel with one leg straightened.
- **Inhale:** Return to the start position.
- (Alternate)
- **Exhale:** Sequentially roll back down to the ground.
- **Focus:** The focus of this exercise is on the TA activation. The gluteals, hamstrings and quadriceps should only play an assistive (secondary) role as far as possible.

### Marching




- **Start:** Lie on your back with your knees bent and spaced hip width apart. Your TA is activated with your lower back in neutral on the mat. Your arms remain relaxed by your side.
- **Exhale:** Lift your leg off of the mat while maintaining your TA activation.
- **Inhale:** Lower the leg to the start position.
- (Alternate)
- **Incorrect:**
  - Putting your spine into imprint.
  - Lifting your leg too high off of the mat (Beyond 90° at the hip).
  - Losing neutral spine ("Popping" your rib cage toward the ceiling).
  - Losing TA activation.
  - Excessively pointing your foot.

### Pelvic Clock




### Ball Squeeze Bridge




- **Start:** Lie on your back with your spine in neutral. Your TA is activated. Place a ball between your bent knees.
- **Exhale:** While squeezing the ball rock your hips back into imprint and continue to sequentially roll your spine up, vertebra by vertebra, starting at the coccyx ending when your shoulders, hips and knees are in a line.
- **Inhale:** Hold in this position.
- **Exhale:** Sequentially roll down and return to the starting position.
- **Inhale:** Release the ball squeeze.
- **Focus:** The focus of this exercise is on segmental control and TA activation. The gluteals, hamstrings and quadriceps should only play an assistive (secondary) role as far as possible.

### Pelvic Clock Bridge




- **Start:** In the bridge position keep your TA activated. Your shoulders and knees should be in a line.
- **Exhale:** Rotate your pelvis to the left (3 o'clock).
- **Inhale:** Return to the start position.
- **Exhale:** Rotate your pelvis to the right (9 o'clock).
- **Inhale:** Return to the start position.
- (Repeat)
- **Exhale:** Sequentially roll back down to the ground.
- **Focus:** The focus of this exercise is on the TA activation. The gluteals, hamstrings and quadriceps should only play an assistive (secondary) role as far as possible.

### Bridging With Knee Lift



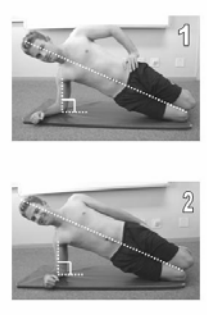
- **Start:** Using a pelvic lift get into the bridge position. Keep your TA activated. Your shoulders, hips and knees should be in a line. In this position your spine should be in a straight line.
- **Exhale:** Lift your foot off of the mat with your knee still bent. Make sure that you keep your foot in a neutral position.
- **Inhale:** Return to the start position.
- (Alternate)
- **Exhale:** Sequentially roll back down to the ground.
- **Focus:** The focus of this exercise is on the TA activation. The gluteals, hamstrings and quadriceps should only play an assistive (secondary) role as far as possible.

### Abdominal Crunch




- **Start:** Lie on your back with your knees bent. Your back is in neutral and your TA is activated. Your head is on the floor and your fingertips are touching your temples. Maintain neutral spine throughout the exercise.
- **Exhale:** Leading from the top of your head sequentially curl up so that the top of your shoulders lift off of the mat. Make sure that your abdominals are drawn in and up. Keep your shoulders down and maintain a tennis ball space between your chin and chest (eyes on knees). Avoid rounding your shoulders by keeping them drawn back (Ensure that your chest remains "open").
- **Inhale:** Hold this position.
- **Exhale:** Return to the starting position.

### Side Bridge On Knees



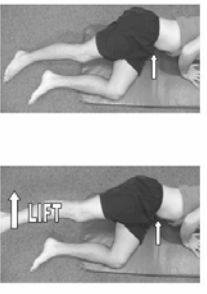
- **Start:** Your arm is placed so that there is a right angle between your arm and the mat. Your knees are together and your hips are off of the mat. Your body should follow a straight line from your knees through the top of your head. Your TA needs to be engaged throughout this exercise. Arm position 1 or 2 can be used.
- **Breathing:** Inhale and exhale in this position.
- **Incorrect:**
  - Losing TA activation.
  - Sinking into your shoulder.
  - Dropping your hips toward the floor.
  - Raising your hips up toward the ceiling.

### Prone Arm Lift




- **Start:** Lie on your stomach with your TA drawn in. Your legs are spaced hip distance apart. Your arms are extended above your head with your palms facing down. Your head and neck are relaxed with your forehead on the mat.
- **Exhale:** Lift one arm off of the floor without moving your head or neck. The movement ends when your hand is between 5 - 10cm off of the mat.
- **Inhale:** Return to the start position.
- **(Alternate arms).**
- **Incorrect:**
  - Losing TA activation.
  - Lifting your head off of the mat.
  - Arching your back.

### Leg Abduction



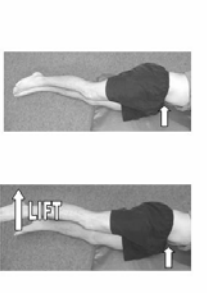
- **Start:** Lie on your side with your TA drawn in. Your top leg is straight while your bottom leg is bent to provide support. Your shoulders and hips are in a line. Your shoulders and hips are positioned one on top of the other (respectively). Your spine is in neutral. Your bottom arm is under your head for support while your top arm assists with stabilization.
- **Exhale:** Lift your top leg toward the ceiling.
- **Inhale:** Return to the start position.
- **Incorrect:**
  - Arching your back and therefore losing neutral spine.
  - Losing TA activation.
  - Excessive side bending (Lateral flexion).

### Prone Leg Lift



- **Start:** Lie on your stomach with your TA drawn in. Your legs are spaced hip distance apart. Your arms are extended above your head with your palms facing down. Your head and neck are relaxed with your forehead on the mat.
- **Exhale:** Lift one leg off of the floor without moving your head or neck or without rounding your back. The movement ends when your leg is between 10 - 15cm off of the mat.
- **Inhale:** Return to the start position.
- **(Alternate legs).**
- **Incorrect:**
  - Losing TA activation.
  - Lifting your head off of the mat.
  - Arching your back.

### Leg Abduction (2)




- **Start:** Lie on your side with your TA drawn in. Both of your legs are straight. Your shoulders and hips are in a line. Your shoulders and hips are positioned one on top of the other (respectively). Your spine is in neutral. Your bottom arm is under your head for support while your top arm assists with stabilization.
- **Exhale:** Lift your top leg toward the ceiling.
- **Inhale:** Return to the start position.
- **Incorrect:**
  - Arching your back and therefore losing neutral spine.
  - Losing TA activation.
  - Excessive side bending (Lateral flexion).

### Kneeling Arm Lift



- **Start:** Your hands are underneath your shoulders and are placed shoulder width apart. Your knees are underneath your hips and are hip width apart. Your TA is contracted.
- **Exhale:** Lift your arm off of the mat while maintaining neutral spine and TA activation.
- **Inhale:** Return to start position.
- **(Alternate arms)**
- **Incorrect:**
  - Losing TA activation.
  - Losing neutral spine by:
    - Rounding your back.
    - Excessively arching your spine.

### Prone Torpedo



- **Start:** Lie on your stomach with your arms by your side, your forehead on the mat and your TA drawn in.
- **Exhale:** Lift your head 5-10 cm off the mat. Lift your shoulders and arms away from the mat at the same time.
- **Inhale:** Hold this position.
- **Exhale:** Return to the mat.
- **Incorrect:**
  - Arching lower spine excessively.
  - Extension (lifting up) the head and neck.

### Kneeling Leg Lift




- **Start:** Your hands are underneath your shoulders and are placed shoulder width apart. Your knees are underneath your hips and are hip width apart. Your TA is contracted.
- **Exhale:** Lift your leg off of the mat while maintaining neutral spine and TA activation.
- **Inhale:** Return to start position.
- **(Alternate legs)**
- **Incorrect:**
  - Losing TA activation.
  - Losing neutral spine by:
    - Rounding your back.
    - Excessively arching your spine.



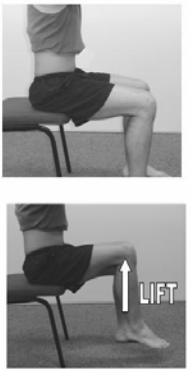
### Opposite Arm And Leg Raise

- ❑ **Start:** Your hands are underneath your shoulders and are placed shoulder width apart. Your knees are underneath your hips and are hip width apart. Your TA is contracted.
- ❑ **Exhale:** Lift your opposite arm and leg off of the mat while maintaining neutral spine and TA activation.
- ❑ **Inhale:** Return to start position.
- ❑ **(Alternate)**
- ❑ **Incorrect:**
  - ❑ Lifting up your head.
  - ❑ Locking your elbow.
  - ❑ Losing neutral spine by:
    - ❑ Rounding your back.
    - ❑ Excessively arching your spine.




### Wall Squat With Ball

- ❑ **Start:** Stand with your weight evenly distributed between both legs. Place your feet slightly in front of your hips with a 15° angle. Your knees are “soft” (not locked). The ball is placed so that it touches the bottom of your shoulder blades and the top of your hips. Your hands are by your side. Your TA is activated throughout the movement.
- ❑ **Inhale:** Squat down until your thighs are parallel to the floor. Your arms can be placed in position 1 or position 2.
- ❑ **Exhale:** Return to the start.
- ❑ **Incorrect:**
  - ❑ Leaning forward off of the ball (losing contact with the ball)
  - ❑ Losing TA activation



### Seated Marching

- ❑ **Start:** Sit with a neutral spine and your TA engaged.
- ❑ **Exhale:** Lift your foot off of the floor while still maintaining your posture and TA activation.
- ❑ **Inhale:** Return to the starting position.
- ❑ **(Alternate)**
- ❑ **Advance:** Reverse breath order.
- ❑ **Incorrect:**
  - ❑ Losing TA activation.
  - ❑ Losing neutral spine.



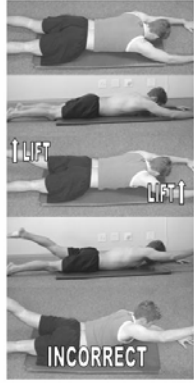
### Hip Hike

- ❑ **Start:** Stand with one foot on a step and the other leg suspended along side. Keep hips level with a neutral spine.
- ❑ **Exhale:** Lower your hip on the free standing leg toward the ground.
- ❑ **Inhale:** Lift your hip on the free standing leg up toward the ceiling.
- ❑ **(Alternate legs).**
- ❑ **Advance:** Change breath order.

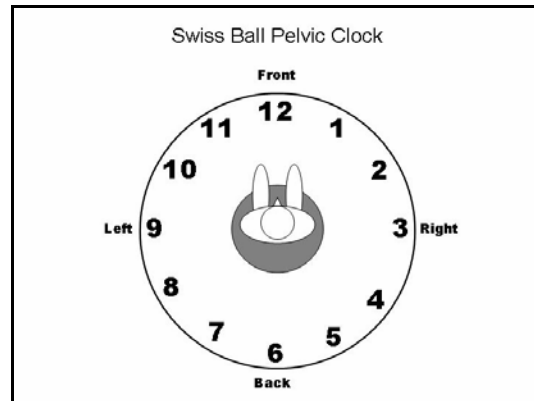
Cape Town

**Phase Three – General Exercises**


### Opposite Arm And Leg Lift



- **Start:** Lie on your stomach with your TA drawn in. Your legs are spaced hip distance apart. Your arms are extended above your head with your palms facing down. Your head and neck are relaxed with your forehead on the mat.
- **Exhale:** Lift opposite arm and leg off of the floor without moving your head or neck. The movement ends when your hand is between 5 - 10cm off of the mat and your leg is between 10 - 15cm off of the mat.
- **Inhale:** Return to the start position.
- **Advance:** Reverse breath order.
- **Incorrect:**
  - Losing TA activation.
  - Lifting your head off of the mat.
  - Arching your back.

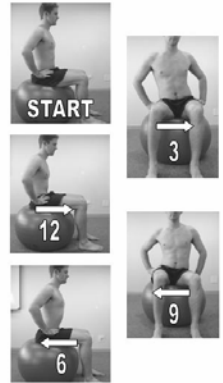


### Prone Bridge On Knees With Arm Lift




- **Start:** Your body is supported off the mat with your arms. There is a straight line between your knees and your shoulders. Your TA is activated.
- **Exhale:** Lift your arm off the mat until your forearm is in line with the top of your head.
- **Inhale:** Lower your arm back to the mat.
- **(Alternate)**
- **Incorrect:**
  - Losing TA activation.
  - Sinking into the shoulders.
  - Losing neutral spine.
    - Dropping your hips toward the floor.
    - Raising your hips up toward the ceiling.

### Pelvic Clock On Ball



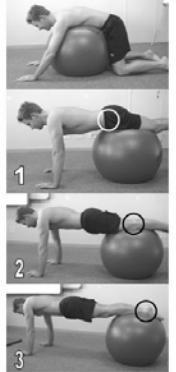
- **Start:** Sit upright on the ball with a neutral spine. Your weight is distributed evenly between both legs. Your TA is drawn in throughout the exercise. Your chest bone (sternum) remains in the middle at all times.
- **Breathing:** Breathe normally throughout all of the movements.
- **3 o'clock:** Move your pelvis to the left.
- **9 o'clock:** Move your pelvis to the right.
- **6 o'clock:** Move your pelvis backward.
- **12 o'clock:** Move your pelvis forward.
- **Incorrect:**
  - Losing contact with the ground with either leg at any time.

### Leg Lift



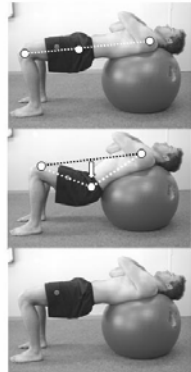
- **Start:** Your hands are underneath your shoulders and are placed shoulder width apart. Your body is positioned as though you are going to perform a push up. Your TA is contracted.
- **Exhale:** Lift your foot approximately 5cm off of the mat while maintaining TA activation.
- **Inhale:** Return foot to the start position.
- **(Alternate)**
- **Incorrect:**
  - Losing TA activation.
  - Sinking into your shoulders.
  - Losing neutral spine by:
    - Rounding your back.
    - Dropping your hips.

### Ball Walk Out




- **Start:** Balance on the ball with both hands and knees touching the floor.
- **Breathing:** Inhale and exhale as normal while you walk out from the ball. Your TA should be activated at all times during the movement.
- **Phase 1:** Walk out to your hips.
- **Phase 2:** Walk out to your knees.
- **Phase 3:** Walk out to your ankles.
- **Incorrect:**
  - Losing TA activation.
  - Losing neutral spine by:
    - Rounding your back.
    - Dropping your hips.
    - Arching your back.
  - Sinking into your shoulders.

### Bridging On The Ball




- **Start:** Your upper back and shoulders are on the ball. Your hips are up so that there is a line between your shoulders hips and knees. Your arms can be crossed in front of your chest or can be by your side for support. Your back is in neutral with your TA activated.
- **Exhale:** Sequentially roll your hips toward the floor, away from the start line.
- **Inhale:** Hold this position.
- **Exhale:** Return to the start.
- **Incorrect:**
  - Losing TA activation.
  - Losing pelvic stability.

### Arm Lift On Ball




- **Start:** Balance on the ball with both hands and feet touching the floor. Your belly button should be aligned approximately with the midline of the ball. Your TA is contracted.
- **Exhale:** Lift your arm off of the floor while keeping it straight and maintaining neutral spine. Your TA should be activated at all times during the movement.
- **Inhale:** Return to start position.
- **(Alternate)**
- **Incorrect:**
  - Losing TA activation.
  - Losing neutral spine by rounding or arching your back.
  - Lifting up your head.

### Leg Lift On Ball




- **Start:** Balance on the ball with both hands and feet touching the floor. Your belly button should be aligned approximately with the midline of the ball. Your TA is contracted.
- **Exhale:** Lift your leg off of the floor while keeping it straight and maintaining neutral spine. Your TA should be activated at all times during the movement.
- **Inhale:** Return to start position.
- **(Alternate)**
- **Incorrect:**
  - Losing TA activation.
  - Losing neutral spine by rounding or arching your back.
  - Lifting up your head.

### Wall Push Up




- **Start:** Place your hands on the wall shoulder width apart. Your feet are together and are positioned slightly behind your hips. Your body is therefore tilted toward the wall at an angle. Your shoulders are relaxed. Your spine is in neutral. Your TA is engaged.
- **Inhale:** Slowly lower yourself toward the wall. Your upper arm should remain below shoulder height, preferably at a 45° angle.
- **Exhale:** Push yourself away from the wall.
- **Incorrect:**
  - Losing TA activation.
  - Losing neutral spine.
  - Dropping your hips toward the wall.
  - Pushing your hips away from the wall.
  - Lifting your shoulders up toward your ears.

### Opposite Arm And Leg Lift



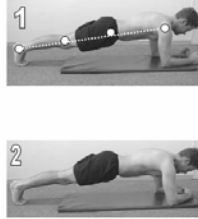
- **Start:** Balance on the ball with both hands and feet touching the floor. Your belly button should be aligned approximately with the mid line of the ball. Your TA is contracted.
- **Exhale:** Lift your opposite arm and leg off of the floor while maintaining neutral spine and TA activation.
- **Inhale:** Return to start position.
- **(Alternate)**
- **Incorrect:**
  - Losing TA activation.
  - Losing neutral spine by rounding or arching your back.
  - Lifting up your head.

### Crab Squat



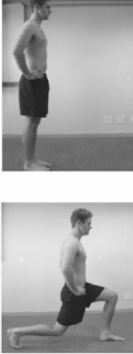
- **Start:** Stand with your legs hip width apart with a flex band tied around your knees (1). Keep your TA activated.
- **Exhale:** Step across applying tension to the flex band (2). Your feet should be turned out to 15° in preparation for the squat.
- **Inhale:** Squat down while keeping your knees apart (resisting the flex band). Hand position 3A or 3B can be used.
- **Exhale:** Stand up from the squat while you continue to resist the band.
- **Inhale:** Step back so that you are in the start position.

### Full Bridge



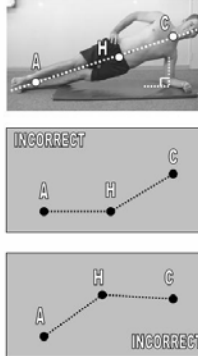
- **Start:** Your body is supported off the mat with your arms. There is a straight line between your ankles and your shoulders. Keep your shoulder blades sliding back and down. Your TA is activated.
- **Breathing:** Inhale and exhale while holding this position.
- **Alternative:** Placing your elbows out at an angle (2) may make it easier
- **Incorrect:**
  - Losing TA activation.
  - Sinking into the shoulders.
  - Lifting your shoulders up towards your ears.
  - Losing neutral spine.
    - Dropping your hips toward the floor.
    - Raising your hips up toward the ceiling.

### Forward Lunge



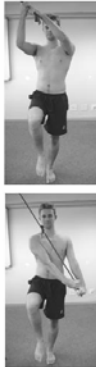
- **Start:** Stand with your legs hip width apart. Your spine is in neutral and your TA is activated. Your hands are by your side with your shoulders back and down.
- **Inhale:** Step forward keeping your legs hip width apart. Your back leg stays in contact with the floor at all times.
- **Exhale:** Push up with your front leg and return to the standing position.
- **(Alternate)**
- **Incorrect:**
  - Losing TA activation.
  - Losing neutral spine.
  - Relying completely on your back leg while returning to the standing position.

### Side Bridge Full




- **Start:** Your arm is placed so that there is a right angle between your arm and the mat. Your legs are together and your hips are off the mat. Your body should follow a straight line from your ankles through the top of your head. Your TA needs to be engaged throughout this exercise.
- **Breathing:** Inhale and exhale in this position.
- **Incorrect:**
  - Losing TA activation.
  - Sinking into your shoulder.
  - Dropping your hips toward the floor.
  - Raising your hips up toward the ceiling.

### Flex Band Chop




- **Start:** Stand on one leg with the non-weight bearing leg raised up in front with a bent knee. Both hips are level and both shoulders are level. Grip the flex band with both hands above shoulder height. The flex band should be attached to an immovable object at a height of 2m.
- **Exhale:** Draw the band diagonally across the front of the body to finish by the opposite hip.
- **Inhale:** Hold the flex band in this position.
- **Exhale:** Slowly return to the start position.
- **Incorrect:**
  - Losing neutral spine.
  - Losing TA activation.
  - Tilting your hips.
  - Tilting your shoulders.
- **Alternative:** Change your position so that you pull the band down on toward your bent knee.

### Flex Band Lift




- **Start:** Stand on one leg with the non-weight bearing leg raised up in front with a bent knee. Both hips are level and both shoulders are level. Grip the one end of the flex band with both hands at waist level. The other end of the flex band needs to be placed under the weight bearing foot.
- **Exhale:** Draw the band diagonally across the front of the body to finish above the shoulder on the weight bearing side.
- **Inhale:** Hold the flex band in this position.
- **Exhale:** Slowly return to the start position.
- **Incorrect:**
  - Losing neutral spine.
  - Losing TA activation.
  - Tilting your hips.
  - Tilting your shoulders.
- **Alternative:** Change your position so that you pull the band down on toward your bent knee.

### Ball Bridge




- **Start:** Your buttocks are touching the ball while your feet are on top of the ball. Your arms are relaxed by your side. Your TA is drawn in.
- **Exhale:** Sequentially roll up vertebra by vertebra until there is a straight line between your ankles and shoulders.
- **Inhale:** Hold this position.
- **Exhale:** Return to the start by sequentially rolling down with your spine.

### Flex Band Raise With Lunge



- **Start:** Stand with your legs hip width apart. Your spine is in neutral and your TA is activated. One leg is forward with a flex band underneath your foot. Your weight is evenly distributed between both legs. Your hands are by your side holding the ends of the flex band. Your shoulders are back and down.
- **Inhale:** Shift your weight to your front foot as you move into a lunge. Raise the ends of the band up until they reach shoulder level.
- **Exhale:** Slowly control the band back down to your sides while you stand up and return so that your weight is redistributed to both legs.
- **Incorrect:**
  - Losing TA activation.
  - Losing neutral spine.
  - Lifting your shoulders up towards your ears.

### Passive Segmental Bridging



- **Start:** Kneeling with legs hip width apart. Your TA is drawn in. Your fingertips are touching your temples and your forehead is on the mat.
- **Exhale:** Start the movement from the top of your head sequentially extending your spine, lifting your upper body away from the mat until you have a neutral spine. Your fingertips remain by your temples. Make sure that your legs remain in the start position.
- **Inhale:** Hold in this position.
- **Exhale:** Return to the start.

University of Cape

## Phase Three – Cricket Specific Exercises

### Push up with plus on ball

**A. Start position**      **B. Push up**  
**C. Push up**      **D. Push up**  
**E. Push up with plus**

**A. Start:** Position your stomach on the ball with your hands flat on the floor in front of you and feet on toes behind you. Activate TA by drawing lower abdominals in and upwards.

**B. Walk out to push up position. Maintain TA activation.**

**C. Keeping feet & lower legs on ball & lower abdominals stabilised, bend elbows & lower yourself down towards the ground. Make sure you do not round your back in doing the push up**

**D. Push up by extending the elbows.**

**E. Once in push up position pull scapulae upwards**

### Hanging hip hike

**A. Start:** Hold onto pull up bar with hands shoulder width apart. Activate TA by drawing lower abdominals up and into spine.

**B. While stabilising abdominals, lift feet to the right without moving the arms and upper body. Hold this position for a few seconds and then return to the start position.**

- This exercise is repeated lifting feet to left side.
- Progress to hold for 10 seconds.

### Jackknife

**A. Start:** Begin by placing feet & lower limbs on ball. Arms shoulder width apart with hands flat on floor in front of you. Activate TA by drawing your lower abdominals up and in towards your spine.

**B. Keeping arms shoulder width apart and hands flat on floor, elbows straight and abdominals stabilised, roll ball towards you by bending knees.**

**C. Whilst maintaining abdominal stability, straighten legs to roll ball back to start position.**

### 180 degree ball pass

**A. Start:** In groups of 2, stand slightly apart back-to-back with partner. Feet shoulder width apart and arms out in front of you. Person 1 holds the ball to start. Both activate TA.

**B. Maintain TA activation & keep feet fixed to ground so only rotating trunk. Person 1 with ball turns to the left and person 2 turns to the right. Person 1 passes ball to person 2.**

**C. Maintaining TA activation, person 2 now with the ball turns to the left and person 1 turns to the right. The ball is passed back to person 1.**

### External shoulder rotation on ball

**A. Start:** Begin with abdominals stabilised, trunk area on ball, legs slightly bent behind you on toes. Arms shoulder width apart hanging down holding weights.

**B. Maintaining position A of body and legs, bend elbows and lift arms to horizontal whilst keeping TA activated.**

**C. Keep body and legs in the same as position A. With upper arms at horizontal level lift hands in front of you so that they are at the same level as the upper arm. Maintain activation of TA throughout exercise.**

### 360 degree ball pass

**A. Start:** In groups of 2, stand slightly apart back-to-back with partner. Feet shoulder width apart and arms out in front of you. Person 1 holds the ball to start. Both activate TA.

**B. Both maintain TA activation and keep feet fixed to the ground only rotate trunk. Person 1, with ball, turns to right and person 2 turns to right now both facing each other pass ball to person 2.**

**C. Maintaining TA activation and footing, turn to left to face each other again and pass ball back to person 1.**

### Reverse back extensions

**A. Start:** Lie face down with stomach over ball with TA activated. Place legs together out behind you, with arms out in front holding onto weighted support.

**B. Maintaining abdominal stability and hands holding onto support, lift feet off the ground until legs are horizontal and in line with the upper body. Hold this position for a few seconds.**

**C. Return to start position.**

### Overshoulder throws

**A. Start:** Begin with trunk rotated to the left, feet facing forward. Activate TA.

**B. Swing arms across body to the right side, bringing ball upwards towards shoulder height. Maintain TA contraction.**




**C. As ball reaches shoulder height on right side, throw it over your shoulder now rotating trunk to the right side. Maintain TA contraction.**

- Repeat starting on right side

Front view

Side view

### Walk forward lunges








**A. Start:** Begin standing up straight, feet slightly apart, hands on hips. Activate TA by drawing lower abdominals up and in towards spine.

**B. Step forward** bending left leg first at 90 degrees to the floor. Keep bent knee behind line of toes. Back (right) leg is bent so that it is parallel to the floor. Maintain stability throughout this movement.

**C. Keeping TA activated,** stand up & step forward with other leg, so that now the right leg is at 90 degrees to the floor, once again not taking the knee beyond the line of the toes. Left leg is now placed parallel close to the floor.

### Good mornings with dumbbells







**A. Start:** Begin standing with feet shoulder width apart, arms at your sides holding weights. Activate TA.

**B. Maintaining TA activation and keeping back straight** bend knees slightly and bend forward at the waist.

**C. Maintain TA contraction,** keeping arms at side stand up straight to return to position A.

### Walk forward lunges with weights








**A. Start:** Begin standing up straight, feet slightly apart, holding weights on either side. Stabilise abdominal area.

**B. Step forward** bending left leg first perpendicular to the floor but keeping knee behind line of toes. Back (right) leg is bent so that it is parallel to the floor. Maintain stability throughout.

**C. Stand up and step forward** other leg, so that now the right leg is perpendicular to the floor and the left leg is parallel close to the floor. Maintaining stability.

### Good mornings on 1-leg








**A. Start:** Begin standing on 1-leg, other leg bend at 90 degrees on bench. Hold barbell on shoulders. Activate TA.

**B. Maintaining TA contraction,** bend forward at waist keeping back straight and head up facing forward.

**C. Maintaining TA contraction,** straighten up to position A and then bend again to return to position B.

### Dumbbell squat








**A. Start:** Begin standing with feet shoulder width apart, arms at your sides holding weights. Activate TA.

**B. Maintaining TA activation,** arms hanging at sides, move into a squat by bending knees, keeping back straight and feeling like you are about to sit on the edge of a chair.

**C. Maintain TA contraction,** keeping arms at side, return to position A.

### Crane Lunges




**A. Start:** Begin standing with feet shoulder width apart, arms at your sides holding weights. Activated TA.

**B. Step forward** bending left leg first perpendicular to the floor but keeping knee behind line of toes. Back (right) leg is bent so that it is parallel to the floor. Maintain stability throughout.

**C. Drive through** from lunge to standing position lifting right leg to 90 degrees, maintain TA activation. Returning to start position.

- Repeat with right leg leading into lunge and lifting left leg.

### Deadlift with dumbbells



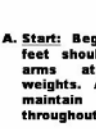




**A. Start:** Bend knees in a squat position with feet shoulder width apart, arms holding weights. Activate TA.

**B. Maintaining TA activation and keeping back straight** begin to straighten body into a full standing position.

**C. Maintain TA contraction,** keeping arms at side stand up straight.

### Opposition Raises

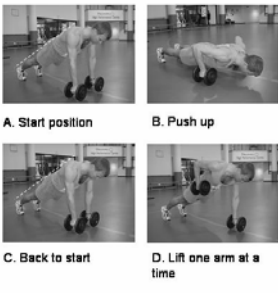
**A. Start:** Begin standing with feet shoulder width apart, arms at side holding weights. Activate TA and maintain contraction throughout exercise.

**B. Lift arms** to shoulder height so that they are parallel with the ground, with the left arm out in front and the right arm out to the side.

**C. Return to start position** and then lift arms again to horizontal this time with right arm out to front and left arm out to side.

Front view A, B and C  
Side view

### Stability Press



**A. Start position**  
**B. Push up**  
**C. Back to start**  
**D. Lift one arm at a time**


**A. Start:** Balance on weights with hands shoulder width apart. Feet hip width apart, legs straight behind you. Keep back straight and activate TA.

**B. Perform** push up, maintaining TA activation and keeping back straight.

**C. Return to start position** whilst maintaining abdominal stability.

**D. Maintain TA activation & balance,** lift alternate arms upwards.

### Knee lift with exercise elastic




**A.**  
**B.**

**A. Start:** Begin by standing straight with hands on hips. Place elastic under right foot and over left knee. Activate TA.

**B. Maintain TA activation** and standing position and lift the left knee to 90 degrees. Hold for a few seconds and then return to start position.

- Repeat exercise balancing on left leg and lift right leg.

### Wall running



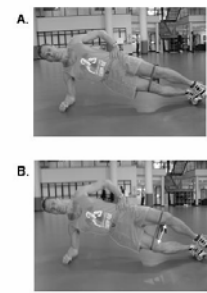
**A.**  
**B.**

**A. Start:** Stand up straight, with one leg straight and other leg bent with foot flat against wall. Activate TA & maintain throughout.

**B. Keeping upper body straight** and TA activated, bend front knee, whilst keeping back foot against the wall. Keep both arms bent in a 'running' position. Then return to start position.

- Repeat on other side.

### Side-bridge with elastic




**A.**  
**B.**

**A. Start:** Place elastic round both knees. Place arm so that there is a 90 degree angle between your arm & the mat. Your legs are together and your hips are off the mat. Your body should follow a straight line from your ankles through to the top of your head. TA must be activated throughout exercise.

**B. Maintaining above position,** open legs pushing elastic apart. The return to start position.

- Repeat exercise on other side

### Back extensions with exercise elastic



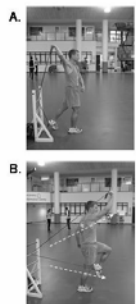
**A.**  
**B.**

**A. Start:** Begin in forward lunge position, with elastic placed under front foot. Make sure that your front knee is behind the line of the toes. Keep back straight and lean forward activating TA.

**B. Maintaining lunge position** and TA activation, straighten up from the waist so that the upper body is now straight. Then return to start position to perform next rep.

- Repeat exercise with other leg in front.

### Opposition flexion with elastic



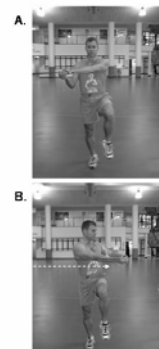
**A.**  
**B.**

**A. Start:** Tie elastic to left foot, and hold with right hand. Stand with back to equipment so that left leg and right arm are behind you. Activate TA.

**B. Pull right arm forward** and across body and kick left leg forward simultaneously. Maintain TA activation throughout. Return to start position

- Repeat exercise lifting left leg and pulling with right arm.
- Progress standing on balance mat.

### Trunk rotation standing on 1-leg




**A.**  
**B.**

**A. Start:** Balance on right leg with left leg bent to 90 degrees. Hold onto elastic on right side. Activate TA and maintain throughout.

**B. Turning the trunk to the left,** pull the elastic to your left side. Maintain stability and balance throughout.

- Move elastic slowly back to start position whilst maintaining TA activation.
- Repeat standing on left leg, with right leg bent to 90 degrees & pulling elastic to the right rotating the trunk to the right side.
- Progress by standing on a balance mat.

### Opposition extensions with elastic



**A.** **B.** **C.**

**A. Start:** Begin facing equipment, with elastic tied around right foot and holding onto it with left arm. Stand up straight whilst activating TA.

**B. Pull left arm up and backwards,** whilst simultaneously pulling right leg backwards, maintain TA activation throughout.

**C. Return to start position** and let right leg and left arm go slightly in front of body before pulling back again.

- Repeat exercise with left leg and right arm.
- Progress standing on balance mat.



**APPENDIX J: NEW MRI CLASSIFICATION SCORESHEET**

UCT/MRC RESEARCH UNIT FOR EXERCISE SCIENCE &amp; SPORTS MED

**STUDY: CLINICAL AND IMAGING FEATURES OF THE LUMBAR SPINE IN ELITE MALE  
SCHOOLBOY CRICKETERS: THE EFFECT OF A PRE-SEASON LUMBAR  
STABILISATION INTERVENTION**

Subject name: \_\_\_\_\_

Date: \_\_\_\_\_

Please tick one of the following boxes corresponding to the MRI image:

**Endplate**

		L <sub>1</sub>	L <sub>2</sub>	L <sub>3</sub>	L <sub>4</sub>	L <sub>5</sub>
0:	Normal	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
1:	Schmorl's/Scheuerman's with NO oedema	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2:	Schmorl's/Scheuerman's with oedema	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3:	Fracture line with oedema	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**Disc tear**

		L <sub>1</sub>	L <sub>2</sub>	L <sub>3</sub>	L <sub>4</sub>	L <sub>5</sub>
0:	Normal	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
1:	Annular tear	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2:	Protrusion	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3:	Extrusion	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**Nerve root**

		L <sub>1</sub>	L <sub>2</sub>	L <sub>3</sub>	L <sub>4</sub>	L <sub>5</sub>
0:	Normal	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
1:	Protrusion, no nerve displacement	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2:	Protrusion with nerve displacement	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3:	Protrusion with nerve compression	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**Disc degeneration**

**L<sub>1</sub> L<sub>2</sub> L<sub>3</sub> L<sub>4</sub> L<sub>5</sub>**

0: Normal height; homogeneous bright white;  
clear nucleus & annulus;  
hyperintense, isointense to cerebral spinal  
fluid signal

1: Normal height; inhomogenous with or  
without horizontal bands; clear nucleus  
& annulus; hyperintense, isointense to  
cerebral spinal fluid

2: Normal to slightly decreased height;  
inhomogenous grey structure;  
unclear nucleus & annulus;  
intermediate signal intensity

3: Normal to moderate decreased height;  
inhomogenous grey to black structure;  
nucleus & annulus distinction lost;  
intermediate to hypointense signal

4: Collapsed disc space; inhomogenous black  
structure; nucleus & annulus distinction lost;  
hypointense signal

**Pars**

				L <sub>1</sub>	L <sub>2</sub>	L <sub>3</sub>	L <sub>4</sub>	L <sub>5</sub>
0:	Normal	R	L	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
1:	Bone oedema	R	L	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2:	Bone oedema plus fracture	R	L	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3:	Severe defect	R	L	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**Facet**

				L <sub>1/2</sub>	L <sub>2/3</sub>	L <sub>3/4</sub>	L <sub>4/5</sub>	L <sub>5/S<sub>1</sub></sub>
0:	Normal	R	L	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
1:	Effusion	R	L	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2:	Facet hypertrophy and effusion	R	L	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3:	Above plus cyst	R	L	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

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## APPENDIX K: ADDITIONAL TABLES &amp; FIGURES

**Chapter 3 Additional Tables****Table K1: Mean and standard deviation results for the Oswestry questionnaire over time for the intervention and control groups.**

	Intervention (n=24)	Control (n=20)	Total (n=44)
Pre-season score	21.7 ± 7.2	24.8 ± 8.2	23.1 ± 7.8
Post-intervention score	19.1 ± 6.2	21.8 ± 5.1	20.4 ± 5.9
Post-season score	19.3 ± 5.3	19.9 ± 6.2	19.6 ± 5.7

**Table K2: Intervention and control Oswestry results over time in those with and without LBP**

	Intervention (n=24)		Control (n=20)	
	LBP (n=15)	NLBP (n=9)	LBP (n=12)	NLBP (n=8)
Pre-season score	21.7 ± 8.1	21.5 ± 6.0	27.0 ± 9.2	21.4 ± 5.3
Post-intervention score	18.6 ± 6.9	20.0 ± 5.2	22.0 ± 5.4	21.6 ± 5.1
Post-season score	18.4 ± 4.2	20.9 ± 6.8	18.2 ± 2.6	22.5 ± 9.0

**Abbreviations: LBP, lower back pain; NLBP, no lower back pain**

**Table K3: Intervention and control group Oswestry results over time divided by discipline**

	Fast bowlers (n=18)		Spin bowlers (n=12)		Batsmen (n=14)	
	Intervention (n=8)	Control (n=10)	Intervention (n=7)	Control (n=5)	Intervention (n=9)	Control (n=5)
Pre-season	19.9 ± 4.3	22.1 ± 4.7	23.2 ± 5.4	22.4 ± 4.3	22.1 ± 10.3	32.4 ± 12.4
Post-intervention	18.4 ± 5.6	20.0 ± 3.7	19.3 ± 3.0	20.6 ± 4.7	19.7 ± 8.7	26.7 ± 5.7
Post-season	17.4 ± 2.6	18.9 ± 3.8	22.9 ± 6.6	20.9 ± 10.4	18.2 ± 5.1	20.9 ± 6.2

**Chapter 4 Additional Tables & Figures****Table K4: Total abdominal wall muscle thickness (mm) separated by cricketing disciplines**

Side	Fast bowlers (n=18)	Spin bowlers (n=13)	Batsmen (n=14)
Dom	24.3 ± 4.0	25.4 ± 4.9	23.8 ± 4.6
ND	26.1 ± 4.1	26.0 ± 3.8	25.3 ± 3.9

**Abbreviations: Dom, dominant side; ND, non-dominant side**

Table K5: Relative abdominal muscle thickness (%) separated by cricketing disciplines

Muscle	Side	Fast bowlers (n=18)	Spin bowlers (n=13)	Batsmen (n=14)	Total group (n=45)
OE	Dom	32.6 ± 4.5	33.6 ± 6.6	35.2 ± 4.4	33.7 ± 5.2
	ND	30.3 ± 4.7	31.9 ± 3.5	34.0 ± 3.7	31.9 ± 4.3
OI	Dom	48.5 ± 4.5	48.1 ± 5.3	47.2 ± 3.6	48.0 ± 4.4
	ND	51.3 ± 4.8	50.0 ± 4.1	48.4 ± 4.4	50.0 ± 4.6
TrA	Dom	18.8 ± 2.5	18.3 ± 3.1	17.6 ± 2.9	18.3 ± 2.8
	ND	18.3 ± 2.4	18.1 ± 3.8	17.7 ± 2.9	18.1 ± 2.9

Abbreviations: OE, external oblique; OI, internal oblique; TrA, transverse abdominis; Dom, dominant side; ND, non-dominant side

Table K6: Change in muscle thickness during abdominal hollowing ( $\Delta$ mm) separated by cricketing disciplines

Muscle	Side	Fast bowlers (n=18)	Spin bowlers (n=13)	Batsmen (n=14)	Total group (n=45)
OI	Dom	1.1 ± 1.2	0.7 ± 0.9	0.5 ± 0.8	0.8 ± 1.0
	ND	1.1 ± 1.0	0.7 ± 0.8	1.0 ± 0.8	0.9 ± 0.9
TrA	Dom	2.1 ± 0.8	1.3 ± 1.2	1.6 ± 1.1	1.7 ± 1.0
	ND	2.0 ± 1.3	1.2 ± 1.1	1.7 ± 1.3	1.7 ± 1.3

Abbreviations: OI, internal oblique; TrA, transverse abdominis; LBP, lower back pain; Dom, dominant side; ND, non-dominant side

Table K7: Absolute abdominal muscle thickness (mm) in cricketers with and without lower back pain

Muscle	Side	LBP (n=27)	NLBP (n=18)
OE	Dom	8.3 ± 2.4	8.2 ± 2.0
	ND	7.9 ± 1.7	8.7 ± 1.8
OI	Dom	11.8 ± 2.0	11.5 ± 2.2
	ND	12.7 ± 2.1	13.3 ± 2.5
TrA	Dom	4.6 ± 1.0	4.3 ± 0.9
	ND	4.5 ± 1.1	4.9 ± 1.0

Abbreviations: OE, external oblique; OI, internal oblique; TrA, transverse abdominis; LBP, lower back pain; NLBP, no lower back pain; Dom, dominant side; ND, non-dominant side

**Table K8: Relative abdominal muscle thickness (%) in cricketers with and without lower back pain**

Muscle	Side	LBP (n=27)	NLBP (n=18)	Total group (n=45)
OE	Dom	33.4 ± 5.0	34.2 ± 5.5	33.7 ± 5.2
	ND	31.6 ± 4.1	32.4 ± 4.6	31.9 ± 4.3
OI	Dom	48.1 ± 4.2	47.8 ± 4.8	48.0 ± 4.4
	ND	50.6 ± 3.8	49.2 ± 5.6	50.0 ± 4.6
TrA	Dom	18.5 ± 2.7	18.0 ± 3.1	18.3 ± 2.8
	ND	17.8 ± 2.8	18.4 ± 3.2	18.1 ± 2.9

**Abbreviations:** OE, external oblique; OI, internal oblique; TrA, transverse abdominis; LBP, lower back pain; NLBP, no lower back pain; Dom, dominant side; ND, non-dominant side

Table K9 shows the absolute abdominal muscle thickness (mm) for cricketers with and without lower back pain separated by discipline. There was a significant interaction for abdominal muscle thickness, discipline, pain and side ( $F_{1,16}=8.26$ ;  $p=0.01$ ). Thus the OI muscle on the non-dominant side was significantly thicker compared to the dominant side in fast bowlers without LBP ( $p=0.004$ ). Once again, due to the few fast bowlers without lower back pain ( $n=4$ ), the significance demonstrated may indicate a false positive (possible Type I error) and the interpretation of this finding should be treated with caution.

**Table K9: Absolute abdominal muscle thickness (mm) in cricketers by discipline, with and without lower back pain**

Muscle	Side	Fast bowlers (n = 18)		Spin Bowlers (n = 13)		Batsmen (n = 14)	
		LBP (n = 14)	NLBP (n = 4)	LBP (n = 8)	NLBP (n = 5)	LBP (n = 5)	NLBP (n = 9)
OE	Dom	8.2 ± 1.7	7.3 ± 2.4	8.8 ± 3.7	8.4 ± 1.2	8.0 ± 2.1	8.6 ± 2.3
	ND	7.6 ± 1.7	9.0 ± 2.1	8.5 ± 1.5	8.1 ± 2.1	8.0 ± 2.1	9.0 ± 1.7
OI *	Dom	12.0 ± 2.0	<b>11.0 ± 2.3</b>	12.2 ± 2.0	12.0 ± 2.0	10.8 ± 2.3	11.4 ± 2.5
	ND	12.9 ± 2.3	<b>15.3 ± 2.9 #</b>	12.7 ± 1.2	13.4 ± 2.7	12.0 ± 2.7	12.3 ± 1.8
TrA	Dom	4.7 ± 1.0	4.1 ± 0.1	4.6 ± 1.2	4.7 ± 1.3	4.1 ± 0.9	4.1 ± 0.8
	ND	4.5 ± 0.9	5.7 ± 0.6	4.6 ± 1.5	5.0 ± 1.1	4.2 ± 1.2	4.6 ± 0.9

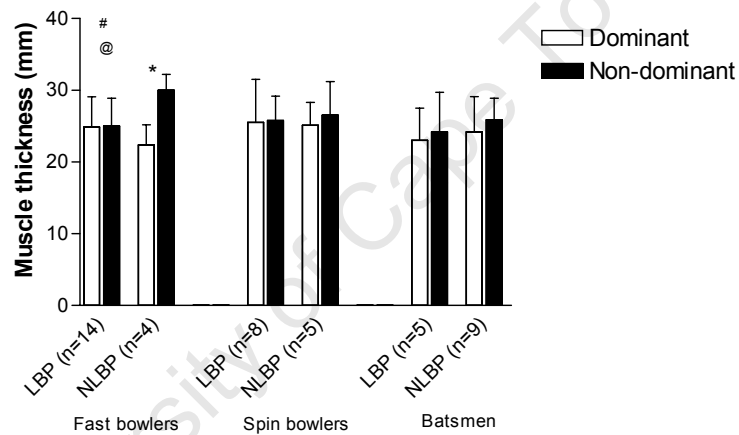
**Abbreviations:** OE, external oblique; OI, internal oblique; TrA, transverse abdominis; LBP, lower back pain; NLBP, no lower back pain; Dom, dominant side; ND, non-dominant side

\* Dominant v non-dominant:  $p=0.001$

# Dominant v non-dominant in fast bowlers with and without lower back pain:  $p=0.004$

Figure K1 shows the total abdominal wall muscle thickness for cricketers with and without lower back pain separated by discipline. There was a significant interaction for the total abdominal muscle thickness, lower back pain and side in the different

cricketing disciplines ( $F_{2,39}=4.32$ ;  $p=0.02$ ). Thus fast bowlers without lower back pain had a significantly thicker abdominal wall on the non-dominant side ( $30 \pm 2.2\text{mm}$ ) compared to the dominant side ( $22.4 \pm 2.8\text{mm}$ ) ( $p=0.0002$ ). This pattern was, however, not present in the spin bowlers and batsmen. As a result, the adaptation in fast bowlers was different from spin bowlers ( $p=0.016$ ) and batsmen ( $p=0.005$ ), so that spin bowlers and batsmen without pain did not show asymmetry. However, the significance of the results for fast bowlers without lower back pain should be treated with caution (possible Type I error) given the fact that there were only four fast bowlers without lower back pain. Therefore, this significance may in fact represent a false positive. Furthermore, the sample groups for the spin bowlers without lower back pain ( $n=5$ ) and the batsmen with lower back pain ( $n=5$ ) are also small, therefore overall the results need to be treated with circumspect.



**Figure K1: Total muscle thickness (OE, OI and TrA) by discipline in cricketers with and without lower back pain**

**Abbreviations: LBP, lower back pain; NLBP, no lower back pain**

**\* Fast bowlers dominant v non-dominant NLBP  $p = 0.0002$ ; # Fast bowlers v spin bowlers  $p = 0.016$ ;**

**@ Fast bowlers v batsmen  $p = 0.005$**

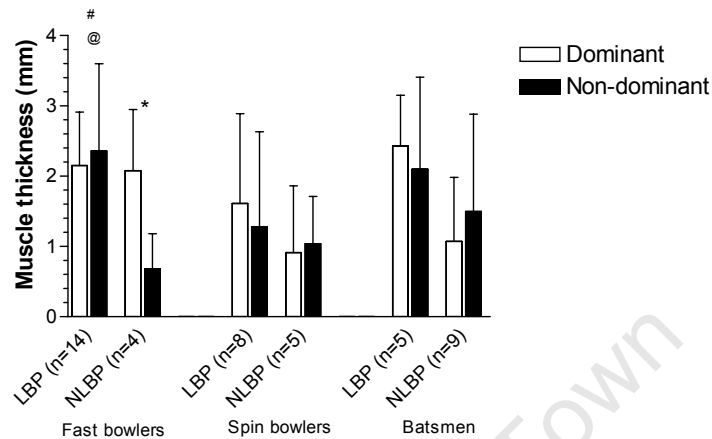
**Table K10: Relative abdominal muscle thickness (%) across cricketing disciplines with and without lower back pain**

Muscle	Side	Fast bowlers (n = 18)		Spin Bowlers (n = 13)		Batsmen (n = 14)	
		LBP (n = 14)	NLBP (n = 4)	LBP (n = 8)	NLBP Pain (n = 5)	LBP (n = 5)	NLBP Pain (n = 9)
OE	Dom	32.7 ± 3.2	32.2 ± 8.5	33.6 ± 7.9	33.5 ± 4.7	34.8 ± 4.3	35.4 ± 4.7
	ND	30.5 ± 4.5	29.9 ± 6.0	32.9 ± 3.2	30.4 ± 3.7	33.0 ± 3.8	34.5 ± 3.7
OI	Dom	48.3 ± 2.8	49.3 ± 8.8	48.4 ± 6.4	47.7 ± 3.3	47.2 ± 4.2	47.2 ± 3.5
	ND	51.4 ± 4.1	51.1 ± 7.6	49.5 ± 3.3	50.7 ± 5.5	49.8 ± 3.7	47.6 ± 4.8
TrA	Dom	18.9 ± 2.6	18.5 ± 2.4	18.0 ± 2.8	18.9 ± 4.0	18.1 ± 3.0	17.4 ± 3.0
	ND	18.1 ± 2.3	19.0 ± 3.0	17.6 ± 3.9	18.9 ± 3.7	17.3 ± 2.5	17.9 ± 3.2

**Abbreviations: OE, external oblique; OI, internal oblique; TrA, transverse abdominis; LBP, lower back pain; NLBP, no lower back pain; Dom, dominant side; ND, non-dominant side**

Figure K2 shows change in TrA muscle thickness during abdominal hollowing in cricketers with and without lower back pain, separated by discipline. There was a significant interaction for change in TrA muscle thickness during abdominal hollowing between discipline, lower back pain and side ( $F_{2,39}=4.29$ ;  $p=0.021$ ). As the data were too complex for post-hoc testing, further analysis was performed using an ANOVA and excluding one discipline at a time. This analysis showed that there was a significant interaction for change in TrA muscle thickness between fast bowlers and spin bowlers ( $F_{1,28}=6.87$ ;  $p=0.014$ ) and fast bowlers and batsmen ( $F_{1,27}=8.65$ ;  $p=0.007$ ). Further analysis showed a significant interaction between fast bowlers with and without lower back pain ( $F_{1,16}=13.65$ ;  $p=0.002$ ). A Tukey's post-hoc test indicated that change in TrA thickness during abdominal hollowing was greater on the dominant side ( $2.1 \pm 0.9\text{mm}$ ) than on the non-dominant side ( $0.7 \pm 0.5\text{mm}$ ) in pain-free fast bowlers ( $p=0.011$ ). Therefore, the pain free fast bowlers were more asymmetrical with respect to TrA muscle function, compared to the fast bowlers with lower back pain. Furthermore, change in thickness of non-dominant TrA was greater in fast bowlers with lower back pain compared to fast bowlers without lower back pain ( $p=0.028$ ). By contrast, there was a more symmetrical change in TrA muscle thickness during abdominal hollowing in fast bowlers with lower back pain as well as

in spin bowlers and batsmen with and without lower back pain. However, the significance of the results for fast bowlers without lower back pain should be treated with caution (possible Type I error) given the fact that there were only four fast bowlers without lower pain, showing a false positive.



**Figure K2: Muscle thickness change from rest to hollowing in TrA by discipline in cricketers with and without lower back pain**

**Abbreviations: LBP, lower back pain; NLBP, no lower back pain**

**\* Fast bowlers dominant v non-dominant NLBP  $p = 0.011$ ; # Fast bowlers v spin bowlers  $p = 0.014$**

**@ Fast bowlers v batsmen  $p = 0.007$**

**Table K11: Posterior lumbar muscle percentage difference (%) between dominant and non-dominant sides (expressed as a percentage of the dominant side)**

Muscle	Fast Bowlers (n=18)	Spin Bowlers (n=13)	Batsmen (n=15)	Total (n=46)
Psoas	0.30 ± 4.53	2.02 ± 8.71	-2.62 ± 5.57	-0.17 ± 6.41
Quadratus Lumborum	4.46 ± 15.28	-0.94 ± 11.43	-5.55 ± 16.07	-0.33 ± 14.89
Multifidus	-2.45 ± 17.67	-2.68 ± 12.51	-3.65 ± 21.58	-2.91 ± 17.46
Longissimus	7.00 ± 13.22	0.80 ± 11.74	3.20 ± 16.28	4.01 ± 13.86
Iliocostalis	-3.50 ± 11.97	0.34 ± 11.00	5.46 ± 7.49	0.51 ± 10.88

Table K12: Absolute cross-sectional area of posterior lumbar muscles separated by cricketing discipline

Muscle	Side	Fast bowlers	Spin Bowlers	Batsmen	Total
		(n = 18)	(n = 13)	(n = 15)	(n=46)
Psoas	Dom	20.7 ± 3.0	20.1 ± 3.4	19.3 ± 3.4	20.1 ± 3.2
	ND	20.6 ± 3.1	19.5 ± 2.4	19.9 ± 3.9	20.1 ± 3.2
Quadratus Lumborum	Dom	8.6 ± 1.5	8.4 ± 1.1	8.1 ± 2.2	8.4 ± 1.7
	ND	8.1 ± 1.7	8.5 ± 1.4	8.5 ± 2.4	8.3 ± 1.8
Multifidus	Dom	6.8 ± 1.5	7.0 ± 1.6	6.7 ± 1.2	6.8 ± 1.4
	ND	6.9 ± 1.6	7.2 ± 1.6	7.0 ± 1.8	7.0 ± 1.6
Longissimus	Dom	7.0 ± 1.3	7.2 ± 1.0	7.0 ± 1.6	7.1 ± 1.3
	ND	6.5 ± 1.3	7.2 ± 1.5	6.7 ± 1.2	6.7 ± 1.3
Iliocostalis	Dom	13.0 ± 3.2	12.8 ± 3.1	12.5 ± 2.5	12.8 ± 2.9
	ND	13.4 ± 3.0	12.7 ± 3.1	11.8 ± 2.5	12.7 ± 2.9

Abbreviations: Dom, dominant side; ND, non-dominant side

Table K13: Posterior lumbar muscle cross-sectional area (cm<sup>2</sup>) for groups with and without lower back pain

Muscle	Side	Fast bowlers (n = 18)		Spin Bowlers (n = 13)		Batsmen (n = 15)	
		LBP	NLBP	LBP	NLBP	LBP	NLBP
		(n = 14)	(n = 4)	(n = 8)	(n = 4)	(n = 6)	(n = 9)
Psoas	Dom	20.1 ± 3.1	22.6 ± 1.6	19.7 ± 2.4	20.7 ± 4.9	20.0 ± 4.4	18.9 ± 2.8
	ND	20.0 ± 3.2	22.8 ± 2.0	19.4 ± 2.4	19.6 ± 2.4	20.8 ± 4.7	19.2 ± 3.4
Quadratus Lumborum	Dom	8.7 ± 1.6	8.0 ± 1.2	8.4 ± 1.3	8.2 ± 0.9	9.3 ± 2.4	7.3 ± 1.7 <sup>s</sup>
	ND	8.3 ± 1.8	7.4 ± 1.2	8.2 ± 1.4	8.8 ± 1.4	9.4 ± 1.9	7.9 ± 2.6
Multifidus	Dom	6.7 ± 1.6	7.0 ± 1.0	6.8 ± 1.9	7.3 ± 1.0	7.4 ± 1.2	6.3 ± 1.0
	ND	7.0 ± 1.6	6.4 ± 1.4	7.1 ± 2.0	7.3 ± 0.8	7.4 ± 2.1	6.7 ± 1.6
Longissimus	Dom	6.9 ± 1.4	7.3 ± 0.7	7.4 ± 1.1	7.0 ± 0.8	7.4 ± 1.9	6.8 ± 1.4
	ND	6.4 ± 1.4	6.4 ± 0.9	7.4 ± 1.8	6.9 ± 0.4	7.0 ± 1.4	6.4 ± 1.0
Iliocostalis	Dom	12.4 ± 3.2	14.4 ± 2.2	12.3 ± 3.6	13.6 ± 2.2	11.9 ± 1.3	12.8 ± 3.1
	ND	12.8 ± 3.2	14.4 ± 1.0	11.6 ± 2.8	14.6 ± 2.8	11.2 ± 1.3	12.2 ± 3.1

Abbreviations: LBP, lower back pain; NLBP, no lower back pain; Dom, dominant side; ND, non-dominant side

**Table K14: Percentage difference (%) between the dominant and non-dominant sides in cricketers with and without lower back pain**

Muscle	Fast bowlers (n = 18)		Spin Bowlers (n = 13)		Batsmen (n = 15)	
	LBP (n = 14)	NLBP (n = 4)	LBP (n = 8)	NLBP (n = 4)	LBP (n = 6)	NLBP (n = 9)
Psoas	0.7 ± 4.7	-0.9 ± 4.1	1.2 ± 7.1	3.3 ± 11.6	-4.2 ± 4.9	-1.6 ± 4.4
Quadratus Lumborum	3.6 ± 16.7	7.6 ± 9.6	2.9 ± 10.0	-7.0 ± 12.0	-2.7 ± 12.4	-7.4 ± 18.6
Multifidus	-4.4 ± 18.1	8.1 ± 12.7	-3.9 ± 12.1	-0.7 ± 14.3	1.7 ± 14.2	-7.2 ± 24.4
Longissimus	4.7 ± 11.3	11.6 ± 20.0	0.3 ± 14.6	1.6 ± 6.3	3.2 ± 17.4	3.2 ± 16.6
Iliocostalis	-4.1 ± 12.8	-1.4 ± 9.9	4.0 ± 9.2	-7.1 ± 10.2	6.2 ± 6.3	4.0 ± 8.4

*Abbreviations: LBP, lower back pain; NLBP, no lower back pain*

### **Chapter 5 Additional Tables**

*Note that: Negative values in the tables below indicate an increase in muscle thickness from pre to post-intervention and post-season*

**Table K15: Percentage change (%) in absolute OE and TrA resting muscle thickness comparing the intervention and control groups during the intervention period**

Testing session	Muscle	Side	Intervention (n=21)	Control (n=18)
Pre-intervention - Post-intervention	OE	Dom	-11.4 ± 29.7	1.6 ± 30.2
		ND	4.8 ± 24.7	-10.4 ± 30.0
	TrA	Dom	-2.9 ± 22.2	-1.8 ± 28.6
		ND	5.9 ± 19.6	-5.5 ± 33.9
Pre-intervention - Post-season	OE	Dom	0.2 ± 32.9	12.4 ± 30.7
		ND	23.0 ± 18.2	15.0 ± 28.9
	TrA	Dom	-7.3 ± 27.5	-2.7 ± 41.7
		ND	-4.9 ± 21.9	-5.7 ± 41.0
Post-intervention - Post-season	OE	Dom	8.7 ± 22.7	9.1 ± 21.7
		ND	-80.2 ± 51.5	-39.8 ± 30.1
	TrA	Dom	-5.3 ± 20.2	-1.8 ± 21.2
		ND	-12.8 ± 17.7	-1.2 ± 20.0

*Abbreviations: OE, external oblique; TrA, transverse abdominis; Dom, dominant; ND, non-dominant*

**Table K16: Change in OE and TrA percentage difference (%) in muscle thickness comparing the intervention and control groups during the intervention period**

Testing session	Muscle	Intervention (n=21)	Control (n=18)
Pre-intervention - Post-intervention	OE	-17.9 ± 47.4	12.2 ± 48.1
	TrA	-8.9 ± 22.8	4.8 ± 31.5
Pre-intervention - Post-season	OE	-23.1 ± 46.3	-3.1 ± 51.6
	TrA	-0.5 ± 27.1	3.2 ± 20.9
Post-intervention - Post-season	OE	-5.3 ± 26.5	-15.3 ± 33.8
	TrA	8.5 ± 23.3	-1.6 ± 26.0

**Abbreviations: OE, external oblique; TrA, transverse abdominis**

**Table K17: Percentage change (%) in relative resting muscle thickness comparing the intervention and control groups during the intervention period**

Testing session	Muscle	Side	Intervention (n=21)	Control (n=18)
Pre-intervention - Post-intervention	OE	Dom	-2.9 ± 21.3	-1.1 ± 22.7
		ND	2.7 ± 16.2	-5.3 ± 18.8
	OI	Dom	-1.8 ± 8.2	-0.7 ± 12.6
		ND	-4.3 ± 13.9	1.9 ± 11.2
	TrA	Dom	3.0 ± 23.1	-6.1 ± 24.6
		ND	2.6 ± 15.1	-0.7 ± 25.1
Pre-intervention - Post-season	OE	Dom	5.7 ± 16.4	6.1 ± 21.7
		ND	17.9 ± 18.8	10.7 ± 17.1
	OI	Dom	-3.8 ± 6.8	-3.4 ± 13.2
		ND	-9.3 ± 13.3	-5.3 ± 13.4
	TrA	Dom	-5.3 ± 28.1	-10.7 ± 29.1
		ND	-10.9 ± 16.1	-11.2 ± 24.3
Post-intervention - Post-season	OE	Dom	6.5 ± 16.1	5.5 ± 19.4
		ND	14.6 ± 18.8	14.6 ± 11.6
	OI	Dom	-2.4 ± 7.6	-3.3 ± 11.1
		ND	-5.5 ± 11.6	-7.4 ± 8.8
	TrA	Dom	-9.5 ± 20.8	-7.1 ± 23.6
		ND	-15.0 ± 16.4	-12.6 ± 18.0

**Abbreviations: OE, external oblique; OI, internal oblique; TrA, transverse abdominis; Dom, dominant; ND, non-dominant**

**Table K18: Percentage change (%) in absolute resting muscle thickness across cricketing disciplines during the intervention period**

Testing session	Muscle	Side	Fast Bowlers (n=17)		Spin Bowlers (n=11)		Batsmen (n=11)	
			Intervention (n=8)	Control (n=9)	Intervention (n=7)	Control (n=4)	Intervention (n=6)	Control (n=5)
Pre-intervention - Post-intervention	OE	Dom	-21.6 ± 30.1	-0.1 ± 33.3	-0.8 ± 28.5	7.6 ± 34.5	-10.1 ± 31.0	0.0 ± 26.9
		ND	-4.1 ± 18.2	-8.5 ± 16.8	10.1 ± 22.7	-21.1 ± 5.7	10.6 ± 33.9	-5.1 ± 55.4
	OI	Dom	-9.5 ± 12.6	0.8 ± 12.5	-7.6 ± 16.2	2.1 ± 17.7	-10.6 ± 18.1	11.5 ± 11.9
		ND	1.3 ± 9.3	-8.7 ± 17.0	5.2 ± 8.6	1.3 ± 12.0	-6.1 ± 13.3	8.0 ± 13.4
	TrA	Dom	9.2 ± 13.2	-1.8 ± 21.7	-20.5 ± 26.7	14.3 ± 16.2	1.5 ± 13.3	-14.8 ± 43.1
		ND	9.8 ± 12.5	3.5 ± 18.3	0.2 ± 25.1	1.2 ± 34.7	7.2 ± 22.2	-27.0 ± 50.2
Pre-intervention - Post-season	OE	Dom	-4.4 ± 26.5	2.7 ± 37.6	7.4 ± 27.6	25.4 ± 18.1	-2.2 ± 48.1	19.7 ± 22.2
		ND	19.5 ± 17.2	20.8 ± 19.9	23.5 ± 23.6	2.8 ± 7.3	27.2 ± 14.3	14.3 ± 49.8
	OI	Dom	-4.3 ± 15.5	2.8 ± 11.6	-1.5 ± 18.0	5.6 ± 30.1	-20.0 ± 26.3	10.4 ± 4.0
		ND	-1.9 ± 25.2	3.6 ± 17.1	-1.7 ± 17.8	-6.1 ± 16.0	-6.7 ± 15.7	7.1 ± 17.3
	TrA	Dom	13.5 ± 13.2	5.6 ± 11.9	-22.9 ± 33.3	6.6 ± 18.9	-16.9 ± 17.7	-25.1 ± 77.2
		ND	-3.8 ± 28.7	6.3 ± 12.5	-9.5 ± 18.9	2.4 ± 34.5	-1.0 ± 17.2	-33.7 ± 67.6
Post-intervention - Post-season	OE	Dom	11.9 ± 19.4	2.0 ± 22.8	5.3 ± 27.5	13.8 ± 21.2	8.6 ± 24.3	18.0 ± 20.0
		ND	-71.9 ± 27.7	-42.8 ± 26.0	-87.4 ± 69.6	-32.8 ± 32.7	-82.7 ± 59.5	-39.8 ± 40.3
	OI	Dom	4.1 ± 14.0	0.6 ± 17.9	5.7 ± 7.1	4.2 ± 22.0	-9.6 ± 22.0	-2.5 ± 12.6
		ND	-3.6 ± 24.2	11.0 ± 9.1	-7.9 ± 19.2	-7.9 ± 14.9	-1.3 ± 15.5	-1.8 ± 17.5
	TrA	Dom	3.0 ± 19.8	3.9 ± 20.1	-2.5 ± 17.9	-9.1 ± 10.7	-19.7 ± 18.1	-6.1 ± 29.5
		ND	-14.2 ± 20.7	0.8 ± 16.2	-12.0 ± 16.1	-2.0 ± 33.3	-12.0 ± 18.2	-4.2 ± 18.0

**Abbreviations: OE, external oblique; OI, internal oblique; TrA, transverse abdominis; Dom, dominant; ND, non-dominant**

**Table K19: Percentage change (%) in resting relative muscle thickness across cricketing disciplines during the intervention period**

Testing session	Muscle	Side	Fast Bowlers (n=17)		Spin Bowlers (n=11)		Batsmen (n=11)	
			Intervention (n=8)	Control (n=9)	Intervention (n=7)	Control (n=4)	Intervention (n=6)	Control (n=5)
Pre-intervention - Post-intervention	OE	Dom	-11.5 ± 21.5	-1.1 ± 27.7	5.6 ± 22.2	2.8 ± 20.0	-1.5 ± 18.8	-4.2 ± 18.1
		ND	-4.8 ± 8.3	-2.9 ± 12.1	5.1 ± 14.8	-16.2 ± 18.3	9.8 ± 23.1	-0.8 ± 28.2
	OI	Dom	-1.2 ± 10.4	-1.6 ± 13.4	-1.2 ± 6.9	-7.1 ± 7.6	-3.4 ± 7.7	6.0 ± 13.2
		ND	-0.2 ± 4.6	-2.6 ± 8.2	-1.9 ± 11.3	6.5 ± 3.8	-12.4 ± 22.0	6.2 ± 17.2
	TrA	Dom	15.8 ± 12.7	-3.9 ± 21.4	-14.3 ± 25.8	3.8 ± 27.7	6.0 ± 20.1	-17.8 ± 28.4
Pre-intervention - Post-season	OE	Dom	-3.4 ± 14.5	0.6 ± 24.7	10.3 ± 11.7	10.4 ± 25.5	12.3 ± 20.3	12.6 ± 12.2
		ND	13.7 ± 19.6	12.3 ± 14.9	19.4 ± 23.6	2.1 ± 14.6	21.7 ± 12.6	14.7 ± 23.2
	OI	Dom	-4.2 ± 7.0	-2.2 ± 10.7	-0.2 ± 5.9	-9.4 ± 17.1	-7.6 ± 6.3	-0.7 ± 15.7
		ND	-6.7 ± 10.3	-7.6 ± 10.7	-6.9 ± 11.6	-5.4 ± 2.2	-15.4 ± 18.3	-1.2 ± 22.3
	TrA	Dom	12.4 ± 14.8	0.1 ± 15.3	-21.1 ± 26.1	-10.4 ± 10.7	-10.5 ± 33.8	-30.1 ± 48.2
Post-intervention - Post-season	OE	Dom	5.5 ± 14.4	0.0 ± 19.1	1.8 ± 20.5	7.0 ± 20.0	13.4 ± 12.3	14.1 ± 20.1
		ND	17.3 ± 19.0	14.5 ± 13.3	15.0 ± 23.2	15.5 ± 5.8	10.5 ± 15.2	14.0 ± 13.9
	OI	Dom	-3.6 ± 10.1	-1.5 ± 10.1	0.7 ± 6.0	-2.4 ± 16.6	-4.3 ± 4.9	-7.2 ± 9.2
		ND	-6.9 ± 13.2	-5.1 ± 9.7	-5.5 ± 12.7	-12.9 ± 5.3	-3.6 ± 9.8	-7.3 ± 8.8
	TrA	Dom	-6.1 ± 24.5	-0.3 ± 25.5	-7.6 ± 16.2	-19.3 ± 21.2	-16.3 ± 22.5	-9.7 ± 21.4

**Abbreviations: OE, external oblique; OI, internal oblique; TrA, transverse abdominis; Dom, dominant; ND, non-dominant**

**Table K20: Change in percentage difference (%) between dominant and non-dominant resting absolute muscle thickness across cricketing disciplines during the intervention period**

Testing session	Muscle	Fast Bowlers (n=17)		Spin Bowlers (n=11)		Batsmen (n=11)	
		Intervention (n=8)	Control (n=9)	Intervention (n=7)	Control (n=4)	Intervention (n=6)	Control (n=5)
Pre-intervention - Post-intervention	OE	-15.3 ± 26.9	8.3 ± 51.0	-14.9 ± 63.6	37.1 ± 52.1	-24.8 ± 55.0	-0.6 ± 41.9
	OI	-12.7 ± 17.2	10.1 ± 20.7	-11.7 ± 13.8	-0.4 ± 18.1	-3.0 ± 22.9	4.6 ± 10.3
	TrA	-2.5 ± 20.0	-5.8 ± 19.0	-16.9 ± 28.6	16.8 ± 53.9	-8.1 ± 19.8	14.2 ± 28.4
Pre-intervention - Post-season	OE	-24.8 ± 28.1	-18.6 ± 61.6	-18.9 ± 60.6	27.8 ± 28.5	-25.9 ± 55.0	-0.1 ± 40.4
	OI	-5.1 ± 27.9	-0.9 ± 17.2	0.8 ± 11.1	15.9 ± 33.7	-10.8 ± 13.6	3.1 ± 19.8
	TrA	19.1 ± 31.4	-1.1 ± 16.1	-9.1 ± 18.2	2.3 ± 37.8	-16.4 ± 12.2	11.5 ± 11.5
Post-intervention - Post-season	OE	-9.5 ± 18.9	-26.8 ± 28.9	-4.0 ± 36.7	-9.3 ± 37.3	-1.2 ± 25.2	0.5 ± 38.4
	OI	7.7 ± 20.0	-11.0 ± 12.9	12.6 ± 15.6	16.3 ± 20.1	-7.8 ± 12.5	-1.5 ± 25.6
	TrA	21.6 ± 23.2	4.7 ± 18.3	7.9 ± 21.8	-14.6 ± 41.1	-8.3 ± 15.3	-2.7 ± 25.9

**Abbreviations: OE, external oblique; OI, internal oblique; TrA, transverse abdominis**

**Table K21: Percentage change (%) in absolute resting total abdominal wall muscle thickness in cricketers with and without lower back pain during the intervention period**

Testing session	Side	Intervention (n=21)		Control (n=18)	
		LBP (n=3)	NLBP (n=18)	LBP (n=14)	NLBP (n=4)
Pre-intervention - Post-intervention	Dom	-17.8 ± 9.3	-5.6 ± 12.6	2.4 ± 13.1	9.2 ± 13.0
	ND	0.6 ± 8.9	4.0 ± 13.4	-4.4 ± 14.0	-3.5 ± 22.6
Pre-intervention - Post-season	Dom	-9.9 ± 10.7	-3.1 ± 21.0	6.8 ± 16.9	11.9 ± 10.4
	ND	12.1 ± 7.2	4.7 ± 12.1	6.5 ± 18.8	5.5 ± 15.5
Post-intervention - Post-season	Dom	6.6 ± 7.8	2.3 ± 15.2	4.4 ± 11.2	2.3 ± 9.4
	ND	11.4 ± 4.1	-0.4 ± 14.1	10.6 ± 12.1	7.9 ± 5.4

**Abbreviations: LBP, lower back pain; NLBP, no lower back pain; Dom, dominant side; ND, non-dominant side**

**Table K22: Percentage change (%) in absolute resting abdominal muscle thickness in cricketers with and without lower back pain during the intervention period**

Testing session	Muscle	Side	Intervention (n=21)		Control (n=18)	
			LBP (n=3)	NLBP (n=18)	LBP (n=14)	NLBP (n=4)
Pre-intervention - Post-intervention	OE	Dom	-38.0 ± 17.7	-7.0 ± 29.3	-2.4 ± 32.8	15.9 ± 13.2
		ND	2.5 ± 27.8	5.2 ± 25.0	-9.4 ± 31.9	-13.8 ± 25.5
	OI	Dom	-11.6 ± 15.1	-8.8 ± 15.1	4.9 ± 12.3	1.0 ± 19.3
		ND	-3.1 ± 18.8	1.1 ± 9.7	-0.8 ± 12.3	-5.3 ± 28.0
	TrA	Dom	-4.2 ± 8.6	-2.7 ± 23.9	-7.1 ± 30.0	16.5 ± 11.7
		ND	5.9 ± 7.4	5.9 ± 21.1	-10.5 ± 35.7	12.1 ± 21.8
Pre-intervention - Post-season	OE	Dom	-11.0 ± 41.3	2.0 ± 32.3	9.7 ± 33.5	21.9 ± 18.3
		ND	29.9 ± 4.6	21.9 ± 19.4	15.8 ± 31.6	12.0 ± 19.7
	OI	Dom	-10.8 ± 11.5	-7.3 ± 21.8	5.8 ± 16.2	4.6 ± 14.2
		ND	4.1 ± 11.1	-4.4 ± 20.6	3.0 ± 15.8	0.2 ± 21.8
	TrA	Dom	-11.5 ± 35.5	-6.6 ± 27.2	-6.9 ± 46.7	12.1 ± 4.8
		ND	0.3 ± 19.2	-5.7 ± 22.8	-8.8 ± 46.0	5.2 ± 11.8
Post-intervention - Post-season	OE	Dom	21.1 ± 18.6	6.7 ± 23.1	9.5 ± 23.9	7.5 ± 13.9
		ND	-54.4 ± 40.9	-84.5 ± 52.8	-38.6 ± 32.1	-43.8 ± 25.2
	OI	Dom	-0.1 ± 12.9	0.9 ± 16.6	0.4 ± 16.2	1.0 ± 21.3
		ND	6.2 ± 7.0	-6.1 ± 20.5	3.2 ± 15.5	3.4 ± 14.1
	TrA	Dom	-7.3 ± 35.8	-4.9 ± 18.1	-0.3 ± 23.1	-6.8 ± 14.5
		ND	-6.2 ± 21.0	-3.9 ± 17.5	1.3 ± 21.4	-10.0 ± 12.6

**Abbreviations: OE, external oblique; OI, internal oblique; TrA, transverse abdominis; LBP, lower back pain; NLBP, no lower back pain; Dom, dominant side; ND, non-dominant side**

**Table K23: Percentage change (%) in relative resting abdominal muscle thickness in cricketers with and without lower back pain during the intervention period**

Testing session	Muscle	Side	Intervention (n=21)		Control (n=18)	
			LBP (n=3)	NLBP (n=18)	LBP (n=14)	NLBP (n=4)
Pre-intervention - Post-intervention	OE	Dom	-17.3 ± 14.4	-0.5 ± 21.6	-3.4 ± 25.0	7.0 ± 10.4
		ND	2.0 ± 24.3	2.8 ± 15.5	-3.8 ± 19.9	-10.6 ± 15.3
	OI	Dom	5.5 ± 6.8	-3.0 ± 8.0	1.5 ± 13.2	-8.3 ± 7.2
		ND	-3.6 ± 15.0	-4.4 ± 14.2	2.6 ± 12.2	-0.8 ± 7.4
	TrA	Dom	11.5 ± 4.6	1.5 ± 24.7	-9.9 ± 26.2	7.5 ± 12.3
		ND	4.8 ± 10.9	2.2 ± 15.9	-5.0 ± 26.2	14.2 ± 14.8
Pre-intervention - Post-season	OE	Dom	0.7 ± 26.7	6.5 ± 15.1	4.4 ± 23.5	11.9 ± 14.7
		ND	19.7 ± 11.4	17.6 ± 20.0	11.7 ± 18.2	7.0 ± 14.0
	OI	Dom	-0.8 ± 3.1	-4.3 ± 7.2	-2.0 ± 14.2	-8.1 ± 8.4
		ND	-8.9 ± 3.8	-9.3 ± 14.4	-5.4 ± 14.9	-5.1 ± 7.3
	TrA	Dom	-4.1 ± 40.7	-5.5 ± 27.0	-13.5 ± 32.1	-0.8 ± 12.9
		ND	-12.7 ± 14.3	-10.6 ± 16.7	-13.9 ± 26.0	-1.7 ± 16.0
Post-intervention - Post-season	OE	Dom	15.9 ± 15.6	5.0 ± 16.0	5.8 ± 20.2	4.3 ± 19.0
		ND	14.9 ± 20.9	14.5 ± 19.1	14.4 ± 11.7	15.4 ± 12.9
	OI	Dom	-6.9 ± 5.0	-1.6 ± 7.8	-4.1 ± 10.8	-0.5 ± 13.6
		ND	-6.2 ± 12.4	-5.4 ± 11.9	-8.2 ± 8.3	-4.7 ± 11.3
	TrA	Dom	-16.2 ± 41.2	-8.4 ± 17.4	-6.3 ± 25.4	-10.1 ± 18.3
		ND	-20.5 ± 28.2	-14.1 ± 14.7	-10.7 ± 19.6	-19.3 ± 9.3

**Abbreviations: OE, external oblique; OI, internal oblique; TrA, transverse abdominis; LBP, lower back pain; NLBP, no lower back pain; Dom, dominant side; ND, non-dominant side**

**Table K24: Change in muscle function during abdominal hollowing in cricketers with and without lower back pain during the intervention period**

Testing session	Muscle	Side	Intervention (n=21)		Control (n=18)	
			LBP (n=3)	NLBP (n=18)	LBP (n=14)	NLBP (n=4)
Pre-intervention - Post-intervention	OI	Dom	-1.3 ± 1.5	-0.2 ± 1.1	0.0 ± 1.5	-0.8 ± 0.4
		ND	0.4 ± 1.9	-0.2 ± 1.6	-0.5 ± 1.9	-1.3 ± 0.9
	TrA	Dom	0.4 ± 1.0	0.1 ± 1.3	-0.6 ± 1.1	0.2 ± 1.0
		ND	-0.6 ± 0.7	-0.3 ± 1.7	-0.4 ± 1.4	0.4 ± 0.8
Pre-intervention - Post-season	OI	Dom	-1.9 ± 1.2	-0.3 ± 1.1	0.1 ± 1.4	0.0 ± 1.1
		ND	0.5 ± 1.6	-0.3 ± 1.1	0.3 ± 0.8	-0.3 ± 1.0
	TrA	Dom	0.4 ± 1.1	0.0 ± 0.9	0.2 ± 1.8	1.0 ± 1.8
		ND	0.2 ± 0.3	0.3 ± 1.1	0.1 ± 1.5	0.7 ± 0.8
Post-intervention - Post-season	OI	Dom	-0.6 ± 1.4	-0.1 ± 1.8	0.0 ± 1.9	0.8 ± 0.8
		ND	0.1 ± 1.9	-0.1 ± 1.9	0.8 ± 1.9	1.0 ± 1.2
	TrA	Dom	0.0 ± 0.7	-0.1 ± 1.3	0.9 ± 1.4	0.8 ± 1.8
		ND	0.7 ± 0.5	0.6 ± 1.31	0.5 ± 1.8	0.3 ± 1.3

**Abbreviations:** OI, internal oblique; TrA, transverse abdominis; LBP, lower back pain; NLBP, no lower back pain; Dom, dominant side; ND, non-dominant side

**Table K25: Change in percentage difference between dominant and non-dominant sides (%) in cricketers with and without lower back pain during the intervention period**

Testing session	Muscle	Intervention (n=21)		Control (n=18)	
		LBP (n=3)	NLBP (n=18)	LBP (n=14)	NLBP (n=4)
Pre-intervention - Post-intervention	OE	-39.3 ± 35.1	-14.3 ± 49.0	5.5 ± 49.4	35.6 ± 40.0
	OI	-10.1 ± 34.2	-9.5 ± 15.1	6.1 ± 16.1	6.5 ± 24.4
	TrA	-10.3 ± 14.9	-8.7 ± 24.2	4.9 ± 35.0	4.5 ± 17.5
Pre-intervention - Post-season	OE	-42.3 ± 29.7	-19.9 ± 48.4	-7.7 ± 57.7	13.0 ± 14.6
	OI	-17.6 ± 25.8	-2.6 ± 18.2	4.0 ± 24.0	3.8 ± 14.7
	TrA	-7.8 ± 19.0	0.8 ± 28.5	2.0 ± 23.5	7.1 ± 7.2
Post-intervention - Post-season	OE	-3.1 ± 32.4	-5.6 ± 26.5	-13.2 ± 36.3	-22.6 ± 25.9
	OI	-7.5 ± 19.8	7.0 ± 17.4	-2.2 ± 22.1	-2.7 ± 17.1
	TrA	2.5 ± 29.1	9.5 ± 23.1	-2.8 ± 29.1	2.6 ± 11.3

**Abbreviations:** OE, external oblique; OI, internal oblique; TrA, transverse abdominis; LBP, lower back pain; NLBP, no lower back pain

**Table K26: Percentage change (%) in posterior muscle cross-sectional area comparing the intervention and control groups pre- and post-season**

Muscle	Side	Intervention (n=8)	Control (n=9)
Psoas	Dom	-0.5 ± 8.2	-4.9 ± 6.0
	ND	-1.5 ± 8.6	-6.1 ± 6.2
Quadratus Lumborum	Dom	-6.0 ± 12.5	0.7 ± 11.9
	ND	-2.0 ± 8.5	-1.1 ± 9.8
Multifidus	Dom	-3.2 ± 10.4	-6.1 ± 8.9
	ND	1.1 ± 16.0	-6.0 ± 12.1
Longissimus	Dom	-2.7 ± 7.9	-1.6 ± 8.2
	ND	-3.8 ± 17.8	-1.4 ± 7.5
Iliocostalis	Dom	-2.1 ± 12.0	-0.7 ± 9.3
	ND	-2.9 ± 9.4	-5.4 ± 9.4

**Abbreviations: Dom, dominant side; ND, non-dominant side**

**Table K27: Change in percentage difference of posterior muscle cross-sectional area between dominant and non-dominant comparing the intervention and control groups pre-intervention verse post-season**

Muscle	Intervention (n=8)	Control (n=9)
Psoas	-0.8 ± 2.5	1.2 ± 6.1
Quadratus Lumborum	-6.5 ± 13.3	-1.9 ± 12.2
Multifidus	-5.9 ± 21.5	-3.5 ± 8.7
Longissimus	-5.9 ± 20.6	0.01 ± 7.2
Iliocostalis	0.7 ± 7.8	3.1 ± 9.5

**Table K28: Change in percentage difference (%) between dominant and non-dominant sides of the posterior lumbar musculature pre-verse post-season by cricketing discipline**

Muscle	Fast Bowlers (n=17)		Spin Bowlers (n=11)		Batsmen (n=11)	
	Intervention (n=8)	Control (n=9)	Intervention (n=7)	Control (n=4)	Intervention (n=6)	Control (n=5)
Psoas	-0.8 ± 2.5	1.2 ± 6.1	4.6 ± 9.2	-0.1 ± 9.9	-0.2 ± 6.2	2.5 ± 7.4
Quadratus Lumborum	-6.5 ± 13.3	-1.9 ± 12.2	-1.2 ± 17.2	9.4 ± 13.1	-2.1 ± 12.5	4.9 ± 27.4
Multifidus	-5.9 ± 21.5	-3.5 ± 8.7	-6.3 ± 12.9	13.5 ± 15.7	-7.9 ± 26.7	-4.9 ± 18.3
Longissimus	-5.9 ± 20.6	0.01 ± 7.2	3.9 ± 17.6	-2.7 ± 12.0	3.1 ± 14.1	1.6 ± 13.8
Iliocostalis	0.7 ± 7.8	3.1 ± 9.5	2.8 ± 10.1	9.5 ± 6.4	0.4 ± 5.8	4.7 ± 12.9

**Table K29: Percentage change in cross-sectional percentage between pre- and post-season by change in lower back pain status**

Testing session	Muscle	Side	Intervention (n=21)		Control (n=18)	
			LBP (n=3)	NLBP (n=18)	LBP (n=14)	NLBP (n=4)
Pre season – Post season	Psoas	Dom	-3.8 ± 8.4	0.0 ± 8.3	-5.3 ± 6.4	-3.6 ± 5.0
		ND	-1.5 ± 5.7	-1.5 ± 9.1	-7.1 ± 6.1	-2.6 ± 5.7
	Quadratus Lumborum	Dom	-2.5 ± 16.6	-6.5 ± 12.3	2.3 ± 12.5	-5.2 ± 8.1
		ND	1.6 ± 9.9	-2.6 ± 8.4	-4.1 ± 8.6	9.3 ± 5.9
	Multifidus	Dom	0.1 ± 14.3	-3.8 ± 10.0	-5.5 ± 10.0	-8.1 ± 3.2
		ND	-5.4 ± 17.6	2.2 ± 16.0	-6.7 ± 13.3	-3.3 ± 6.9
	Longissimus	Dom	1.9 ± 4.0	-3.5 ± 8.2	-2.7 ± 8.9	2.2 ± 3.9
		ND	14.9 ± 6.7	-7.0 ± 17.2	-1.0 ± 7.3	-3.1 ± 9.1
	Iliocostalis	Dom	1.5 ± 7.9	-2.7 ± 12.6	-1.3 ± 10.5	1.2 ± 1.8
		ND	-1.1 ± 7.1	-3.3 ± 9.9	-5.4 ± 9.9	-5.3 ± 8.9

**Abbreviations: Dom, dominant; ND, non-dominant**

**Negative values show an increase from pre to post-intervention and post-season**

**Table K30: Percentage difference between dominant and non-dominant sides of the posterior lumbar musculature pre and post season by change in lower back pain status**

Testing session	Muscle	Intervention (n=21)		Control (n=18)	
		LBP (n=3)	NLBP (n=18)	LBP (n=3)	NLBP (n=18)
Pre season – Post season	Psoas	1.7 ± 6.9	-2.1 ± 2.9	1.9 ± 7.2	-0.8 ± 6.6
	Quadratus Lumborum	-3.7 ± 14.6	-2.1 ± 12.2	7.4 ± 16.0	-14.6 ± 9.1
	Multifidus	-8.5 ± 20.7	4.8 ± 6.3	1.1 ± 16.0	-4.5 ± 8.6
	Longissimus	2.2 ± 18.0	-12.6 ± 9.4	-1.7 ± 9.9	5.1 ± 9.0
	Iliocostalis	1.1 ± 7.9	2.2 ± 8.7	4.6 ± 10.3	6.5 ± 8.9

**Negative values show an increase from pre to post-intervention and post-season**

**Chapter 8 Additional Tables & Figures****Table K31: Lumbar flexibility percentage difference between pre- and post-intervention in cricketers**

Lumbar flexibility test	Intervention (n=21)	Control (n=18)
Forward flexion (cm)	0 ± 4	-2 ± 6
Lumbar extension (deg)	-2 ± 9	1 ± 15
Rotation Dom (deg)	13 ± 24	6 ± 18
Rotation ND (deg)	16 ± 23	6 ± 18
Lateral flexion Dom (cm)	-12 ± 12	-17 ± 10
Lateral flexion ND (cm)	-12 ± 12	-18 ± 13
Straight Leg Raise ND (deg)	-4 ± 14	-2 ± 12
Straight Leg Raise Dom (deg)	-5 ± 11	-3 ± 13

**Abbreviations: cm; centimeters; deg, degrees; Dom, dominant; ND, non-dominant**

**Table K32: Change in lumbar flexibility across cricketing disciplines during the intervention program**

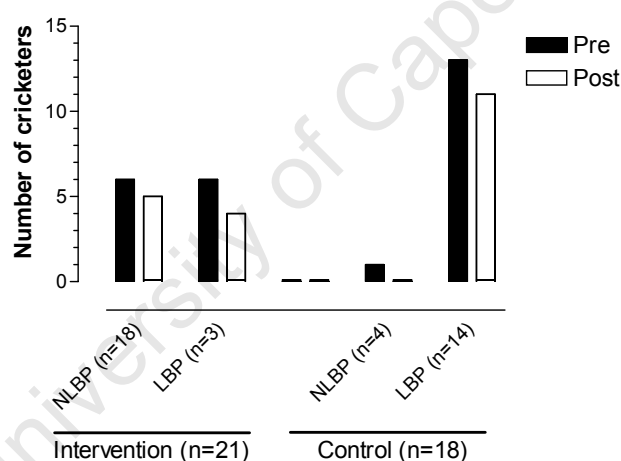
Lumbar flexibility test	Intervention (n=21)			Control (n=18)		
	Fast bowlers (n=8)	Spin bowlers (n=7)	Batsmen (n=6)	Fast bowlers (n=9)	Spin bowlers (n=4)	Batsmen (n=5)
Forward flexion (cm)	2 ± 4	0 ± 4	-2 ± 5	-2 ± 3	-5 ± 8	2 ± 6
Lumbar extension (deg)	-2 ± 5	-5 ± 8	2 ± 14	-2 ± 12	-4 ± 14	9 ± 20
Rotation Dom (deg)	20 ± 22	5 ± 28	13 ± 22	7 ± 20	1 ± 18	8 ± 18
Rotation ND (deg)	19 ± 23	13 ± 28	17 ± 21	8 ± 18	-9 ± 10	15 ± 18
Lateral flexion Dom (cm)	-11 ± 13	-7 ± 13	-20 ± 5	-17 ± 9	-14 ± 15	-21 ± 8
Lateral flexion ND (cm)	-13 ± 13	-6 ± 13	-19 ± 4	-18 ± 10	-9 ± 20	-23 ± 9
Straight Leg Raise ND (deg)	-9 ± 13	3 ± 15	-4 ± 11	0 ± 4	-11 ± 16	3 ± 15
Straight Leg Raise Dom (deg)	-9 ± 13	-3 ± 10	-4 ± 10	-1 ± 10	-11 ± 17	0 ± 14

**Abbreviations: cm; centimeters; deg, degrees; Dom, dominant; ND, non-dominant**

**Table K33: Change in lumbar flexibility in cricketers with and without lower back pain during the intervention program**

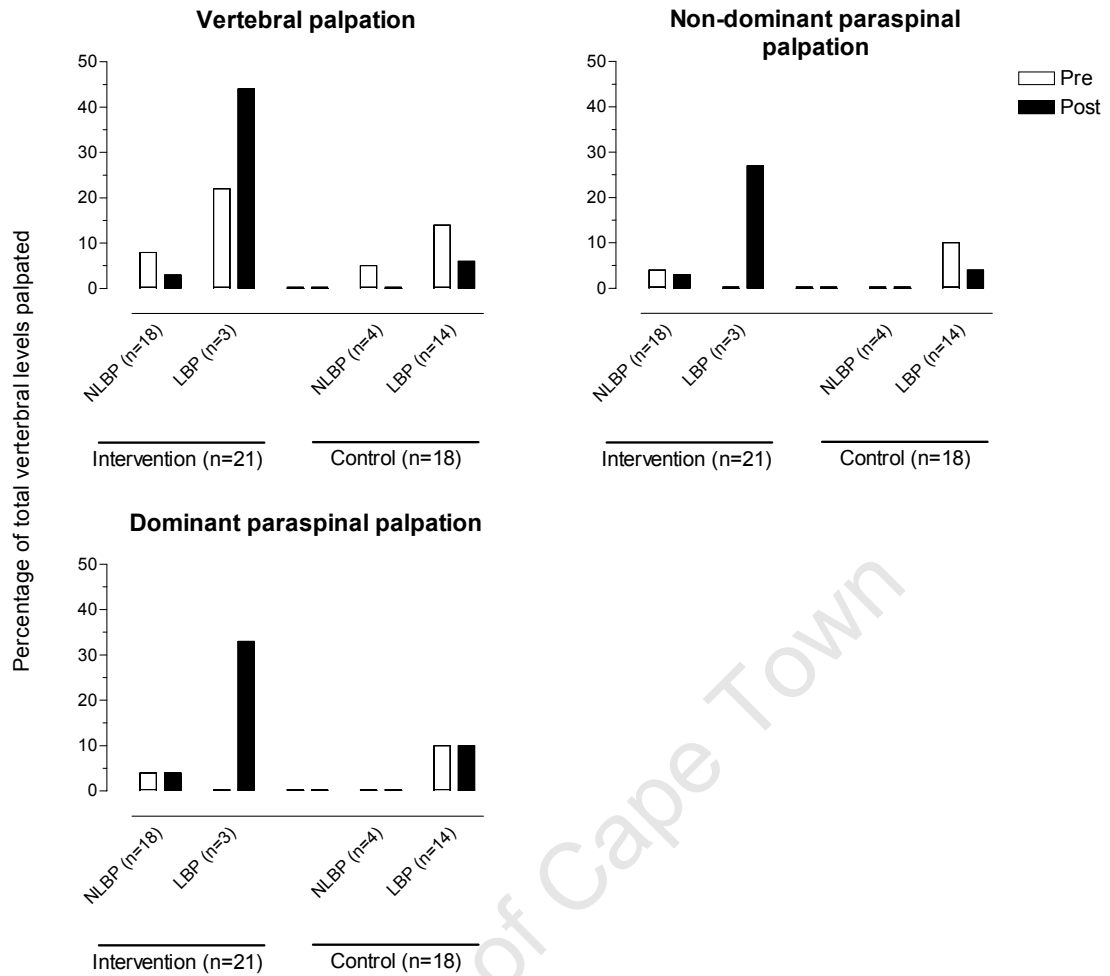
Lumbar flexibility test	Intervention (n=21)		Control (n=18)	
	LBP (n=3)	NLBP (n=18)	LBP (n=14)	NLBP (n=4)
Forward flexion (cm)	-3 ± 6	1 ± 4	-3 ± 5	1 ± 7
Lumbar extension (deg)	4 ± 4	-3 ± 9	1 ± 9	2 ± 31
Rotation Dom (deg)	25 ± 13	11 ± 25	6 ± 19	7 ± 20
Rotation ND (deg)	27 ± 16	15 ± 24	5 ± 18	9 ± 19
Lateral flexion Dom (cm)	-20 ± 5	-11 ± 12	-20 ± 10	-10 ± 7
Lateral flexion ND (cm)	-19 ± 6	-11 ± 12	-19 ± 14	-11 ± 8
Straight Leg Raise ND (deg)	-7 ± 8	-3 ± 14	-2 ± 13	-1 ± 4
Straight Leg Raise Dom (deg)	-12 ± 3	-4 ± 12	-4 ± 13	0 ± 14

**Abbreviations: cm; centimeters; deg, degrees; Dom, dominant; ND, non-dominant**



**Figure K3: Cricketers with positive single hyperextension rotation tests with respect to change in lower back pain status during the intervention program**

**Abbreviations: NLBP, no lower back pain; LBP, lower back pain; Pre, pre-intervention; Post, post-intervention**



**Figure K4: Percentage of total vertebral levels with pain on palpation of the vertebrae and paraspinal regions separated by lower back pain status pre- and post-intervention**  
**Abbreviations: Pre, pre-intervention; Post, post-intervention**

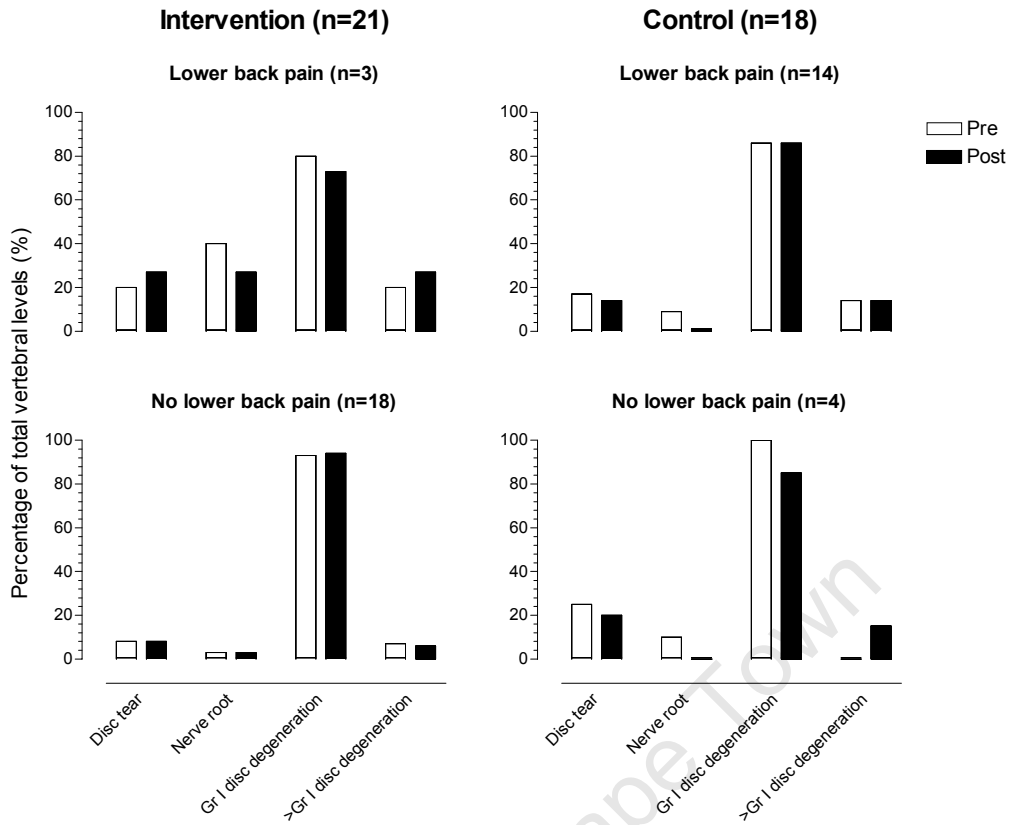


Figure K5: Percentage occurrence of lumbar disc and nerve root pathology in cricketers with and without lower back pain pre- and post-intervention

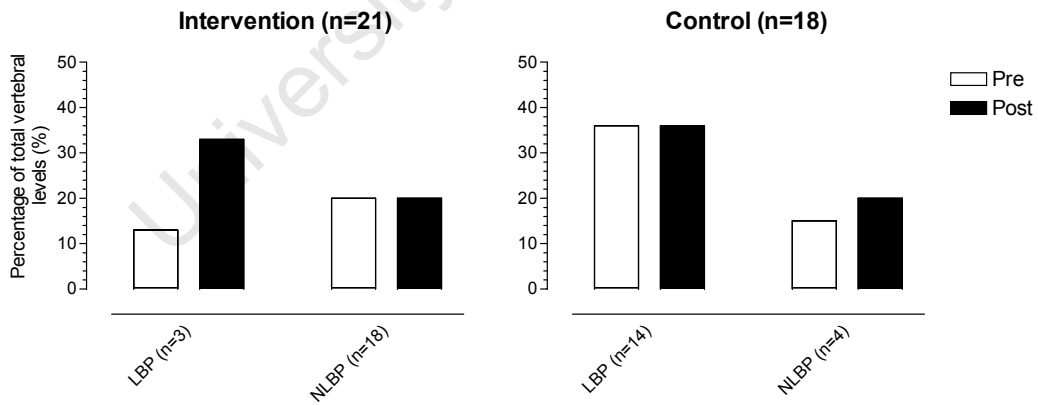


Figure K6: Percentage occurrence of endplate pathology in cricketers with and without lower back pain pre- and post-intervention

**Chapter 9 Additional Tables****Table K34: Shoulder counter-rotation (°) and the presence or absence of lower back pain**

Shoulder angle (°)	LBP (n=14)	NLBP (n=4)
Mean shoulder counter-rotation (°)	45.7 ± 15.7	45.7 ± 14.5
95% confidence limits (°)	36.7 - 54.8	22.8 - 68.7
Maximum shoulder angle (°)	245.3 ± 18.2	242.7 ± 25.8
95% confidence limits (°)	234.8 - 255.8	201.6 - 283.7
Minimum shoulder angle (°)	198.9 ± 10.3	195.8 ± 22.5
95% confidence limits (°)	192.9 - 204.8	159.9 - 231.7

**Abbreviations:** LBP, lower back pain; NLBP, no lower back pain

**Table K35: Total dominant and non-dominant muscle thickness (mm) comparing degree of shoulder counter-rotation in fast bowlers**

Muscle	20-40 degrees (n=6)	> 40 degrees (n=9)
Dominant	24.7 ± 2.0	23.7 ± 4.7
Non-dominant	26.8 ± 2.5	25.4 ± 4.9

**Table K36: Absolute muscle thickness (mm) comparing degree of shoulder counter-rotation in fast bowlers**

Muscle	Side	20-40 degrees (n=6)	> 40 degrees (n=9)
OE	Dom	7.8 ± 1.7	7.8 ± 1.9
	ND	8.8 ± 2.1	7.3 ± 1.5
OI	Dom	12.2 ± 1.0	11.5 ± 2.5
	ND	13.1 ± 1.3	13.6 ± 3.2
TrA	Dom	4.7 ± 1.0	4.4 ± 0.8
	ND	5.0 ± 0.9	4.5 ± 0.9

**Abbreviations:** OE, external oblique; OI, internal oblique; TrA, transverse abdominis; Dom, dominant; ND, non-dominant

**Table K37: Percentage difference (%) between dominant and non-dominant sides comparing degree of shoulder counter-rotation in fast bowlers (non-dominant side relative to dominant side)**

Muscle	20-40 degrees (n=6)	> 40 degrees (n=9)
External Oblique	-23.3 ± 63.5	4.5 ± 19.4
Internal Oblique	-7.7 ± 14.1	-21.1 ± 28.6
Transverse Abdominis	-7.9 ± 26.0	-5.4 ± 24.8
Total thickness	-9.0 ± 15.8	-8.8 ± 19.2

Table K38: Relative muscle thickness (%) comparing degree of shoulder counter-rotation in fast bowlers

Muscle	Side	20-40 degrees (n=6)	> 40 degrees (n=9)
OE	Dom	31.4 ± 5.5	33.0 ± 4.2
	ND	32.7 ± 6.3	28.8 ± 3.2
OI	Dom	49.6 ± 5.8	48.3 ± 3.8
	ND	48.9 ± 4.7	53.2 ± 4.2
TrA	Dom	19.0 ± 3.4	18.7 ± 2.2
	ND	18.4 ± 2.3	18.0 ± 2.5

**Abbreviations:** OE, external oblique; OI, internal oblique; TrA, transverse abdominis; Dom, dominant; ND, non-dominant

Table K39: Percentage difference between dominant and non-dominant sides of the posterior muscles comparing degree of shoulder counter-rotation in fast bowlers

Muscle	20-40 degrees (n=6)	> 40 degrees (n=9)
Psoas	-0.2 ± 4.2	0.5 ± 5.1
Quadratus Lumborum	9.6 ± 8.7	3.2 ± 17.7
Multifidus	2.3 ± 5.9	-5.6 ± 22.0
Longissimus	12.4 ± 13.8	4.2 ± 13.3
Iliocostalis	-7.6 ± 12.9	-1.4 ± 12.1

### **Chapter 10 Additional Tables & Figures**

Table K40: Percentage change (%) in total resting abdominal wall muscle thickness comparing fast bowlers in the intervention and control groups during the intervention period

	Muscle	Intervention (n=7)	Control (n=8)
Pre-intervention v post-intervention	Dom	-8.7 ± 10.6	2.3 ± 7.1
	ND	-0.9 ± 10.2	-7.2 ± 11.8
Pre-intervention v post-season	Dom	-0.1 ± 15.3	6.4 ± 12.2
	ND	4.1 ± 16.1	9.6 ± 14.0
Post-intervention v post-season	Dom	7.6 ± 12.9	4.1 ± 10.4
	ND	4.8 ± 13.7	15.9 ± 7.0

**Abbreviations:** Dom, dominant; ND, non-dominant

**Table K41: Percentage change in absolute resting muscle thickness comparing fast bowlers in the intervention and control groups during the intervention period**

Testing session	Muscle	Side	Intervention (n=7)	Control (n=8)
Pre-intervention - Post-intervention	OE	Dom	-25.0 ± 30.8	-0.1 ± 35.7
		ND	-7.3 ± 17.1	-9.0 ± 17.9
	OI	Dom	-7.5 ± 12.2	-0.7 ± 12.5
		ND	0.1 ± 9.3	-12.7 ± 12.6
	TrA	Dom	9.1 ± 14.2	3.3 ± 16.5
		ND	7.2 ± 10.9	6.9 ± 16.1
Pre-intervention - Post-season	OE	Dom	-7.2 ± 27.2	6.5 ± 38.2
		ND	19.5 ± 18.5	21.5 ± 21.1
	OI	Dom	-1.9 ± 15.1	4.5 ± 11.1
		ND	-3.0 ± 27.0	1.5 ± 17.0
	TrA	Dom	14.3 ± 14.1	3.9 ± 11.6
		ND	-7.9 ± 28.4	6.6 ± 13.3
Post-intervention - Post-season	OE	Dom	11.6 ± 21.0	5.8 ± 21.1
		ND	23.9 ± 17.7	28.1 ± 15.6
	OI	Dom	-0.7 ± 30.8	16.6 ± 38.9
		ND	-4.2 ± 32.7	25.6 ± 33.7
	TrA	Dom	3.7 ± 21.3	-1.0 ± 14.7
		ND	-15.7 ± 22.0	-1.9 ± 14.9

**Abbreviations:** OE, external oblique; OI, internal oblique; TrA, transverse abdominis; Dom, dominant; ND, non-dominant

**Table K42: Change in the percentage difference between dominant and non-dominant sides comparing fast bowlers in the intervention and control groups during the intervention period**

Testing session	Muscle	Intervention (n=7)	Control (n=8)
Pre-intervention - Post-intervention	OE	-15.3 ± 29.1	8.7 ± 54.5
	OI	-8.1 ± 11.8	13.1 ± 19.9
	TrA	1.0 ± 18.7	-5.1 ± 20.1
Pre-intervention - Post-season	OE	-27.7 ± 29.0	-17.0 ± 65.6
	OI	-0.4 ± 26.5	2.8 ± 13.9
	TrA	25.3 ± 28.0	-3.3 ± 15.7
Post-intervention - Post-season	OE	-12.3 ± 18.4	-25.8 ± 30.7
	OI	7.7 ± 21.6	-10.3 ± 13.7
	TrA	24.3 ± 23.6	1.8 ± 17.1

**Abbreviations:** OE, external oblique; OI, internal oblique; TrA, transverse abdominis

**Table K43: Percentage change in relative resting abdominal thickness (%) comparing fast bowlers in the intervention and control groups during the intervention period**

Testing sessions	Muscle	Side	Intervention (n=7)	Control (n=8)
Change pre v post Intervention	OE	Dom	-14.4 ± 21.5	-1.4 ± 29.6
		ND	-5.9 ± 8.4	-1.6 ± 12.2
	OI	Dom	0.8 ± 9.3	-3.4 ± 13.1
		ND	0.8 ± 3.9	-5.1 ± 3.5
	TrA	Dom	15.9 ± 13.7	0.8 ± 17.3
		ND	7.7 ± 9.1	13.3 ± 10.2
Change pre v post season	OE	Dom	-6.1 ± 13.1	2.5 ± 25.7
		ND	14.6 ± 21.0	14.0 ± 14.9
	OI	Dom	-1.9 ± 2.8	-2.7 ± 11.3
		ND	-6.4 ± 11.0	-9.2 ± 10.2
	TrA	Dom	13.0 ± 15.9	-3.4 ± 12.1
		ND	-12.0 ± 18.7	-4.2 ± 12.5
Change post intervention v post season	OE	Dom	5.1 ± 15.5	2.0 ± 19.4
		ND	19.1 ± 19.7	15.0 ± 14.1
	OI	Dom	-3.6 ± 10.9	0.0 ± 9.7
		ND	-7.6 ± 14.1	-3.9 ± 9.6
	TrA	Dom	-5.9 ± 26.4	-6.4 ± 18.9
		ND	-21.8 ± 18.8	-21.0 ± 14.9

**Abbreviations:** OE, external oblique; OI, internal oblique; TrA, transverse abdominis; Dom, dominant; ND, non-dominant

**Table K44: Change over time in TrA muscle thickness ( $\Delta$ mm) during abdominal hollowing comparing fast bowlers in the intervention and control groups**

Testing sessions	Side	Intervention (n=7)	Control (n=8)
Change pre v post Intervention	Dom	0.5 ± 3.0	2.3 ± 2.4
	ND	2.8 ± 3.5	-0.5 ± 2.5
Change pre v post season	Dom	0.7 ± 2.0	2.8 ± 4.8
	ND	1.8 ± 5.1	1.4 ± 5.1
Change post intervention v post season	Dom	0.2 ± 4.0	0.5 ± 4.3
	ND	-0.1 ± 4.9	2.0 ± 4.7

**Abbreviations:** Dom, dominant; ND, non-dominant; LBP, lower back pain; NLBP, no lower back pain

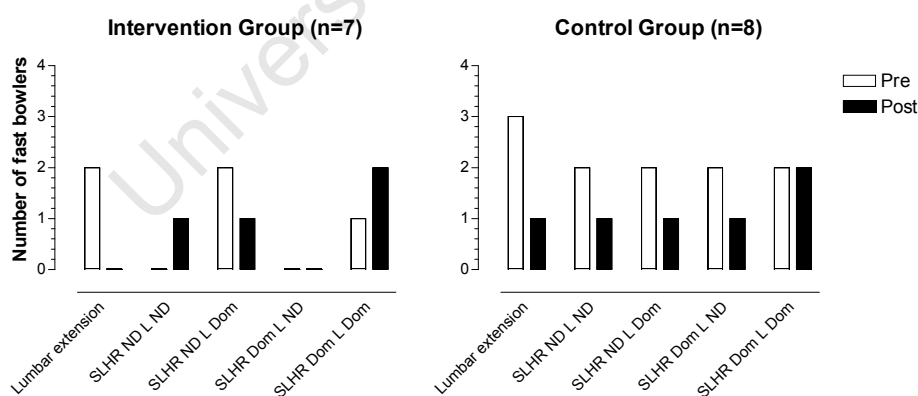
**Table K45: Change between dominant and non-dominant sides (%) for the posterior paraspinal muscles for the intervention and control groups pre and post-intervention (pre season % difference – post season % difference)**

	Muscle	Intervention (n=7)	Control (n=8)
Change pre v post season	Psoas	-1.26 ± 2.43	0.12 ± 5.57
	Quad Lumborum	-8.51 ± 12.96	-5.07 ± 8.40
	Multifidus	-6.28 ± 23.14	-1.53 ± 6.77
	Longissimus	-6.35 ± 22.13	0.55 ± 7.54
	Iliocostalis	1.83 ± 7.65	2.44 ± 9.92

**Table K46: Percentage change (%) between pre- and post-season testing of lumbar muscle cross-sectional area for the intervention and control group pace bowlers**

Muscle	Side	Intervention (n=7)	Control (n=8)
Psoas	Dom	-2.8 ± 11.4	-4.0 ± 3.5
	ND	-1.5 ± 10.8	-4.0 ± 4.2
Quad Lumborum	Dom	-10.5 ± 16.7	-5.6 ± 8.8
	ND	-1.0 ± 9.2	0.3 ± 8.5
Multifidus	Dom	-4.6 ± 14.2	-6.5 ± 6.9
	ND	-0.4 ± 16.8	-4.9 ± 6.6
Longissimus	Dom	-5.4 ± 7.4	-1.7 ± 6.6
	ND	-1.6 ± 23.6	-2.4 ± 7.8
Iliocostalis	Dom	2.0 ± 8.9	-2.1 ± 9.0
	ND	0.5 ± 8.7	-4.1 ± 7.7

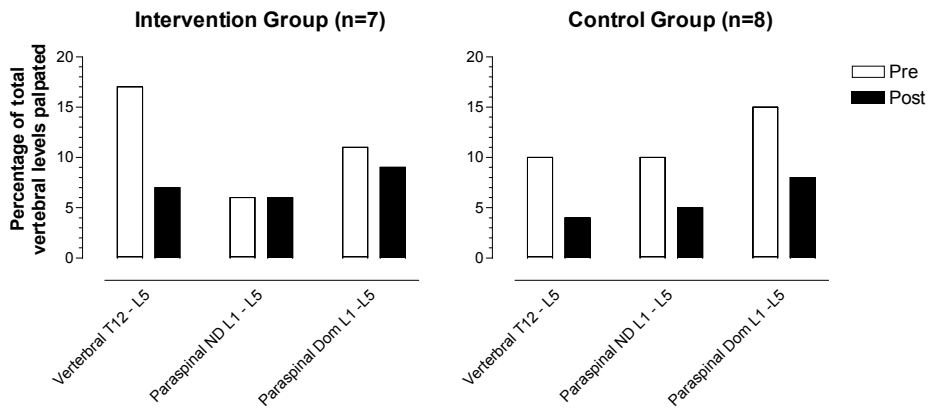
**Abbreviations: Dom, dominant; ND, non-dominant**



**Figure K7: Change in occurrence of positive clinical findings comparing fast bowlers in the intervention and control group during the intervention period**

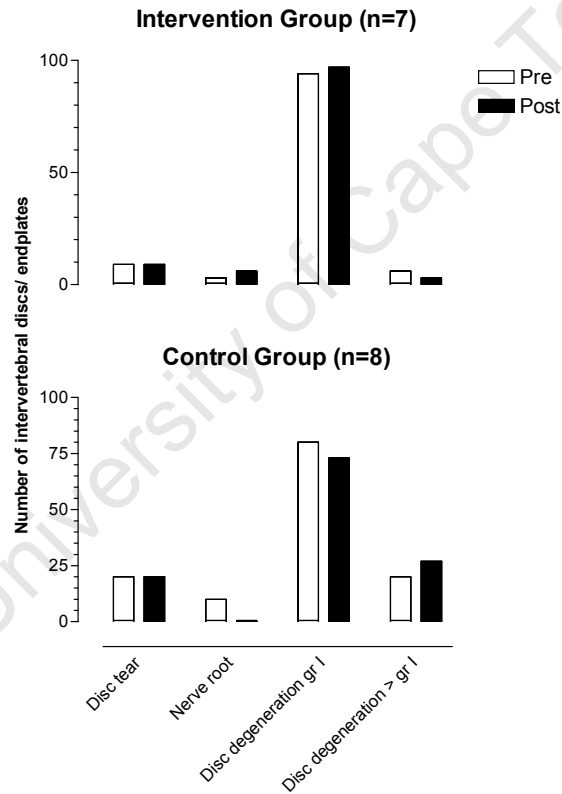
**Abbreviations: SLHR, single leg hyperextension rotation test; ND, non-dominant; Dom, dominant; Pre, pre-intervention; Post, post-intervention**

**Note that: ND leg ND means that the subject stood on the non-dominant leg whilst rotating his upper body to the non-dominant side; ND leg Dom means that the subject stood on the non-dominant leg whilst rotating his upper body to the dominant side; Dom leg ND means that the subject stood on the dominant leg whilst rotating his upper body to the non-dominant side; Dom leg Dom means that the subject stood on the dominant leg whilst rotating his upper body to the dominant side**



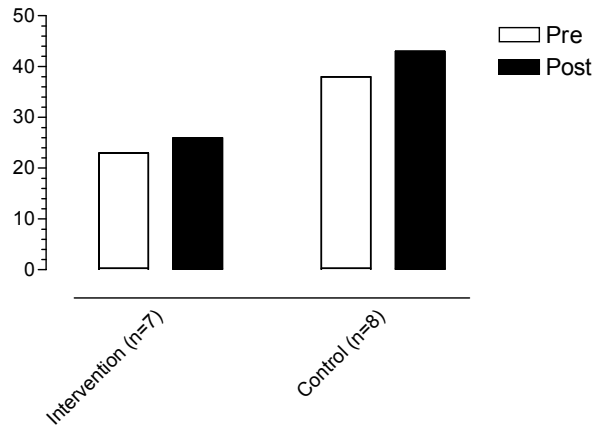
**Figure K8: Percentage occurrence of pain on palpation of the vertebrae and paraspinal regions comparing fast bowlers in the intervention and control group during the intervention period**

**Abbreviations: ND, non-dominant; Dom, dominant; Pre, pre-intervention; Post, post-intervention**



**Figure K9: Change in percentage occurrence of disc and nerve pathology comparing fast bowlers in the intervention and control group during the intervention period**

**Abbreviations: gr; grade; Pre, pre-intervention; Post, post-intervention**



**Figure K10: Change in percentage occurrence of endplate pathology comparing fast bowlers in the intervention and control group during the intervention period**

**Abbreviations: Pre, pre-intervention; Post, post-intervention**

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