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The epidemiology and risk factors associated with lower back pain in cyclists

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A dissertation prepared by Mandy Marsden (MRSMAN001) in partial fulfillment of the requirements for the Master of Philosophy degree in Sports Physiotherapy (MPhil Sports Physiotherapy) from the University of Cape Town

2009

DECLARATION

I, Mandy Marsden, hereby declare that the work on which this dissertation is based is my original work (except where acknowledgements indicate otherwise) and that neither the whole work nor any part of it has been, is being, or is to be submitted for another degree in this or any other university.

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ACKNOWLEDGEMENTS

This study would not have been possible without the help of many people. I am deeply appreciative of those who have encouraged me and provided me with invaluable assistance:

- My supervisor Professor Martin Schwellnus for his knowledge and expertise.
- Janine Gray for her initial guidance and encouragement, and Andrew Gray for helping to conduct the questionnaire survey
- Professor Mike Lambert for his help with the statistical analysis
- Dr Dale Rae for her help with the statistical analysis
- Dr Jeroen Swart for his advice and knowledge
- Graham Button, my husband, for his patience and support which enabled me to complete this thesis

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ABBREVIATIONS

BDC	Bottom Dead Centre of crank arm of pedal (6 o' clock)
BMI	Body Mass Index
C7	Seventh cervical vertebra
EMG	Electromyographic
FR	Flexion Relaxation
LBP	Lower Back Pain
L1	First Lumbar Vertebra
L5-S1	Joint between the fifth lumbar vertebra and the first sacral level
L4-5	Joint between the fourth and fifth lumbar vertebra
MVIC	Maximum voluntary isometric contraction
NP group	No Pain group
NSCLBP	Non-Specific Chronic Lower Back Pain
PFP	Patello-Femoral Pain
PSIS	Posterior Superior Iliac Spine
Q angle	Quadriceps angle
SD	Standard Deviation
SLM	Superficial Lumbar Multifidus muscle
S2	Second sacral level
TDC	Top Dead Centre of crank arm of pedal (12 o'clock)
TES	Thoracic Erector Spinae muscles
T1	First thoracic vertebra

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ABSTRACT

Background: lower back pain (LBP) appears to be a common overuse injury in cycling. However, there are few scientific studies that report on the epidemiology, aetiology and risk factors associated with LBP in cyclists. The prolonged flexed posture that the cyclist maintains during cycling may lead to increased mechanical strain of the lumbar spine, resulting in the development of LBP. It has been suggested that LBP in cyclists may be prevented and alleviated by adjusting certain bicycle parameters to match the anthropometric measurements of the cyclist. Aims of this thesis: the research reported in this thesis consists of a literature review and two research parts. In the first research part, a descriptive cross-sectional survey was conducted, to investigate 1) the epidemiology and 2) the nature of LBP in cyclists, and 3) possible risk factors associated with LBP in cyclists. In the second research part, a case control study was conducted, to investigate the association between LBP in cyclists and 1) flexibility and 2) anthropometric measurements, and 3) bicycle set-up parameters. Methods: in the cross-sectional survey 460 cyclists at the registration of a 109km cycling race completed a questionnaire pertaining to: 1) personal demographics, 2) training history, and 3) lower back pain history. In the case control study 20 subjects with LBP and 20 asymptomatic subjects (NP group) were recruited. Flexibility and anthropometric tests were conducted on the subjects. Various parameters of the bicycle set-up were measured relative to the anthropometrics of the cyclist. Results: in the cross-sectional survey, the self –reported annual incidence of LBP in cyclists was 42.9%, and the lifetime prevalence was 50.7%. LBP in cyclists occurred on average 1.38 hours after cycling commenced. Cyclists in the LBP group weighed more ($p=0.039$) and were significantly taller than those in the NP group ($p=0.011$), but the BMI's were similar. Cyclists in the LBP group cycled a greater distance per week than those in the NP group ($p=0.010$). In the case control study bilateral hamstring flexibility was significantly less in the LBP group compared with the NP group (left and right, $p=0.001$). Hip flexion and ankle plantar flexion range of movement were also reduced in the LBP group, in particular right leg hip flexion ($p=0.026$) and right ankle plantar flexion ($p=0.034$).There was a significant difference in the reach ratio [total upper body length(upper body + arm) / total reach(diagonal reach from saddle to handle bars)] between the LBP and the NP group. Conclusion: lower back pain is a common overuse cycling injury that is associated with prolonged cycling. Intrinsic risk factors associated with LBP in cyclists are increased height and body weight, and reduced hamstring flexibility, as well as reduced hip and ankle flexibility. Lower back pain in cyclists may be prevented by increasing hamstring and general lower limb muscle flexibility, and by increasing the diagonal reach distance from saddle to handle bars. Keywords: lower back pain, cyclists, risk factors, epidemiology, bicycle set-up, hamstring flexibility.

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CHAPTER 1 - INTRODUCTION AND SCOPE OF THESIS

Cycling has become increasingly popular as a recreational and competitive sport since the 1980s. It is regarded as a favourable sport for achieving cardio-respiratory fitness without encountering the high repetitive joint impact loads that are associated with other weight - bearing sports[59;142;149]. There is however, still a risk for sustaining both acute traumatic, as well as overuse injuries in cycling[24;27;36;76;98;118]. Despite this potential injury risk in cycling, there have been limited studies on the epidemiology of overuse cycling injuries[14;79;127;149;151]. This lack of scientific data does not enable the health practitioner, coach or the cyclist to correct or prevent overuse injuries in cycling. Specifically, factors such as 1) matching the cyclist's anthropometry with the size and settings of the bicycle (bicycle set-up), 2) training techniques or 3) biomechanics have not been well studied.

Apart from knee pain, lower back pain (LBP) and neck pain appear to be two of the more common overuse injuries in cycling. However the reported statistics of cyclists with LBP and neck pain vary between studies. A point prevalence[*] of 10 - 48%[14;151] of neck pain, and 10 - 60% of LBP[14;24;151] has been reported by cyclists who responded to questionnaire surveys. Besides affecting performance back pain also interferes with the enjoyment of cycling for competitive and recreational cyclists.

During cycling, the cyclist is placed in a position that is determined by the bicycle size and settings, as well as the cyclist's anatomy and alignment. However, it is obvious that in cycling, the lower back is maintained in a flexed posture for long periods. Therefore, recommendations for an optimal cycling posture, which potentially reduces mechanical loads on the lower back, may prevent back pain in cycling. In the published scientific literature there are guidelines for the correct bicycle set-up that are concerned mainly with improving cycling performance and efficiency rather than creating comfort and preventing overuse injuries[20;21;26;107;129;137;158]. Several scientific and quasi -scientific formulae are used for determining the saddle height, and adjustments are often made in the distance from the saddle to the handle bars, and handle bar height to alleviate back pain in cyclists[33;36;98;99;127;130]. Anthropometric measuring systems with corresponding computer programmes and measuring instruments are also used by some bicycle retailers to aid customers in determining the correct bicycle set-up (Cyclefit and "fit-kit")[33;126].

[*] The definitions for epidemiological terms are detailed in section 2.3

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However, very few epidemiological studies have been conducted to investigate the association between back pain and specific parameters of a bicycle set-up. Likewise very few intervention or biomechanical studies have been conducted to investigate the effect of specific bicycle adjustments on back pain, alterations to joint mechanics, or tensile forces on the spine and pelvis. Much of the information available on LBP in cyclists is therefore anecdotal[20;21;33;99;130].

Training methods and their possible association with the development of LBP in cyclists have also received little attention. An association between lower back pain and factors such as terrain, incorrect use of gear ratios and the intensity of cycling during training and races has not been investigated. Neck pain in cyclists has been shown to be associated with windy conditions, hilly terrain, longer distance and duration of time cycling[37].

Specific intrinsic biomechanical factors that may be related to the development of LBP in cyclists have also not been studied well. The physical response of the cyclist's body to the prolonged flexed position of cycling, and its association with LBP has also received little attention in the published scientific literature[18;22;126;132]. Risk factors which may predispose the cyclist to LBP such as flexibility of the spine, trunk muscle stability, lumbo-pelvic angles and hamstring flexibility have also received little or no attention[18;33;126;132;151].

Therefore, the first aim of this thesis was to review the current literature on the epidemiology and aetiology of LBP in cyclists. The second aim of the thesis was 1) to study the epidemiology of LBP in cyclists and to explore possible extrinsic risk factors that may be associated with LBP in cyclists, and 2) to investigate the association between the bicycle set-up and various anthropometric measurements (as intrinsic risk factors) that may be associated with LBP in cyclists.

In chapter 2, a review of the epidemiology, possible pathomechanical mechanisms as well as risk factors associated with LBP in cyclists will be presented. In chapter 3 an original research study investigating the epidemiology and possible extrinsic risk factors for lower back pain in cyclists will be presented. In chapter 4 a research study investigating the intrinsic risk factors related to bicycle set-up and cyclist anthropometrics will be presented. Finally in chapter 5 a summary of the findings of this thesis, and clinical implications and future research directions of this work will be presented.

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CHAPTER 2 - A REVIEW OF LOWER BACK PAIN IN CYCLISTS WITH SPECIFIC REFERENCE TO RISK FACTORS

2.1 INTRODUCTION

Cycling is generally regarded as a sport with great potential for fitness and rehabilitation[20], Additionally, cycling has the added value of not being associated with repetitive joint impact[59;142;149]. Despite this advantage, it has been shown that there is still a risk for the development of acute traumatic as well as overuse injuries in cycling[23;27;36;76;98;99;118].

Although there are good data in the published literature on the incidence of traumatic injuries in cyclists[27;76;118], there are only a few studies that document the incidence, and even fewer, the prevalence of overuse injuries in cyclists. In addition it is difficult to draw comparisons between the limited number of studies of overuse injuries, as population samples, and time periods over which studies were conducted (exposure) vary between studies. However, studies consistently report that knee pain and specifically the patellofemoral pain (PFP) syndrome, is the most common overuse injury in cyclists[14;79;149;151].

A 10 - 60% point prevalence of LBP has been reported in results from questionnaire surveys in cyclists[14;24;151]. In cyclists who participated in 2 multi-day stage events (805km over 8 days; and 7242km over 80 days), an incidence of 2.7 – 15% of LBP has been reported[79;149].

However there are no known studies that report the lifetime prevalence of LBP in cyclists. It has been reported that lower back pain is more common in some athletes than others. There have been reports that show a high lifetime prevalence of LBP in wrestlers[39]. Elite gymnasts[135] and adolescent multi - disciplinary athletes[77] have also shown a higher point prevalence of LBP when compared with matched controls.

In addition to the limited research on the epidemiology of overuse injuries in cycling, and specifically on LBP, there are also very few studies that have been done to determine the aetiology of LBP in cyclists. The aim of the cyclist is to produce maximal power at the pedals to propel the bicycle forward[20]. In order to maximise velocity for a given power output, the cyclist has to flex the hips and spine in an attempt to reduce the frontal cross-sectional area of the body, thereby reducing aero-dynamic drag. This prolonged flexed posture may be an important factor contributing to lower back pain in cyclists as posterior active and passive spinal structures may be subjected to increased load and strain in this position. It has been

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postulated that in this prolonged flexed position during cycling passive structures such as the posterior annulus of the intervertebral disc may develop micro damage, ligaments may become overstrained, and that spinal muscles may lose power through fatigue and altered motor control[99;133;140;149].

Therefore, to optimise the cyclist's position and thus limit strain and injury of the lower back, while maintaining efficient power output, specific attention must be paid to the correct bicycle "set-up". The bicycle "set-up" refers to the various adjustable parameters on the bicycle, including, amongst others, seat height, reach distance from seat to handle bars and saddle angle. These parameters must be adjusted relative to the cyclist's unique anthropometric measurements to ensure correct positioning of the cyclist on the bicycle[20;21;98]. Although various researchers and authors have documented advice for the "optimal" bicycle set-up, much of the advice appears to be anecdotal or concentrates on performance (power output) rather than on injury prevention and comfort of the cyclist[19;20;33;98;127;130].

In this chapter the definition and classification of LBP will first be reviewed. This will be followed by a review on what is currently known about the epidemiology of LBP in cycling. A brief review of the anatomy and biomechanics of the spine related to cycling will follow. This is important as it will provide a basis for the discussion of possible pathomechanical models for the development of LBP in cycling. Finally, the risk factors for LBP in cyclists will be reviewed.

2.2 DEFINITION AND CLASSIFICATION OF LOWER BACK PAIN

Lower back pain may be defined as pain in the lower back or lumbar region,[101] and may be intermittent or constant[100].

There are many different classifications of LBP[113]. Acute LBP can be defined as pain that has been present for less than 6 months and having had no pain for the year preceding the present onset[28;38]. Chronic LBP can be classified as LBP of a continuous or recurrent nature for more than 6 months[28;38]. Acute LBP in sport may be attributed to specific incidents whereas chronic LBP often has no apparent cause and is classified as an overuse injury[43;113].

It is important to note, that LBP is a symptom and not a diagnosis. Furthermore, LBP is often not associated with a documented underlying structural abnormality and this must be considered when attempting to interpret epidemiological reports on LBP. Most cases of LBP are classified as non–specific because a definitive diagnosis can often not be obtained by current imaging and other diagnostic methods[38].

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In the traditional medical patho-anatomical approach, lower back pain has been classified as spondylogenic, neurogenic, viscerogenic, vascular or psychogenic LBP[104]. For the purposes of this review and this thesis LBP associated with cycling will be confined to the spondylogenic type of LBP[157].

Spondylogenic LBP may be defined as pain originating from the spinal column and its associated structures[157] and is considered to be the most common cause of LBP[157]. The nature of spondylogenic LBP is mechanical and it is typically aggravated by general and specific movements, postures and activities, while it is relieved, to some extent, by rest[157]. The pain may originate from underlying pathology in the bony components of the spinal column, the spinal facet joints, the sacro-iliac joints or the soft tissues (discs, ligaments and muscles).. A brief outline of the combined anatomical and pathological classification of sponylogenic lower back pain in athletes is depicted in Table 2.1[53].

Table 2.1 Pathology of spinal anatomical structures in athletes[53]

Anatomical Structures	Pathology
Bone – vertebral body, growth plate, pedicle, lamina, transverse process, spinous process	Fractures, spondylolysis, spondylolysthesis, infections, inflammation, metabolic disorder, neoplasia
Joint – facet joints	Fractures, degeneration, arthritis, arthrosis
Intervertabral disc	Herniation, annular tears, infection, inflammation
Muscle	Sprains, strains
Ligament	Sprains, strains

The two models that have been used to explain the mechanical nature and the development of spondylogenic LBP are the Motor control model[123;125], and the Mechanical loading model[1;113;147].

The Motor control model categorises LBP according to mal-adaptive movements and motor control impairments which result in ongoing tissue loading and mechanical provocation of pain[113;123;125].

The Mechanical loading model describes high and low levels of physical activity as being reported risk factors for LBP, while moderate levels of activity appear to be protective[8;106;113]. Mechanical factors such as sustained low load postures as in sitting, bending and twisting are associated with the initial development, and with recurrences, of LBP.

Cycling is characterized by a sustained low load in a flexed posture of the spine, and this is sometimes combined with rotation[1;2;94;103;119]. These mechanical exposures can also be influenced by ergonomic factors, such as the saddle angle and reach distance from saddle to handle bars in cycling. Individual physical factors, such as where in its range a spinal articulation is loaded (neutral zone vs. elastic zone), reduced trunk muscle strength and impaired flexibility have also been reported to be associated with LBP[1;2;30;94;113].

A clearer clinical understanding of spondylogenic pain may be gained by categorising LBP according to the two models which have been described. However, an exact clinical diagnosis may still not be obtained, as there is often little evidence of radiographic abnormality in the majority of lower back pain disorders, and symptoms persist beyond normal tissue healing time. This has led to a description of non-specific chronic lower back pain (NSCLBP), which may serve as a descriptive term for spondylogenic pain without an anatomical-pathological diagnosis [30;38]. It is for this reason that there is an increased emphasis on sub-classifying LBP patients on criteria other than radiological abnormality. Patients that present with NSCLBP have been reported to show distinctly different clinical patterns although this notion has not been well validated in scientific studies[113].

Furthermore, sub-groups of NSCLBP patients have been classified according to the directional basis of back pain provocation “patterns” and their individual clinical presentation. One of these sub-groups is the “flexion pattern” pain disorder[113]. Flexion pattern pain disorders are clinically characterised by LBP that is reproduced by sustained and repeated flexion of the lumbar spine while being relieved by extension of the lumbar spine. This clinical pattern is reported to be associated with no spinal mobility impairment but a loss of lower lumbar lordosis. This pattern is also associated with dysfunction of the lumbar multifidus muscles, together with a compensatory upper lumbar lordosis[113]. Flexion pattern LBP disorders are thought to result from a loss of neutral zone control of the spinal motion segment with resultant repetitive strain of the spine at the end of the range of flexion[113]. This pattern is particularly important to consider in this thesis, as cyclists with lower back pain may well represent a group of athletes where a flexion strain pain disorder of the lumbar spine is present[113].

In summary, for the purpose of this thesis the discussion of LBP will be confined to spondylogenic LBP, which is defined as pain originating from the spine and its associated structures. The mechanical nature and development of spondylogenic LBP is described by two descriptive “models”. The “Motor control model” categorises LBP according to maladaptive movements and motor control impairments which perpetuate mechanical provocation of pain.

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The “Mechanical loading model” also associates sustained low load postures, such as sitting in cycling, with LBP. In addition the term “non-specific chronic lower back pain” (NSCLP) may be used to describe undiagnosed spondylogenic LBP with no evidence of radiological abnormality. A sub-group of NSCLBP patients are described as having a “flexion pattern pain disorder” in which pain is reproduced by sustained flexion and relieved by extension. Cyclists with LBP may fall into this sub-group.

The epidemiology of LBP in cyclists will now be reviewed, followed by a review of the spinal anatomy and biomechanics.

2.3 EPIDEMIOLOGY OF LOWER BACK PAIN IN CYCLISTS

In order to create a context for the epidemiology of lower back pain in cyclists, the epidemiology of LBP in the general population and other athletes will be discussed first. As mentioned in the definition of LBP (section 2.2), it is important to emphasize that low-back pain is a symptom, not a diagnosis. Most often, LBP is not associated with an underlying structural abnormality, and this is an important consideration when interpreting epidemiological reports of low-back pain[38].

The epidemiology of LBP in cyclists in this study is defined by the prevalence and incidence of this overuse injury. The prevalence of LBP refers to the number of cyclists who experience LBP at any point in time. Point prevalence describes cyclists who experience LBP at a particular point in time, and lifetime prevalence refers to cyclists who have experienced cycling related LBP at some point in their entire cycling career. The incidence of LBP is always linked to exposure over a particular time period e.g. hours of cycling, in a staged cycle tour over a number of days, or over a one year period (annual incidence).

Lower back pain is common in the general population, and a lifetime prevalence of 60 – 90% has been reported[38;111;139]. The annual incidence of LBP in the general population has been reported in various studies and ranges from 2%[139] to 37%[117] and as high as 64%[81]. Furthermore a high percentage of LBP disorders (almost 90%) resolve within a 4-week period[29;111] while a smaller number of LBP disorders (10 – 40%) become chronic[29;38].

There are conflicting reports as to whether athletes in general are at a higher risk of developing back pain than non-athletes[15]. In one study the lifetime prevalence of low-back pain in wrestlers (59%) was significantly higher than that of age-matched controls (31%)[45]. Likewise a significantly higher point prevalence of LBP was found in elite gymnasts (75%) compared

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with a control group (31%)[135]. Adolescent multi-disciplinary athletes reported a higher point prevalence of LBP (46%) compared with non-athletes (18%)[77]. In contrast a lower point prevalence of LBP was reported in former multi-disciplinary elite athletes[145] (29%), compared to non-athletes (44%).

It appears that LBP is more common in some athletes than in others. In a prospective study it was found that wrestlers had the highest point prevalence of severe low-back pain (54%), while rates were lower for tennis (32%), and soccer players (37%)[86]. Wrestlers were again found, in another study, to have a higher lifetime prevalence of low-back pain of 59% compared with 23% in heavyweight lifters[45]. Competitive male and female rowers had a 15% and 25% point prevalence of low-back pain, respectively[54]. In a study with a small sample size a high incidence of LBP was reported in elite rhythmic gymnasts (six of seven), over a seven-week period[62]. Therefore, the prevalence and incidence of LBP varies in different sports, but interpretations of data are difficult as the same methodology and definitions for LBP have not been consistently applied in all studies.

The focus of this thesis is on cycling, but there are no known published data on the lifetime prevalence of lower back pain in cyclists. A number of research surveys have investigated overuse injuries among recreational cyclists and elite cyclists [79;149;151]. The incidence of LBP in two separate staged multi-day cycling events varied from 2.7 - 15%. The details of these studies indicate that: 1) only 2.7% of the participants (n=113) in a bicycle tour (805km over 8 days) reported significant LBP[149], and 2) 15% of the participants (n= 89) in a long distance cycle tour (4500 miles over 80 days) experienced LBP[79]. Point prevalence statistics of LBP in cycling ranged from 10 - 60% and details of the studies indicate that: 1) 10% of cyclists (n=20) who responded to a research questionnaire suffered from LBP (it is not clear what the actual prevalence of LBP was in the larger group of which the 20 respondents were a subset[14]) 2) 30% of cyclists (n=518) who responded to a mail questionnaire experienced LBP[151], 3) 60% of cyclists reported suffering from LBP in a squad medical questionnaire of 424 elite cyclists, and this made LBP the most common problem that the riders encountered.

It is clear that there are limited studies on the epidemiology of LBP, in particular studies that report the lifetime prevalence of LBP in cyclists. Furthermore, the methodology employed by researchers in studies that have been conducted varies considerably, and this makes interpretation of the data difficult. Thus, there is a need to conduct further studies to determine the extent to which LBP is a problem in cyclists, and this will be explored in the first research chapter of this thesis.

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2.4 ANATOMY AND BIOMECHANICS OF THE LUMBAR SPINE AND PELVIS

In this section the anatomy and biomechanics of the lumbar spine, in particular the passive and active muscular support systems will be reviewed. A brief discussion of the anatomy of the pelvis and its ligamentous attachments to the lumbar spine, as well as the attachment origin of the hamstring muscles to the pelvis will follow. The position of the cyclist and the bicycle set-up will then be discussed and this will be related to the anatomy and biomechanics of the cyclist.

2.4.1 THE SPINAL MOTION SEGMENT

The joint system of the lumbar spine is comprised of a series of basic anatomical units that are known as the motion segments. A single motion segment consists of two vertebrae and their respective articulations. The main articulations between the vertebrae in a motion segment are the intervertebral disc and the two facet joints[53].

It has been suggested that when pathological changes occur in one part of the motion segment, this results in secondary pathological changes in another part of the same segment or in adjacent segments[53]. It has also been suggested that the biomechanical manifestation of early excessive loading in a motion segment is hypomobility which occurs in the early phase of the pathology, while hypermobility classically occurs in the latter phase of the pathology[53]. Secondary soft tissue changes (muscle spasm and shortening of ligaments, fascia and musculo-tendinous structures) can also contribute to pain and altered mobility[53].

The lumbar spine, and each motion segment, requires support systems to withstand mechanical loads that are placed on it during static postures and while moving.

2.4.2 SPINAL SUPPORT SYSTEMS

The lumbar spine is supported by three inter-relating systems:[116]

- the passive support system (bone, cartilage and ligamentous structures)
- the active support system (muscle control)
- the neural control system

Sensory feedback between the active and the passive systems provides co-ordination between all systems[108].Therefore failure in one support system can result in compensation in

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another system[108]**.** The muscular and neural systems are dynamic and can change their supportive role depending on the forces acting on the lumbar spine.

Specific passive structures which bear loads placed on the spine in the various positions will now be discussed.

2.4.3 PASSIVE SUPPORT SYSTEMS OF THE LUMBAR SPINE

The passive support structures of the spine are the facet joints, the spinal ligaments, and the intervertebral disc. The role of these structures in absorbing various forces that are applied to the spine will be briefly reviewed[157].

Generally if anterior and axial torque forces are applied, the facet joints play a major role in dissipating the forces[157]. If lateral and posterior shear forces, axial compression forces, and flexion forces are applied to the spine, the intervertebral disc appears to be the major load-bearing element of the spine. The ability to absorb and dissipate these forces is significantly reduced when lumbar intervertebral disc degeneration occurs[157]. Cycling places the cyclist in a flexed and sometimes slightly rotated spinal position (depending on spinal asymmetry or if the cyclist turns to look behind for advancing cyclists or traffic). The facet joints and discs therefore jointly play a role in dissipating forces applied to the spine during cycling. A more detailed description of the function of the passive support systems of the spine will follow with specific reference to cycling.

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2.4.3.1 FACET JOINTS

The normal facet joints guide the movement of the motion segment, facilitate movement in the sagittal plane (flexion/extension) and limit movements in rotation (torsion) and flexion[157]. The facet joints are not major load bearers except in the lower lumbar spine, where they can accommodate up to 20% of a compressive load[157]. In the sustained flexed position during cycling, it appears that the facet joints facilitate a degree of flexion in the sagittal plane and thereafter, with the aid of spinal ligaments, limit excessive flexion movement of the spine. The facet joints would also limit the combined movement of flexion and rotation when the cyclist turns to look behind for advancing cyclists and traffic.

2.4.3.2 SPINAL LIGAMENTS

The strongest ligaments in the spine are the anterior longitudinal ligament and the facet joint capsules. The interspinous-supraspinous ligament complex is of intermediate strength and the

weakest is the posterior longitudinal ligament[157]. The ligamentum flavum has a function of stretching rather than restraining[157]. However the relative contribution of the spinal ligaments to the overall stability of the spine relative to muscle support is not well documented[157].

Spinal ligaments have viscoelastic properties that allow the ligaments to slowly elongate and resist tensile forces over time[136;148;150]. Deformation or a change in strain of the ligament tissue can occur over time if a constant load is applied, such as during prolonged sitting in a flexed position on a bicycle. This is a biomechanical characteristic known as creep[136;148;150]. In resisting tensile forces ligaments should allow just enough movement without injury to vital structures[157]. Passively the ligaments should maintain tension in a segment thereby minimising the work of the muscles[157]. In the flexed position, which is characteristic of cycling, the posterior spinal ligaments are therefore subjected to a prolonged stretch. It has been postulated that creep may set in which may lead to increased laxity of the intervertebral joints[22].

2.4.3.3 INTERVERTEBRAL DISCS

The intervertebral disc has a fibrous outer casing (the annulus) that contains a gelatinous inner structure, the nucleus pulposus. The annulus consists of 3 layers: the outermost fibres that attach between the vertebral bodies and the under surface of the epiphyseal ring; the middle fibres which pass from the epiphyseal ring on one vertebral body to the epiphyseal ring of the vertebral body below, and the innermost fibres that pass from one cartilage endplate to another. The anterior fibres of the annulus (closest to the abdomen) are strengthened by the powerful anterior longitudinal ligament, while the posterior longitudinal ligament provides only weak reinforcement, especially at L4-5 and L5-S1 levels. This is worth considering in relation to the prolonged stretch that is applied to posterior spinal structures in the seated position of cycling[157].

The annulus is a laminated structure with the fibrous lamellae running obliquely. This disposition of the fibres permits resistance of the torsional strains. The nucleus pulposus is constained by the fibres of the annulus. When a vertical load is applied to the vertebral column, the force is dissipated radially by the gelatinous nucleus pulposus. Distortion and disruption of the nucleus is resisted by the annulus[157].

The first stage of a disc rupture would appear to be detachment of a segment of the hyaline cartilage plate. The integrity of the confining ring of the annulus is then disrupted. Nuclear

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material can then escape between the vertebral body and the displaced portion of the hyaline plate[157].

Regardless of loads on the spine and the support of muscles and ligaments, the final determining factor in injury to the spine is the intradiscal pressure of the intervertebral disc[157]. Intradiscal pressure is the pressure created in the disc when a load is applied to the spine. Because the nucleus pulposus is gelatinous, the load associated with axial compression is distributed not only vertically, but also radially throughout the nucleus. This radial distribution of the vertical load (tangential loading of the disc) is absorbed by the fibres of the annulus which can be compared with the 'hoops' in a barrel. The 'hoops' around the barrel resist a load of water and when a high load is applied, the 'hoops' will break.

The ability to transfer fluid from the disc to adjacent vertebral bodies minimises the rise in intradiscal pressure on sudden compression loading. The fluid transfer is through two routes: a) the bi-directional flow from vertebral body to disc and from disc to vertebral body and b) the diffusion through the annulus from blood vessels on its surface. Sudden severe loading of the spine may produce a rise in fluid pressure within the vertebral body that is large enough to produce a "bursting" fracture. However a sustained repetitive load to the spine may also result in disruption of this fluid transfer resulting in injury to the disc[104;157].

The intradiscal pressures in various postures and loading positions have been studied[104]. It has been that if forces exceed what the disc space can absorb, injury to the motion segment occurs and pathologic changes occur in the three joint complex[157]. However, intradiscal pressures in the flexed position of cycling have not been recorded.

In summary, the passive support structures of the spine are the facet joints, the spinal ligaments and the intervertebral disc. With particular reference to cycling, facet joints resist rotation and flexion forces imposed on the spine, while the intervertebral disc resists flexion forces applied to the spine[157]. Spinal ligaments enhance this support, and have visco-elastic properties that allow the ligaments to slowly elongate and resist tensile forces over time[136;148;150]. An increase in the intradiscal pressure, beyond what the disc space can absorb, may be a final determining factor in disruption and injury to the spinal motion segment.

The load bearing capacity of the passive structures of the spine are enhanced by the active support systems of the spine; specifically, the abdominal muscles, the intra abdominal pressure mechanism and the deep spinal muscles. In the next section, the role of the active support systems in creating functional stability, and enhancing spinal support will be reviewed.

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2.4.4 ACTIVE AND NEURAL LUMBAR SPINE SUPPORT SYSTEMS

As already mentioned, lumbar spine stability depends not only on passive support structures, but also on active support (muscle) and neural control. Active support of the lumbar spine and neural control are integrated, and therefore these two systems will be discussed together. The following elements of these two systems will be discussed: 1) transversus abdominus muscles, oblique muscles and the thoraco-lumbar fascia, 2) the intra-abdominal pressure mechanism, and 3) deep lumbar stabilisers.

2.4.4.1 TRANSVERSUS ABDOMINIS MUSCLE, OBLIQUE MUSCLES AND THE THORACOLUMBAR FASCIA

The transversus abdominis as well as the internal and external oblique muscle groups have been recognised as the main contributors to functional stability of the lumbar spine[71;108;109;156]. It is believed that the function of these muscle groups is enhanced by the co-contraction of the multifidi, interspinales and intertransverserii muscles, as these muscles provide a stabiliser function to individual motion segments[58;71;108;109;156].

The lateral raphe of the thoraco-lumbar fascia has attachments to the transversus abdominis. Contraction of the transverus abdominis can therefore limit segmental spinal movement by generating tension in the lumbar fascia[9;58;109]. This fascial tension transmits a compressive force to the spinal column, which enhances its stability and assists in the recruitment of the multifidi muscle groups. Fascial tension may prevent injury by restricting vertebral displacement[58;109]. In addition to the functional co-contraction of the abdominal and spinal muscles in order to create stability of the lumbar spine, it has also been suggested abdominal muscles work in synchronicity with another group of muscles, thus contributing to an increase in intra-abdominal pressure, which further enhances spinal support.

2.4.4.2 THE INTRA-ABDOMINAL PRESSURE MECHANISM

There is evidence that increased intra-abdominal pressure, even with limited participation of the abdominal or back muscles, augments the stability of the spine[42]. A synchronous contraction of the abdominal muscles, the diaphragm and the muscles of the pelvic floor is required to increase pressure in the abdominal and thoracic cavities[109]. Co-contraction of the lower back muscles and the abdominal oblique muscles also result in an increase in intra-abdominal pressure, thus stabilising the spine[121]. The intra-abdominal pressure mechanism is thus an efficient system for enhancing spinal support which does not require undue muscle

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energy. A brief overview of the specific role of the deep lumbar stabilisers will now be discussed.

2.4.4.3 DEEP LUMBAR STABILISERS

The results of scientific studies have supported the role of the deep lumbar stabiliser muscles in providing stability to the lumbar spine[121]. The anti-gravity function of the trunk muscles provides trunk stability and protects the spinal column during movement of the limbs and the forces that are imposed through limb loading[58;71]. The deep stabiliser muscles need to be continuously active over long periods of time by generating low forces. The multifidus muscle is active during full range of motion of spinal flexion and bilateral rotation and also contributes to the stability of the pelvis in extension movements of the lower limb[87;122]. The multifidus muscle plays an important role in standing or in a seated posture (such as during cycling)[13;87]. The multifidus as well as transversus abdominis muscles have also been shown to contract in anticipation of reactive forces that are produced by limb movements, irrespective of the direction of this movement[58]. The multifidi have been shown to be atrophied in patients with lower back pain [55].

Therefore, in order to minimise loading of the motion segment of the spine, specific muscular contractions are required prior to the performance of any task. The transversus and multifidi muscles have been recognised as being primarily responsible for stabilising the spine[87;156]. Intramuscular (fine needle) electromyographic (EMG) studies have shown that the deep lateral erector spinae and the quadratus lumborum muscle may also assist with spinal stabilisation in the fully flexed posture[5;87], which may be the case during cycling.

Spinal support is thus enhanced by the muscular and neural systems. Co-contraction of abdominal and spinal muscles, as well as pelvic floor and diaphragmatic muscles contribute to overall spinal stability. In particular, the transversus abdominus muscles and the deep lumbar multifidi muscles play an important role in maintaining spinal stability.

The lumbar multifidi muscles have attachments to the sacrum and ilium of the pelvis. In addition, there are ligamentous attachments between the lumbar spine, sacrum and pelvis. This results in an interactive relationship between these various anatomical structures. The role of the pelvis in linking the spine and the lower limbs will now be discussed.

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2.4.5 THE PELVIS – LINKING THE SPINE AND LOWER LIMBS

The pelvis can be considered as a structure that couples the spine and the lower limbs. The pelvis has been described as a basic platform with three large levers acting on it (the spine and the two lower limbs). There are ligamentous and muscular attachments between the lumbar spine and the pelvis, and between the sacrum and the pelvis. As a result of these connections, movement of the sacrum with respect to the iliac bones, or vice versa, can affect the joints between L5-S1 and between the upper lumbar levels. Anatomical and functional disturbances of the pelvis or the lumbar region can therefore influence each other[146].

There are also muscular and ligamentous connections between the pelvis and the lower limbs. The following known anatomical characteristics of specific muscles and ligaments demonstrate this interactive relationship between the spine, pelvis and the lower limbs[146]:

- The lower lumbar multifidi muscles insert into the sacrum and also into the medial cranial aspects of the ilium.
- The ventral and dorsal sacro-iliac joint ligaments, the sacrotuberous and sacrospinous ligaments span and connect the sacrum and the lumbar spine.
- The iliolumbar ligaments are direct fibrous connections between the iliac bone and L4 and L5 vertebral levels.
- The long head of the biceps femoris hamstring muscle originates from the ischial tuberosity of the pelvis, as well as the sacrotuberous ligament and inserts at the head of the fibula and the lateral tibial condyle[102].
- The semitendinosus and semimembranosus hamstring muscles originate from the ischial tuberosity of the pelvis and insert on to the tibia[102].

Cycling involves a constant repetitive movement of the lower limbs and also incorporates a large range of hip flexion and extension excursion during the pedalling movement. The resultant contraction and stretch of the hamstring muscles may therefore affect the position and movement of the pelvis. This movement may have an indirect effect on the lumbar spine through the biceps femoris attachment to the sacrotuberous ligament (which, as mentioned spans and connects the sacrum and lumbar spine).

The interactive relationship between the lumbar spine, sacrum, and pelvis, and the role of the pelvis in coupling the spine and the lower limbs has been described[146]. This provides a significant background for a discussion of the proposed biomechanical function of the spine, pelvis and lower limbs during cycling (section 2.6.1.1).

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The discussion of the relevant spinal anatomy related to cycling, provides an important background for the discussion of mechanical loads that the spine is subjected to during cycling, and the importance of the correct bicycle set-up in minimising these loads. This will be reviewed in the next section.

2.4.6 BICYCLE "SET-UP" AND BIOMECHANICS OF THE LUMBAR SPINE DURING CYCLING

In contrast to sports such as running, there is little information where the mechanical load on the lumbar spine during cycling has been studied[3;7;19;25]. However in order to minimise the static and dynamic loads on the lumbar spine in cycling, the correct bicycle "set-up" appears to be important for a cyclist. Bicycle "set-up" can be defined as the adjustment of the alterable parts of the bicycle frame in order to create an optimal fit or match between the individual anthropometrics of the cyclist and the bicycle. Besides minimising abnormal mechanical loads on the body, the optimal bicycle set-up should create comfort for the cyclist and also enhance power and efficiency[19-21;33;127;130]. Furthermore flexibility in the lumbar spine, pelvis and hamstring muscles of the cyclist may affect their ability to attain and maintain a comfortable and efficient posture on the bicycle[33].

In the following section the optimal position of the cyclist on the bicycle will be discussed as well as how the body adjusts to cycling in different positions. Adjustments to the bicycle set-up and how these changes may affect the cyclist's position and recommendations for alternative bicycle designs will also be reviewed.

2.4.6.1.1 CYCLIST'S POSITION

In the seated position during cycling the optimal position is one of hip flexion, anterior pelvic tilt and a reduced spinal kyphosis. Firstly, this position would reduce the frontal cross-sectional area of the body[20;52;80;140], thereby minimising wind resistance and this could improve cycling speed and performance[80]. Secondly, this position may also reduce the risk of spinal injury. However, very few cyclists, often only elite cyclists, maintain this ideal position. Most cyclists maintain a position in which there is a varying degree of spinal flexion, as well as varying angles of antero- posterior pelvic tilt[16;126]. As previously discussed, the prolonged flexed position that is required for cycling could place constant passive tension on the posterior spinal structures such as spinal and sacro-iliac ligaments, muscles (multifidi and erector spinae), fascia, and increase pressure in the intervertebral discs. This increased tension may predispose these structures to strain injuries[53;123;125]. Furthermore, the repetitive movements of

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the lower limbs during cycling can transmit forces to the trunk which must be absorbed[18;19]. Therefore poor positioning of the trunk and pelvis during cycling could potentially cause strain on the posterior spinal structures due to ineffective absorption and transmission of these forces[18;19]. The flexibility of the cyclist may also influence the ability to maintain the trunk flexion that is optimal for cycling performance. In particular inflexibility of the hamstring muscles could result in posterior tension on the pelvis resulting in the pelvis assuming a posterior tilt position[102;146].

2.4.6.2 SPINAL ADAPTATION TO DIFFERENT CYCLING POSITIONS

As far as could be determined there is almost no published research on the possible biomechanical adaptation of the lumbar spine to different positions that a cyclist assumes while cycling. In one study electromyography (EMG) was used to study the adaptation of the lumbar spine to different positions adopted by cyclists in high performance cycling (including hands resting on the upper part of the hand grips, lower part of the hand grips and in the standing position)[140]. In this single study, 3 elite cyclists were tested, radiographs were taken in the different positions and changes in the lumbar spine were measured. In addition surface EMG activity of abdominal, lumbar and thoracic paravertebral muscles was measured. The main results of this study showed that the cyclists' position involved a change from lumbar lordosis to kyphosis when changing from the standing position to the sitting position. To obtain a more aerodynamic position, where the cyclist supported himself on the lower part of the hand grips, the cyclist flexed the hips and bent the pelvis forward without changing disc angles. The researchers concluded that, although the changes observed could modify the normal biomechanics of the lumbar spine, the overall mechanical load is reduced by shifting weight onto the upper limbs. The shift of mechanical load ensured that cycling did not generate forces which are dangerous for the spine. Additional findings of this study were that that hip flexion rather than lumbar spine position changed with cycling position[140].

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2.4.6.3 BICYCLE SET -UP

The bicycle set- up may also influence the mechanical load that will be placed on the lumbar spine and rest of the body during cycling. There are a number of key bicycle set-up parameters which could influence the cyclist's position – in particular the pelvic and spinal position. The key bicycles set-up parameters are: frame size, seat tube angle, seat height, reach, saddle set-back, saddle angle and handle bar height (Figure2.1)

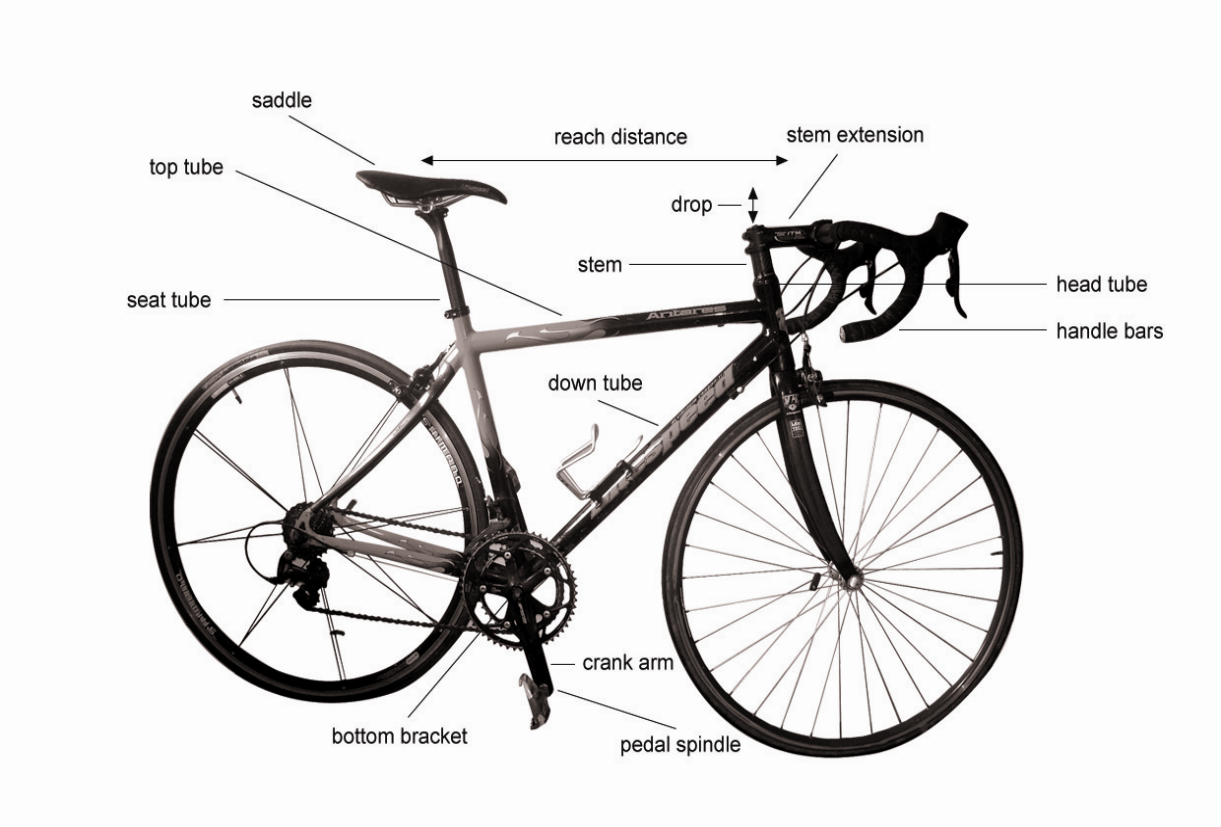

Figure 2.1: The components of a road bicycle that may relate to bicycle set-up

A. FRAME SIZE

The first step in the bicycle set-up, before various key adjustments can be made to the bicycle, is to select the correct frame size. In general, recommendations for the selection of frame size are vague and are not necessarily based on sound scientific research[98]. Several authors suggest that when the cyclist stands in cycling shoes and then straddles the frame there should be about 2 - 5cm between the crotch and the top horizontal tube. It is also suggested that about 5 - 10cm of the seat tube should be visible once saddle height is established[21;98].

There are two important aspects that must be considered when selecting the correct frame size. These are the seat tube angle and the top tube length.

The seat tube angle is an important angle on the bicycle. It is the angle formed by the seat tube with the ground. The most common seat tube angle is between 72-74 degrees. This allows an average sized cyclist to assume the recommended position when seated on the bicycle so that the knee is directly over the pedal spindle. Only minor adjustments to the fore and aft position of the saddle are then required[21].The seat tube angle is related to femur length. A longer femur length requires a smaller seat tube angle and this tends to move the

cyclist back on the bicycle. The cyclist with a short femur would require a larger seat tube angle to position the knee far enough forward[21].

The top-tube length is determined by the ratio of the upper body (or torso length) to the leg length. A recommendation by Mark Hodges, a former director of coaching for the US cycling team, which requires scientific validation, is to divide height in inches by the pants inseam in inches. A value greater than 2.2 indicates that the torso length is long relative to the leg length, whereas, a value of less than 2.0 indicates that the torso length is disproportionately short relative to leg length[20].

This anecdotal theory suggests that if the leg length is short relative to a longer torso, a frame with a closer relationship between the seat tube length and the top tube length (centre of the seat tube to the centre of the head tube) would be required. A “long” frame, for a cyclist with a long torso, may have a 58cm seat tube and a 59cm top tube; a “short” frame, for a cyclist with a short torso, may have a 54cm seat tube and a 52cm top tube[20].

B. SEAT HEIGHT

During the cycling motion, flexion and extension of the hip, knee and ankle joint must occur within certain limits for a cyclist to obtain maximum power output from the pedal cycle as well as remain comfortable[18]. If the seat is too high, power is diminished as the lower limb muscles are lengthened and have to contract beyond their optimal length–tension range[18]. Furthermore, increased seat height can result in compensatory excessive hip extension and this could result in the loss of a stable pelvic core[18]. A rocking motion of the pelvis can also occur if the seat is too high and this can propagate movement to the spine, which can cause fatigue in the lower back muscles and spinal joint structures. The upper body musculature, the gluteal muscles and the hip adductor muscles can also fatigue in an effort to maintain stability. In addition a raised saddle can result in excessive knee extension that may lead to locking of the knee joint. This would place excessive stress on the posterior structures of the knee such as the posterior knee joint capsule and the hamstring and gastrocnemius muscle groups.

On the other hand if the seat is too low there is increased knee flexion throughout the pedal cycle, particularly in the top dead centre (TDC) position of the pedal or crank arm. The increased knee flexion can result in an increase in patello-femoral and suprapatellar loading[96]. The quadriceps muscle, gluteus maximus muscle, hamstring muscles and gastrocnemius muscles may also function in a sub-optimal length tension relationship.

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The optimal saddle height is measured from the pedal spindle to the top of the saddle. The optimal saddle height for cycling has been estimated, but this was based on studies measuring mainly power output[49] and caloric expenditure[26;107;129]. In these studies it has been shown that oxygen consumption is minimised at approximately 100% of trochanteric height, or 106 – 109% of pubic symphysis height (measured from the ground standing barefoot)[47;49;107].

The optimal saddle height has also been determined using additional formulas based on the metabolic and empirical data[20;21] by cyclists such as John Howard (who measures the knee angle with the pedal in the bottom dead centre position), and Greg Le Mond (who multiplies the inseam measurement -floor to crotch, by 0.883 to obtain the distance from the centre of the bottom bracket to the top of the saddle[20;21]).

Finally, it should be noted that the crank length determines the size of the pedal circle, which in turn relates to the vertical distance the cyclist's feet rise from the bottom of the pedal cycle to the top. Therefore, to maintain a chosen saddle height, a change in crank length would require an equal alteration in saddle height[20;21].

C. REACH

The reach is defined as the measurement from the centre of the seat tube/post to the transverse position of the middle of the handle bars[20;21]. The reach is a parameter that mainly affects upper body position on the bicycle. The reach position varies considerably between individual cyclists as it depends on a variety of factors including the cyclist's upper body length, flexibility, experience and comfort[19]. An important consideration is that although an "optimal" posture may be adopted by the cyclist, cycling still places the upper body in an unnatural position.

It has been suggested that low back pain in cyclists may be related to an incorrect reach[33;98;99]. It has also been suggested that a relatively good reach set-up position should allow the cyclist to maintain an anteriorly tilted pelvis, a flat back without excessive flexion of the lumbar and thoracic spine, retracted scapulae, unlocked elbows and relaxed shoulders.

However, opinions differ regarding the correct reach distance from the saddle to the handle bars. One opinion is that, in order to prevent back pain in cycling, the reach should be decreased so that the cyclist can adopt a posterior pelvic tilt position[14;20;99;130]. A directly opposing opinion is that most often the cyclist experiences problems in the lower back due to insufficient reach, and that the reach distance should in fact be increased[33]. This suggestion

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originates from a group that has formulated an anthropometric measuring system to determine the individual's optimum cycling position (used by some 200 bicycle shops in Europe). The measuring system is based on data from a series of measurements of cyclists, including one study of 200 males and 200 females[33].

The explanation that motivates the suggestion that reach distance should be longer rather than shorter is based on logical anatomical principles. However, further research would be required for adequate validation of this explanation. These researchers suggest that if the reach is too short the lumbar spine is placed in a position of increased flexion, and the cervical spine may often assume an increased lordotic position relative to the thoracic kyphosis. This position of the spine is contrary to the natural form of the spine, and this may may lead to neck and back pain. A shortened reach, and the resultant increase in lumbar flexion may result in a posterior tilt of the pelvis, and this may cause the buttocks to slide forward on the saddle. This position of the pelvis, coupled with excessive flexion of the lumbar spine may place increased mechanical strain on the posterior spinal structures such as the ligaments and discs[33]. By increasing the reach distance and allowing the pelvis to adopt an anterior pelvic tilt, the cyclist can maintain a more neutral position of the vertebral column, thereby creating a more stable posture closer to the rear of the saddle. This position shifts the balance from the ischial tuberosities to the rami of the os ischii and the pubis on both sides. Tilting the pelvis forward may then minimise the stretch on the erector spinae and the external obliques and this could relieve pressure on the lower back. It has also been suggested that an anterior pelvic tilt may pre-stretch the gluteus maximus and this may enhance power development during cycling[33;127].

A shortened reach from the saddle to the handle bars would require the cyclist to assume a more vertical posture, thereby minimising the aerodynamic position favoured for racing. The racing saddle is also not designed for upright sitting which could lead to increased pressure through the saddle, and a greater likelihood of pressure sores developing in the perineal area[33]. In a standard retail bicycle frame, the length of the top tube (measured from the centre of the seat tube to the centre of the head tube) is proportional to the length of the seat tube and corresponds to the upper body measurements of the average-sized cyclist requiring that frame size[20;21].

Reach is the combined measurement of handle bar extension (stem length) and top tube length. The reach distance may be altered incrementally by changing the stem extension/ length. The stem is a removable part of the bicycle. There are recommendations for

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determining the correct stem extension, but these have not been validated by research. One of the recommendations is that the bicycle may be mounted on a wind-load simulator with the cyclist assuming a riding position with the hands in the drops of the handle bars. A plumb line is then dropped from the nose while the cyclist looks down at a 45 degree angle to the floor surface. The plumb line should fall about 2.5cm behind the handle bars. While maintaining the same position, the cyclist looks at the front hub which should be obscured from view by the handlebars. If this is so, the stem length is correct [20]. Some anthropometric measuring systems for determining bicycle set-up take into account the combined measurement of upper body length and arm length in order to determine a relative measurement of the reach[33].

As discussed, specific individual anthropometric measurements are required to determine the correct reach distance. However studies have shown that female riders may require a shorter reach distance than males with an equal inside leg length. A popular assumption is that females relative to males have a shorter upper body and relatively longer legs. The results from one study in 200 males and 200 female cyclists did not confirm this hypothesis and showed that the average upper to lower body ratio was identical in males and females at 0.70[33]. In this study, it was also documented that when both torso and arm length were combined to determine the reach, a difference between male and female cyclists (although not significant) was shown. The average ratio of torso length plus arm length to inside leg length was 1.52 for males and 1.49 for females. This means that the average female riders have 1 - 1.5cm shorter reach than male riders with an equal inside leg length. These findings were also confirmed in another study[69].

D. SADDLE SET-BACK

Saddle set-back is the longitudinal position of the rear (or front, depending on where the measurement is initially taken from) of the saddle behind the centre of the bottom bracket. As previously stated, adjusting the stem length changes the reach distance, but the reach distance is also altered by moving the saddle backwards or forwards. Moving the saddle has a direct effect on the position of the leg relative to the pedal spindle. It has been recommended that the posterior part of the patella should be positioned directly over the pedal spindle when the crank arm is in the horizontal forward position[20;21]. The knee-to-pedal relationship is based on the so-called neutral saddle position. This neutral saddle position also allows the apex of the sacrum to be in line with the rear of the saddle, so that a stable position on the saddle can be obtained[59;69]. In one study it was documented that females had a slightly longer femur than males, but that there was no significant difference in the ratio of upper leg

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length to total inside leg length (for males = 0.71, females = 0.73. This means that females have an upper leg length that is on average 1cm longer than males with an equal pubic-symphysis height. Therefore, it was recommended that the saddle setback for females should be approximately 0.5cm greater than for males[33].

E. HANDLE BAR HEIGHT

The handle bar level, or the drop, is the difference in height between the handle bar stem and the top of the saddle. This is an important factor in the relationship between the optimal reach position and cycling efficiency. An extended and sufficiently deep drop should be adopted to create a more aerodynamic posture. However, a larger drop (or lower handle bars) may result in a posture which may increase stresses on the lumbar and the cervical spine especially when racing over longer distances[92;99;124]. It is also important to note that excess weight bearing on the handle bars can cause compression neuropathies in the hand[21].

There are empirical recommendations for determining handle bar height, which have not been well researched. It has been suggested that the height of the handle bars should at least 2.5 – 5cm below the top of the saddle for a short cyclist and as much as 10cm for a tall cyclist[21]. Furthermore, recommendations have also been proposed based on research where anthropometric measurements in male and female cyclists were determined[33]**.** In one study the measurement of the length of the torso and the arm length were combined to determine drop and handle bar level[33]. Adjustments could then be made around these averages if the cyclist experienced cervical or lumbar complaints. The training level, lower body flexibility and abdominal strength would also facilitate riding with a deeper posture.

F. SADDLE ANGLE

The saddle angle is an important factor that can influence the position of the pelvis. A downward tilting saddle would allow the pelvis to assume a more anterior tilt, while a saddle in which the nose was tilted upwards would tend to place the pelvis in more of a posterior tilted position. An increased anterior pelvic tilt and a resultant decreased tensile stress to the longitudinal ligaments of the lumbar spine have been reported with a downward tilting saddle[126]. In one research study, the effects of bicycle seats with anterior-medial cut-outs on pelvic angle, trunk angle and comfort in female cyclists were investigated[16]. The results of this study showed that partial and complete cut-out designs can increase anterior pelvic tilt, while saddles with a complete cut-out design may increase trunk flexion angles regardless of hand

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position. Furthermore the partial cut-out design may be more comfortable than a standard or complete cut-out saddle.

To date, the recommendations for saddle angle are largely empirical. It has been suggested that the saddle should be parallel to the ground or slightly tilted up[20;130]**.** The parallel position could minimise the pressure on the perineal area and this would reduce the risk of developing saddle sores, as well reducing the risk of urologic and neuropathic complications, particularly in males[98;120]. The correct tilt of the saddle can be determined using a spirit level that is placed on the longitudinal axis of the saddle[120].

G. SUMMARY

When choosing a bicycle the correct frame size must first be selected. Frame size is selected with particular reference to the seat tube angle and the top tube angle (and this depends on the leg length of the cyclist, and the upper body to lower body ratio of the cyclist respectively). Following frame size selection, the parameters on the bicycle which then need to be adjusted to ensure a good bicycle set-up, specific to the cyclist's unique anthropometrics, include: 1) seat height, 2) reach, 3) handle bar height and 4) saddle angle. Although road bicycles are designed to optimise speed and efficiency during cycling, many cyclists, despite adjustments to the bicycle set-up, still experience back and neck pain. Alternative bicycle designs that may reduce back injury and discomfort have to be considered and will now be discussed.

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2.4.6.4 ALTERNATIVE BICYCLE DESIGN

In an effort to reduce neck and LBP in cycling, and ensure more comfortable cycling, some cyclists use adapted bicycles that create a more natural or physiological spinal position. The hybrid bicycle is an example of this and is a combination of a mountain bicycle and a road bicycle that creates comfort without sacrificing too much on speed.

In one study, the effects of a different pedal unit position on the dorso-lumbar angle was determined using radiographic techniques[138]. The results of this study showed that when the pedal unit was placed behind the saddle axis, a more physiological dorso-lumbar angle was created and this was significantly different to the angle created in the standard position of the pedal unit in front of the saddle axis. However, whether this position could 1) produce efficient and comfortable cycling over a long distance, and 2) reduce lower back pain requires further investigation.

It is clear from the discussion of the bicycle set-up, that the set-up must be specifically measured for each cyclist. The various parameters of the bicycle set-up are often inter-related, and must therefore be carefully adjusted to ensure injury prevention, comfort and efficient cycling. However, there are no studies that have investigated the relationship between intrinsic anthropometric variables in the cyclist, bicycle set-up and subsequent development of lower back pain in cyclists. This area requires further investigation, and will be addressed in one of the experimental chapters in this thesis.

The discussion of the related anatomy and the bicycle set-up provides a background for the discussion of the different hypotheses for the development of lower back pain in cyclists.

2.5 PATHOMECHANICS OF LOWER BACK PAIN IN CYCLISTS

There are limited research data to determine the possible pathomechanical mechanisms responsible for the development of LBP in cyclists. Furthermore, existing research is often limited by sub-optimal study designs and sample sizes. In this section, the data in support of the different hypotheses for the pathomechanics of LBP in cyclists will be reviewed.

As previously stated, the cyclist adopts an abnormal flexed position to enhance aerodynamics, thereby improving work efficiency and maximising cycling speed. The cyclist also attempts to reduce the frontal cross-sectional area, and this requires flexion of the hip joints and flexion of the thoraco-lumbar spine. This position of the spinal column during cycling differs markedly from the standing position. Ideally the cyclist should aim for a horizontal flattening of the trunk that can be achieved partly through an anterior tilt of the pelvis which would then minimise thoracolumbar flexion. It would be difficult for the cyclist to attain this position if there is limited flexibility in the hamstring muscles, capsular and ligamentous structures of the hip, lumbar spine or the sacro-iliac joints. Regardless of limitations in flexibility, the fact that the cyclist is seated already increases the tendency for the lumbar spine to assume a flexed position.

It has been documented by various researchers that there is an association between LBP and frequent forward bending[10;88] and prolonged sitting with the lumbar spine in a flexed position[6;10;89;152]. As previously mentioned, spinal flexion is also associated with increased discal pressures[104]. These mechanisms for the development of LBP could possibly be applied to cyclists who spend extended periods in a flexed position. However, the main difference in cycling is that a portion of the cyclist's mass is supported on the handlebars, unlike the open chain positions that are encountered in occupational and other settings. Furthermore, cyclists are not stationary, and the lumbar spine also has to absorb intersegmental joint reaction forces

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and moments that are generated by the lower limbs during pedalling. These forces and moments are transferred through the thoracolumbar spine while the trunk is in a flexed and sometimes rotated position.

In addition to the mechanical factors that have been mentioned above, it has also been proposed that there may be ischaemic pain originating in the lumbar disc during cycling. Due to the fact that the disc is predominantly avascular, maintaining the lower back in a stretched, static position may eliminate the normal discal movement that is necessary for nutrients to enter the disc and metabolic waste to move out. This is another possible pathophysiological mechanism that may lead to pain. Intermittent movement, to provide relief is suggested by proponents of this theory[128].

Therefore it is clear that a number of hypotheses to explain the pathomechanics of cycling related lower back pain have been suggested[22;99;140;149]. These hypotheses can be classified as: 1) the flexion relaxation hypothesis, 2) the muscle fatigue hypothesis, 3) over-activation of the spinal extensors hypothesis, 4) the altered motor control hypothesis, 5) the mechanical creep hypothesis and 6) the disc ischaemic hypothesis. These hypotheses for the development of LBP in cyclists will now be reviewed.

2.5.1 THE FLEXION RELAXATION HYPOTHESIS

The term flexion relaxation (FR) was first used to describe a sudden onset of myoelectric silence in the erector spinae (ES) muscles of the back during standing in full flexion in healthy individuals[44]. The FR response may also occur in sitting postures[112]. This research will be reviewed, and thereafter research will be reviewed for evidence of FR during seated cycling.

The flexion-relaxation hypothesis for the development of LBP in cyclists suggests that a deactivation of the erector spinae muscles occurs as the spine maintains a flexed position during cycling. As muscles relax, load is then shifted to the passive structures such as the ligaments and possibly the deeper muscles[23;44;73;95;112]. This results in structures such as the ligaments and intervertebral discs being placed at higher risk, as has been shown to occur when muscle forces are reduced during lifting[74]. A number of researchers have attempted to determine if FR occurs in prolonged sitting. The relaxation of the muscles has been defined as a reduction in maximum voluntary isometric contraction (MVIC) to either less than 1% of the surface EMG levels during upright sitting[23] or 3% of MVIC[73;95;112].

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A controlled trial in a laboratory was conducted to determine if FR occurs in individuals that are subjected to the seated forward flexed (slumped) sitting position[23]. In this study, surface electromyography was used to measure the muscle activity of the erector spinae muscles at the thoracic and lumbar levels in 22 subjects. In this study, 5 trials each of standing and seated forward flexion were performed. The results showed that in the seated forward position, FR occurred in the thoracic erector spinae muscles, but not in the lumbar erector spinae muscles[23]. In a second laboratory controlled trial FR in the thoraco-lumbopelvic muscles was investigated when moving from an upright to a flexed seated posture (slump). Twenty four healthy subjects were analysed, and surface electromyography was used to measure the activity in the superficial lumbar multifidus (SLM) and the thoracic erector spinae (TES). The results of this study showed that the superficial lumbar mutifidus exhibited FR at midrange flexion in sitting, but that the activity of the TES was highly variable (11 subjects demonstrating a decrease in activity, and 13 and increase in muscle activity)[112]. This suggests that during sitting, FR of the superficial lumbar multifidus may occur in the absence of FR in the lumbar erector spinae (as shown in the first study). As lumbar multifidus is considered to be an important segmental stabiliser of the lumbar spine[153] this may be of more clinical significance.

As mentioned, FR is considered to be a normal physiological response in healthy individuals during standing. The reason for this is that deactivation of the spinal extensor muscles allows the gluteal and hamstring muscles to lower the flexed trunk even further by allowing the pelvis to rotate around the hips. In a prospective repeated-measures cohort study of 54 patients with chronic LBP, there was an absence of the FR response in trunk flexion in standing[105]. Trunk flexion in standing is often momentary, with the individual soon returning to an erect posture. It has been shown that the myoelectrical silence of erector spinae muscles ceased when subjects returned to extension[35]. Although the FR response is considered a normal response it may become dysfunctional when a flexed posture is maintained for a prolonged time period after FR has occurred. This may indeed be the case in cycling and prolonged relaxation of spinal stabilising muscles may place a cumulative excessive load on the passive structures of the spine.

A different mechanism for the FR response in sitting when compared with standing has also been suggested. It has been proposed that in sitting there is a transfer of load to other muscles that control the thoracolumbar spine at mid-range rather than load transfer to the passive system or other active structures at the end of range[112]. This hypothesis is supported by some research results that show an increase and/or sustained discharge of motor activity in the thoracic erector spinae (TES). This increased activity in the TES precedes the offset of the

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superficial lumbar multifidus and the transverse fibres of the internal oblique muscles at mid-range of flexion (during the movement phase towards the slump position)[112]. However, in this single study, surface EMG was used. This therefore only provides insight into the superficial trunk muscles and not the deeper muscles such as the deep fibres of lumbar multifidus, transversus abdominus and psoas muscle.

In summary, it has been shown in one study that the FR response occurs in sitting, although research results from another study do not support this finding. A different mechanism of load transfer has also been proposed in sitting relative to standing. Evidence that the flexion-relaxation hypothesis could explain the development of lower back pain in cycling will now be reviewed.

In one case control study, possible differences in spinal kinematics and trunk muscle activity were examined in 9 cyclists with, and 9 cyclists without non-specific chronic LBP. Trunk muscle activity was recorded with surface electromyography (EMG) while the pain group cycled until the onset of LBP (38.5±12.7 min) and the non-pain group cycled until a level of discomfort (54.5±12.3 min). Results of this study showed that the lumbar multifidi did not exhibit a significant reduction in muscle activity. The data from this study therefore do not support the flexion relaxation hypothesis for LBP in cyclists[22].

In another controlled trial, trunk muscle activation during different cycling positions, using intra muscular and surface EMG, was measured in 6 non-cycling athletes (3 male and 3 female). Although limited by the small sample size, the results from this study showed that the lumbar erector spinae (LES), (which were monitored with surface electrodes), had very low activity (<5% MVIC), throughout the pedal cycle, but 3% and less MVIC in the racing flexed position. This may indicate a degree of FR of the lumbar erector spinae during seated cycling. The activity levels of the LES increased significantly in the standing and sprint standing positions[70]. As previously mentioned, the results of one study in cyclists failed to show the FR response in the lumbar erector spinae in short duration forward sitting/ slump sitting[23]. Slump sitting, however, places the spine in a very different position to the cycling position. It is also important to consider the fact that a cyclist supports a large percentage of the upper body weight on the handle bars and this shared load distribution may affect trunk muscle recruitment.

In summary, research to ascertain whether the FR response occurs in the flexed/ slumped seated position is not definitive. The results from one study showed no FR response in the lumbar erector spinae, and those from another study showed FR of the superficial lumbar multifidus. A review of studies to identify if the FR response occurred in the seated cycling

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position revealed only one study in which FR of the erector spinae occurred in the flexed racing position. However, this study was limited by a small sample size.

2.5.2 MUSCLE FATIGUE HYPOTHESIS

The muscle fatigue hypothesis suggests that the deactivation of spinal extensors is a sign of muscle fatigue rather than a manifestation of the flexion relaxation response. Evidence for this hypothesis as a possible pathomechanical mechanism of LBP in cyclists will now be discussed.

In one case control study, muscle fatigue was investigated in cyclists with and without back pain. Seven cyclists were compared in each group using bilateral surface EMG on the lumbar erector spinae muscles and various other muscles in the body while they cycled. The results showed that there is evidence of increased muscle fatigue in the erector spinae of the lower back pain group (LBP) when compared to cyclists in the control group. It was interesting to note that the LBP group had significant fatigue in the right erector spinae muscle, indicating that there was a possible asymmetrical loading at the end of the test. These researchers suggest that this increased muscle fatigue may aggravate LBP in cyclists[132]. However the study is limited by a small sample size and the fact that in a case control design no cause – effect relationship can be demonstrated. Therefore additional studies may be necessary to validate these findings. Furthermore the researchers did not discuss the mechanism by which the fatigue in these muscles may aggravate low back pain - an area which may also be explored in future research. Additionally, only surface EMG was used and studies where fine wire electrodes are used to monitor activity in deeper muscles such as lumbar multifidi may be of value. This is important as it has been shown that the lumbar multifidi display greater fatigue rates in subjects with chronic lower back pain relative to asymptomatic control subjects in the general population[11].

In summary, evidence supporting the muscle fatigue hypothesis is limited to one study with a small sample size. Additional research is necessary to validate this hypothesis.

2.5.3 OVER-ACTIVATION OF SPINAL EXTENSORS HYPOTHESIS

Another hypothesis for the development of LBP in cyclists suggests that over-activation of the spinal extensor muscles may cause muscle contracture and increased tissue strain across the lumbar spine in cyclists[99;133;140;141;149]. This mechanism has previously been suggested for the development of low back pain in the general population[63]. In one case series study, changes

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in the lumbar spine EMG activity of the abdominal, lumbar and thoracic paravertabral muscles during different cycling positions on different bicycles was evaluated in 3 elite asymptomatic cyclists[140]. In this study, there was an increase in contraction of the lumbar extensor muscles that was proportional to pedalling intensity. Furthermore it was observed that the abdominal muscles remained relaxed during all pedalling intensities. It was suggested that this imbalance between flexor and extensor muscles of the trunk may cause lumbar pain in cyclists without adequate training[140]. This study is however limited by a very small sample size, and the fact that only asymptomatic cyclists were tested. The study also does not provide details of how long the cyclists were cycling for. This is an important factor to consider when analysing the relationship between the onset of lower back pain in symptomatic cyclists and altered lumbar muscle activity.

In summary, the results from a small case series indicate that over-activation of the spinal extensors, leading to muscle contracture, may result in tissue strain of the lumbar extensors resulting in LBP in cyclists. Activity levels of the lumbar extensors increased proportionally relative to cycling intensity. This hypothesis, however, requires more research.

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2.5.4 ALTERED MOTOR CONTROL HYPOTHESIS

An imbalance of activity of the paravertebral spinal muscles on either side of the spine may also be a mechanism for the development of LBP in cyclists. In the case control study that was previously described in detail (section 2.5.2), muscle activity was recorded in the lumbar erector spinael muscles (with surface EMG) of 7 cyclists with and 7 cyclists without LBP. The results of the study showed that the lower back pain subjects had significant more fatigue in the right erector spinae muscle after a period of cycling (30 minutes) compared to asymptomatic cyclists. These results suggest that there may be an asymmetrical loading of the spine at the end of the test. The researchers postulated that the asymmetry in loading may be due to the dominance of the natural side in work sharing. All the cyclists in this study were right handed[132].

In another previously mentioned case control study[22] (section 2.5.1), differences in spinal kinematics and trunk muscle activity were investigated in 9 cyclists with LBP, and in 9 cyclists without LBP. The cyclists in the pain group showed a trend towards increased lower lumbar rotation and flexion, and this was associated with a loss of co-contraction of the lumbar multifidi. The findings of this study suggest that both altered motor control and altered kinematics of the lower lumbar spine may be associated with the development of lower back pain in cyclists. It was interesting to note that this motor pattern preceded the onset of LBP

during cycling. Therefore, it was suggested that this may indicate an inherent movement abnormality rather than a reflex response to pain. With the onset of pain there was also no evidence of an effective adaptive response to pain to reduce the amount of rotation and flexion of the lower lumbar spine[22].

It has also been noted that the lumbar multifidus becomes inhibited and reduces in size in patients with lower back pain (LBP) in the general population[9;31;55;58]. A possible explanation could be that the atrophy of the multifidus is not secondary to LBP, but that an atrophied or weaker lumbar multifidi resulted in reduced lumbar stability, and this caused LBP.

Therefore, there is some evidence that altered motor control of both the lumbar erector spinae and the multifidus muscles may be associated with the development of LBP in cyclists. This hypothesis also requires further investigation.

2.5.5 MECHANICAL CREEP HYPOTHESIS

Mechanical creep is a biomechanical characteristic which refers to a deformation or a change in strain of the ligament tissue which can occur over time if a constant load is applied to these structures[136;148;150]. Researchers suggest that mechanical creep may occur in the lumbar spine ligaments during prolonged sitting in a flexed position on a bicycle[22]. Details of this hypothesis will now be discussed.

Increased loads may be transferred to the spinal ligaments of the lumbar spine during cycling, whether this is as a result of reduced muscle support due to the FR response, muscle fatigue or lack of co-contraction of lumbar stabilisers during cycling[23;44;73;95;112]. It has been suggested that mechanical creep may occur, due to prolonged forward flexion, and that this results in accumulated micro-damage in the soft tissue structures such as the spinal ligaments and the posterior annulus leading to lower back pain[136;148]. It has also been proposed that once creep has occurred in the spinal ligaments, a mechano-reflex arc from the ligaments to the muscles may cause deactivation of the spinal muscles and this may result in a further reduction in spinal support and injury. The spinal ligaments may also not play as large a role in maintaining stability as previously thought, and the deactivation of the spinal muscles by the ligament-muscle reflex arc is thought to have more of an effect on spinal stability[23].

In one laboratory controlled study in an animal model (cats), electromyographic (EMG) activity of the L1–L7 multifidus muscles were recorded while applying a prolonged steady displacement to the lumbar spine through the L4–L5 supraspinous ligament, simulating a

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moderate anterior flexion. In this study, prolonged flexion of the lumbar spine resulted in tension-relaxation and laxity of the viscoelastic structures, loss of reflexive muscular activity within 3 minutes, and spasms (diagnosed by EMG) in the multifidus and other posterior muscles[154].

In another animal study, the effect of 20 minutes of static flexion on the lumbar multifidus of felines and the associated recovery time was investigated. The results showed that there was an initial sharp decrease of multifidus EMG activity followed by muscle spasms. Full recovery of residual strain in the L4/L5 supraspinous ligament and multifidus activity was not obtained until 7 hours of rest. It was concluded that static flexion of the lumbar spine places excessive strain on the viscoelastic tissues, resulting in spasms and requiring long periods of rest before normal function[64].

In a human study, creep, which developed during a short static lumbar flexion (10 minutes), elicited significant changes in the muscular activity pattern of the flexion-relaxation phenomenon[131]. In this study, the muscles seem to compensate for the loss of tension in the lumbar viscoelastic tissues and the spasms that developed suggest that some micro-damage occurred in the viscoelastic tissues[131].

Data supporting the mechanical creep hypothesis for the development of LBP in cyclists is however limited. The results from the case control study that was previously discussed (section 2.5.1) do not appear to support the hypothesis that spinal creep occurs in cyclists. In this study, spinal kinematics and trunk muscle activity was documented in cyclists with and without non-specific chronic LBP (n=18). Spinal kinematics was measured by an electromagnetic tracking system. The results showed that the spinal kinematics for the pain and non-pain group remained stable throughout the cycling period. These results therefore do not support the hypothesis that spinal creep occurs resulting in the development of back pain in cyclists[22]. Prolonged stretch applied to the spinal ligaments during cycling may 1) not induce creep, 2) induce minimal creep that did not alter spinal kinematics or joint structure or 3) cause activation of the ligament–muscle reflex arc, resulting in deactivation of spinal muscles as previously suggested. Additionally, although the pain group cycled until the onset of lower back pain, the overall length of time cycling (38.5±12.7 min for LBP group and 54.5±12.3 min for non-pain group) may also not have been a sufficient time period for creep to set in. Furthermore, it is possible that creep in the spinal ligaments may be delayed in cycling because of the shared load distribution of the body weight on the handle bars. Cyclists usually cycle for time periods exceeding an hour, and low back pain often escalates with an increase

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in cycling time. Therefore it will be important to study cyclists over a longer period of time to assess the possible onset of the FR response, manifestations of spinal creep and the possible appearance of associated muscle spasm.

In summary, data from two animal studies showed the negative effects of creep on the visco–elastic tissues of the spine, as well as the associated muscle spasms in the multifidi muscles that are caused by sustained static flexion. However, in a single human study, short duration static lumbar flexion showed that creep resulted in a loss of tension in the lumbar visco-elastic tissues which was associated with muscle spasm that could indicate micro-damage to the visco-elastic tissues. However, in a single study investigating spinal kinematics in cyclists, no evidence of creep was demonstrated.

2.5.6 DISC ISCHAEMIA HYPOTHESIS

It is well established that up to the age of 8 years the intervertebral discs of a human have a blood supply, but thereafter discs are dependent for their nutrition on diffusion of tissue fluids[128]. As mentioned previously, this fluid transfer is through two mechanisms a) the bi-directional flow from vertebral body to disc and from disc to vertebral body and b) the diffusion through the annulus from blood vessels on its surface. Movement of the spine is thought to aid this fluid transfer in and out of the disc[128;157].

It has also been hypothesised that ischaemic pain may originate from the lumbar disc[128]. The lumbar disc is predominantly avascular. Lower back pain may be caused by maintaining the lower back in a stretched, static position. In this position, the normal mechanism for nutrients to enter the disc and metabolic waste to move out is reduced, and this process may cause pain. Intermittent cyclical loading of the disc may possibly aid fluid movement in and out of the disc, thus reducing pain[128].

SUMMARY: PATHOMECHANICS OF LOWER BACK PAIN IN CYCLISTS

In summary, a number of hypotheses have been suggested to explain the pathomechanics of the development of low back pain in cyclists. In general, there is very little scientific evidence to support these hypotheses, and in many instances these hypotheses seem contradictory. However, it is also possible that these hypotheses represent a continuum of, and do not explain the development of LBP in cyclists in isolation. It is important to note that in all the studies that investigate possible pathomechanics of LBP in cyclists, the behaviour of muscles and spinal kinematics in cyclists with LBP were only monitored for a short time period (less

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than an hour [22;132;140]). It is possible that by beginning to record motor patterns after a time period exceeding an hour, and thereafter by, continuing to record over a longer period, more accurate information on the pathomechanics of LBP in cyclists will be obtained. In most instances cycling sessions and races far exceed one hour.

It is possible that a broader hypothetical model for the pathomechanics of LBP in cyclists can be suggested. For example, initially during cycling fatigue of the spinal extensors may set in (muscle fatigue hypothesis)[132]. The FR response may be delayed for a time period during cycling because, unlike in flexed sitting postures, in cycling there is shared weight bearing of the trunk through the arms and hands which are supported on the handle bars. However, if this position is maintained for long enough, FR may occur, and this may be followed by the first signs of creep as the load is transferred from the active supporting structures to passive supporting structures. The stretch on the ligaments may then cause a ligament-muscle reflex arc which may further deactivate the spinal stabilising muscles[23]. A further reduction in spinal muscle support may then place increased load on the spinal ligaments which eventually leads to damage of the ligaments and reflex muscle spasms in the spinal muscles, a mechanism that has been described in the sitting posture in non-cycling athletes. A lack of co-contraction of the stabilising lumbar multifidi, as documented in some studies[22;132], may contribute to increased flexion and rotation of the lumbar spine which may cause an asymmetrical strain on passive structures as active muscle support becomes reduced.

Finally in addition to the proposed physiological changes, ischaemic pain from the disc may also contribute to the LBP. The disc is largely avascular, and the blood supply to the disc may be further compromised due to the sustained flexed posture.

However, it is clear from this review on possible pathomechanics of LBP in cyclists that there are very few data to support any of these hypotheses, and this requires further investigation. A review of the possible intrinsic and extrinsic risk factors that have been associated with LBP in cyclists may provide information to determine the possible causes of LBP in cyclists.

2.6 RISK FACTORS ASSOCIATED WITH LOWER BACK PAIN IN CYCLISTS

Although the aetiology of LBP in cyclists is still unclear, a few studies have reported possible risk factors that may be associated with the development of LBP in cyclists. Scientific evidence to support each of these risk factors is however limited. The factors which place the cyclist at risk of developing an injury may be categorised into extrinsic and intrinsic risk factors. Extrinsic

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risk factors are external factors which may influence the cyclist such as training and the environment. Intrinsic risk factors are inherent characteristics of the cyclist [age, body mass index, physiological parameters (conditioning, muscle strength, muscle balance) and behavioural parameters]. The factors that have been suggested as possible risk factors for LBP in cyclists are summarised in Table 2.2. A detailed discussion of each risk factor and the scientific basis for each risk factor will be presented. Additional studies which report risk factors associated with developing LBP in the general population will also be discussed where these may have relevance to LBP in cyclists. The evidence for each risk factor will be reviewed using evidence-based medicine criteria. Established evidence-based medicine guidelines will be used. For each risk factor the evidence can range from Level I (strong evidence) to Level IV (very weak or no evidence)[115].

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Table 2.2: Extrinsic and Intrinsic Risk Factors for LBP in cyclists (level of evidence according to evidence based medicine (EBM) criteria)[115].

Risk factors		Study details and reference	Level of evidence (I-IV)[115]
Extrinsic risk factors	**Training and racing factors:**		
	Distance cycled	Positive association: Cross sectional survey[151]	III
	Low gear usage	Positive association: Cross sectional survey[151]	III
Intrinsic risk factors	**Muscle dysfunction:**		
	Asymmetrical spinal muscle firing patterns	Positive association: case control [22;132]	III
	Imbalance of trunk muscles	No association: case series[140]	IV
	Weak hip flexors and abductors	Positive association: case series[85]	IV
	Flexibility:		
	Lumbo-pelvic inflexibility	No association: case control[17]	III
	Anthropometry :		
	Cyclist / bicycle fit (pelvic tilt / saddle angle)	Positive association: prospective cohort [126]	I

2.6.1 EXTRINSIC RISK FACTORS ASSOCIATED WITH LBP IN CYCLISTS

2.6.1.1 TRAINING/RACING ERRORS AND ENVIRONMENTAL CONDITIONS

In a number of endurance sports, notably running, training errors are consistently listed as extrinsic risk factors for injury[66;67;83;143]. Therefore, in cycling, training parameters such as training distance, training on hilly terrain, and correct gear selection could be extrinsic factors that may be associated with the development of LBP. In a single questionnaire survey, 30.3% of the 518 cyclists (294 male and 224 female) who experienced lower back pain reported that

LBP was aggravated by increased distance cycled per week, use of lower gears (this creates increased resistance during pedalling, but enhances power for forward propulsion of the bicycle) and less years of cycling[151]. The use of low gears and attempting to participate in long distance cycling races may also lead to the development of LBP during races.

Furthermore, environmental conditions such as windy conditions may also alter the risk of developing LBP in cyclists. In one questionnaire survey conducted directly after cyclists had completed a series of cycling races, cyclists reported that the development of neck pain was associated with windy conditions, hilly terrain and long distance cycling[37]. However, we are not aware of any other studies where training parameters and environmental conditions as possible risk factors for LBP in cyclists have been investigated.

There are no known published studies on the frequency of stretching in cyclists. In one cross sectional study of 225 runners; asymptomatic runners were significantly more likely to stretch prior to training ($p=0.028$) and racing ($p=0.003$) compared to runners who suffered from lower back pain[83].

In this section, possible extrinsic risk factors associated with LBP in cyclists have been suggested. However, very few studies have been conducted to support these as possible risk factors for LBP in cyclists and therefore this requires further investigation.

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2.6.2 INTRINSIC RISK FACTORS ASSOCIATED WITH LBP IN CYCLISTS

A number of intrinsic risk factors for the development of LBP in cyclists have been proposed. These include 1) muscle dysfunction parameters including: asymmetrical paravertebral muscle firing patterns, strength and imbalance of trunk muscles and weak hip flexor and hip abductor muscles, 2) flexibility parameters, in particular lumbo-pelvic inflexibility, and 3) anthropometric parameters (including the cyclist / bicycle fit). Current scientific evidence in support of each of these intrinsic risk factors will now be reviewed. Other possible intrinsic factors that may be associated with the development of LBP in cyclists will also be suggested. These include hamstring flexibility and asymmetrical leg length.

2.6.2.1 MUSCLE DYSFUNCTION COMPONENTS AS RISK FACTORS FOR LBP IN CYCLISTS

A. ASYMMETRICAL PARAVERTEBRAL MUSCLE FIRING PATTERNS

It has been suggested that asymmetrical firing patterns of the lumbar muscles on either side of the spine may affect spinal kinematics and support[22;72], and therefore be a risk factor for LBP in cyclists. In one case control study (previously discussed in section 2.5.1) differences in spinal kinematics and trunk muscle activity were documented in cyclists with and without non-specific chronic LBP (n=18)[22]. It was noted that the symptomatic group had increased lumbar flexion and rotation at the onset of cycling (pre- testing), indicating a possible predisposed risk to the development of lower back pain in cycling[22]**.** Additionally, with the onset of pain there was no evidence of an effective adaptive response by reducing the amount of flexion and rotation of the lower lumbar spine. These cyclists also showed an associated loss of co-contraction of the lumbar multifidus. Although the cyclists in this study did not exhibit obvious scoliosis, the increased spinal flexion and rotation may affect the symmetrical firing of para-vertabral multifidi thus reducing spinal support**.**

A similar asymmetry in firing patterns was also shown in the lumbar erector spinae muscles in another case control study (previously discussed in section 2.5.2)[132]. Cyclists with LBP were compared with cyclists without LBP (n=14). Surface EMG results showed higher muscle fatigue in the erector spinae of the lower back pain group (LBP) when compared to their controls. It was interesting to note that the LBP group had significant fatigue in the right erector spinae muscle which may indicate that there was an asymmetrical loading at the end of the ride. The researchers suggest that the asymmetry in loading may be due to the dominance of the right side in work sharing, as all cyclists in this study were right handed[132].

In summary, there are some research data that show asymmetrical firing patterns of the para-vertebral multifidi and erector spinae muscles in cyclists with LBP, with one side showing greater fatigue than the other. This may be a risk factor for developing LBP in cyclists. Studies using ultrasound imaging have shown unilateral atrophy of the lumbar multifidus in patients with acute and sub-acute LBP[56] in the general population. Further research is however necessary to determine whether the muscle atrophy existed before the LBP began or occurred as a result of the LBP.

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B. DECREASED STRENGTH AND IMBALANCE OF TRUNK MUSCLES

It has been suggested that an imbalance in trunk muscle activity, particularly weak abdominal muscles relative to over-active back extensors, may be a risk for the development of LBP in cyclists. In a case series study previously mentioned (in section 2.5.3) changes in the lumbar spine produced by different cycling positions on different bicycles, used during competitions, were studied. In this study 3 elite asymptomatic cyclists were tested and EMG recordings were taken from the abdominal, lumbar and thoracic paravertabral muscles during cycling. The results showed that there was an increase in spinal extensor muscle activity that was proportional to pedalling intensity. The abdominal rectus muscles remained relaxed in all cycling positions. It was suggested that the imbalance which occurs between the flexor and extensor muscles could cause lumbar pain in cyclists without adequate training[140].

However, the EMG activity in the transversus abdominis muscles was not measured as this would require intra- muscular wire electrode insertion rather than surface electrode placement. There may have been activity in this muscle relative to the rectus abdominis, as the transversus abdominis muscle together with external and internal obliques has been shown to play a role in stabilisation of the lumbar spine[57] .

In another controlled trial, muscle activity in various muscles, including 3 layers of the abdominal wall, was measured during several positions of cycling using intramuscular EMG placement[70]. Activation of the transversus abdominis, internal and external obliques was recorded. The results showed that the abdominal muscles were activated to relatively low but continual levels except during standing and sprinting[70].

In the general population, the lumbar multifidi have shown a greater fatigue rate in patients with chronic lower back pain compared to asymptomatic control subjects[11]. Other researchers have also documented that that the lumbar multifidus becomes inhibited and reduces in size in lower back pain (LBP) sufferers[9;31;55;58].

In summary the results of two studies have shown low levels of abdominal muscle activity during cycling (not sprinting or standing). In contrast the spinal muscles have shown increased levels of activity proportional to increased levels of cycling intensity. These studies were on asymptomatic subjects and the imbalance in trunk muscle activity as a risk factor for LBP in cyclists would require further investigation in cyclists with LBP. Furthermore, studies to document intramuscular EMG activity in the abdominal and posterior spinal muscles in cyclists with and without LBP, over a longer time period of cycling, are necessary.

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C. WEAK HIP FLEXORS AND ABDUCTORS

It has been suggested that there is a possible association between psoas dysfunction (weakness) and LBP in cyclists[70;85]. The psoas muscle is a primary hip flexor that originates from the lumbar vertebrae and is constantly active through a wide hip flexion range of movement during cycling. This high activity level of psoas during cycling suggests that further research is required investigating the possible association of psoas dysfunction or overuse with LBP in cyclists[70].

In one research study in cyclists, EMG activity of the psoas muscle was studied during cycling. The results of this study showed that psoas muscle activity ranged from 14% of MVIC during the upstroke phase of normal cycling, to 60% of MVIC during sprinting. It was also documented that a flexed posture increased psoas activity at TDC of the pedal cycle. The researchers therefore suggested that cyclists should not consciously flex the torso during cycling, particularly when the psoas, hip, or low back is at risk, for example following injury or surgery[70].

In a single case report it was suggested that weak hip flexor and abductor muscles may be additional predisposing causes of lower back pain in cyclists. In this report, an attempt was made to treat the LBP of a competitive cyclist who complained of 6 month duration of cycling related lower back pain. Initially the cyclist was treated with joint mobilisation of the lumbar spine and core strengthening of the deep lumbar and abdominal muscles. Although this resulted in a reduction in pain after a three month period, the cyclist was unable to resume pain free training. The cyclist was re-examined and diagnosed with internal snapping hip syndrome that was prompted by a subjective report of a “popping” sensation deep in the hip when moving his hip from flexion into extension. Internal snapping hip syndrome is a painful lesion of the iliopsoas caused by snapping of the tendon over the iliopectineal eminence or the anterior femoral head when the femur is extended from a flexed position, and has shown to be associated with weak hip flexor and abductor muscles[68]. After participating in a programme of hip flexor and abductor strengthening over a 6 week period, the cyclist was able to ride 300km a week virtually pain free[85].

In summary, there are very few data in support of the hypothesis that weak hip flexors and abductors are associated with an increased risk of developing LBP in cyclists. It has been shown that the psoas muscle is very active during cycling. In a single case, a strengthening programme for the psoas and hip abductor muscles was shown to reduce LBP in a

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symptomatic cyclist[85]. However, further investigation is required to confirm the possible association between psoas dysfunction and the development of LBP in cyclists.

2.6.2.2 FLEXIBILITY COMPONENTS AS RISK FACTORS FOR LBP IN CYCLISTS

A. LUMBO-PELVIC INFLEXIBILITY

It has been suggested that reduced hip flexibility coupled with excessive lumbar motion during forward bending results in LBP in the general population[12;41]. However, there are few studies in which this has been investigated. In one case control study, differences in lumbar spine and hip motion where compared in non-athletic subjects with and without lower back pain. The results of this study showed that subjects with a history of back pain had similar amounts of lumbar spine and hip motion when compared with asymptomatic subjects[41].

In one prospective study, the impact of flexibility on lower back pain was investigated in a group of adolescent multi-disciplinary athletes and non-athletic controls[78]. In this study a decreased range of motion of the lower lumbar levels was predictive of LBP in the female subjects[78]. In another study among 116 top male Swedish multi-disciplinary athletes, there was no correlation between spinal flexibility and back pain[134].

Finally, in a case control study the association between LBP and the level of lumbo-pelvic inflexibility (sit and reach tests) was studied in athletes (cyclists and runners) and compared to a sedentary control group. The results showed that there was no correlation between hip and lower back inflexibility and LBP in athletes (cyclists and runners). This study was limited in its methodology due to 1) lack of control for age, and 2) the flexibility test chosen may not have been adequate[17].

Therefore, it appears that the results from a limited number of studies do not support the association between inflexibility and LBP in the general population and in athletes. Further research to evaluate lumbo pelvic inflexibility as a risk factor for LBP in cyclists is however necessary.

2.6.2.3 ANTHROPOMETRIC COMPONENTS AS RISK FACTORS FOR LBP IN CYCLISTS

A. CYCLIST/BICYCLE FIT - PELVIC TILT AND SADDLE ANGLE

The factors to consider when setting up a bicycle have been reviewed (section 2.4.6). The parameters include the following: saddle height, saddle set-back position, reach and saddle

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angle. Currently, the recommendations for bicycle set-up are given based on averages. It is important to consider that recommendations do not necessarily reflect an individual's riding style. On this basis it is necessary to individualize a bicycle set-up according to each cyclist's anthropometric measurements, as an incorrect bicycle set-up may increase the risk of LBP in cyclists.

In one study, it has been documented that by altering the bicycle set-up, anterior knee pain (patellofemoral pain - PFP) could be reduced. In this study, PFP was decreased by raising the saddle height and inserting a medial forefoot wedge under the cycling shoe[144]. However, very few studies have been conducted to determine if the bicycle set-up is associated with LBP in cyclists.

It has been suggested that a forward or anterior pelvic tilt (APT) is favourable for cycling as it may reduce the tensile forces on the lumbo-sacral spine, thereby reducing the risk of LBP in cyclists[33;126]. An APT and forward position of the trunk may help distribute a greater percentage of the body weight over the handlebars, thereby reducing the load on the seat and lumbar vertebrae of the spine [33]. Additionally, an increased APT is thought to facilitate a more favourable aerodynamic position in competitive cyclists[93].

The biomechanical inter-relationship between the lower limb, pelvis and the lumbar spine has been studied in walking. Therefore, pelvic biomechanics in walking, and how this may relate to LBP will be reviewed briefly. During the swing phase of the right leg in walking the cranial part of the right iliac bone tends to rotate dorsally with respect to the sacrum[46]. Stated otherwise, at the right side, the top of the sacrum inclines forward relative to the iliac bones (nutation of the sacrum). Nutation of the sacrum increases ligament tension and sacroiliac joint compression[46].

We are not aware of any published research that specifically addresses the biomechanical inter-relationship between the spine, pelvis and the lower limbs during cycling. It may be possible that during the upward hip flexion stroke of the pedal cycle, which is a movement similar to the swing phase of walking, the cranial part of the iliac bones may also rotate dorsally, and the sacrum may nutate and incline forward relative to the iliac bones. This posterior rotation of the ilia relative to the sacrum may also be increased in the sitting posture relative to the standing posture. Therefore, if the seat nose of the bicycle was tilted upward (posteriorly) the posterior rotation of the ilia may be further increased and the nutation of the sacrum may be increased. As already stated, nutation increases ligament tension. It is therefore possible that increased sacral nutation causes excessive ligament tension of the sacroiliac ligaments (especially the sacrotuberous ligament) and indirectly increased strain on

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the lumbar spine due to its connections to the sacroiliac ligaments. This theory would however require further research using biomechanical studies.

It may also be possible that when the knee joint is almost fully extended in the bottom dead centre position of the pedal cycle, inflexibility of the hamstring muscles may create tension on the attachment of the hamstring muscles at the ishcial tuberosity. This increased tension may cause excessive posterior rotation of the ilia and result in increased tension in the sacroiliac ligaments and therefore indirectly on the lumbar spine.

In one controlled clinical trial[126] the pelvic/spine angles at different seat angles on different bicycles (10 asymptomatic subjects per bicycle) was measured by serial fluoroscopic investigations. The results of this study showed that there was a tendency towards hyperextension of the pelvic/spine angle, and this resulted in an increase in tensile forces at the promontorium (the most prominent anterior projection of the top/ base of the sacrum). It was shown that these forces could be reduced by adjusting the seat angle to create an anterior inclining angle. The hyperextension of the pelvis was greater in the seated position on the road bicycles compared to mountain and town bicycles. The findings were then applied to a group of 80 cyclists who suffered from lower back pain. An adjustment of the saddles of these cyclists, by inclining the saddle anteriorly by 10-15 degrees, resulted in improvement in the incidence and magnitude of LBP in 70% of the cyclists [126]**.** A downward tilted saddle would place the pelvis in an anteriorly tilted position.

In a single case control study the mean angles of APT, and the variability of APT angles were compared in 17 elite cyclists and 17 matched non-cyclists. The APT was assessed in the long- sitting position with the chest as close to thighs as possible and was measured using a digital inclinometer over L5-S1 intervertebral space. The results showed that the APT angles were significantly greater, and that there was less variability in the APT in elite cyclists, compared with matched non- cyclists[93]. Although it was not measured in this study, the elite cyclists may have had more flexible hamstring muscles. This would increase the anterior pelvic tilt and create a more ideal length-tension muscle relationship that could increase the cycling efficiency. In future research studies, it may be of value to compare the tilt of the pelvis in asymptomatic cyclists with cyclists who suffer from LBP. Regardless of the fact that certain cyclists may have higher anterior tilt angles, the position of the saddle can still alter the tilt of the pelvis, and must therefore be adjusted to match the individual's anthropometrics. This adjustment will facilitate the attainment of an anterior tilt of the pelvis on the bicycle.

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In summary, the attainment of an anterior pelvic tilt in the seated position of cycling is considered favourable to avoid the development of LBP. A posterior pelvic tilt is thought to increase strain on the spine and posterior pelvic structures, including the sacro-iliac ligaments. It has been shown that elite cyclists have an increased anterior pelvic tilt relative to non-cyclists. In a single study, anterior tilting of the saddle reduced tensile forces at the spine and sacrum, and a reduced LBP in 70% of cyclists[126]. One of the possible mechanisms that may result in an increased ATP, and thereby reduce LBP in cyclists is increased hamstring flexibility. However, this requires further investigation.

2.6.3 ADDITIONAL RISK FACTORS ASSOCIATED WITH LBP IN CYCLISTS

In the general population, it has been suggested that inflexible hamstring muscles, a specific component of flexibility, is also a possible risk factor for developing LBP during cycling. Asymmetrical leg length, an anthropometric component, is also suggested as a risk factor for developing LBP in cyclists. These factors have not been studied or recorded as possible risk factors for LBP in cyclists. However, there is a rationale for these factors to be related to the development of LBP in cyclists and this deserves discussion.

2.6.3.1 HAMSTRING MUSCLE FLEXIBILITY

The origin of the hamstring muscle group is at the ishcial tuberosities. Inflexibility of the hamstring muscles can be defined as a decreased hamstring dynamic length and can be measured relative to straight leg raise range of movement. A reduced hamstring flexibility may pull the pelvis into a posterior tilt position, thereby reducing the normal lumbar lordosis and increasing the risk of LBP in cyclists (reviewed in section 2.6.2.3 - pelvic tilt). Therefore, hamstring inflexibility may predispose to LBP in the general population and possibly in cyclists[84].

In one case control study of 150 subjects the control subjects had significantly higher values for the straight leg raise test (a measure of hamstring flexibility) than a chronic back pain group[61]. However, in another large cross-sectional study in which factors associated with lower back pain were investigated in 600 subjects, there was no association between lower back pain and hamstring inflexibility[110].

To date, there are no studies that have explored a possible relationship between inflexibility of the hamstrings and posterior structures (such as the hip capsule, fascia or sacral ligaments) and the development of lower back pain in cyclists. It may be possible that inflexibility in these

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posterior structures resist the ability to anteriorly tilt the pelvis during cycling. The pelvis may be pulled into a posterior tilt when the leg is in the stretched position or bottom dead centre position of the cycling stroke. Limitations in hamstring flexibility may also affect the length tension relationship in these muscles which in turn may inhibit efficiency of muscle contraction and cycling performance. Therefore, hamstring inflexibility as a possible risk factor for LBP in cyclists requires further investigation.

2.6.3.2 ASYMMETRICAL LEG LENGTH

Asymmetrical leg length has also been implicated as a possible cause for lower back pain in the general population. In one case control study, the association between chronic back pain and the short leg syndrome, was examined[48]. The results of this study showed that there was no relationship between chronic back pain and a leg length discrepancy. In another randomised control intervention study, the effect of conservative correction of a leg-length discrepancy ($\leq$10mm) was studied in 33 patients with chronic LBP. The results of this study showed that there was a reduction in lower back pain in subjects whose leg length difference was corrected with a shoe insert[34].

In cyclists with a leg length difference, an asymmetry of the pedal cycle may result in slight rocking of the pelvis as well as a loss of efficiency during cycling. The asymmetrical forces resulting from rocking of the pelvis may be propagated to the spine, thereby fatiguing the spinal muscles[19]. Shoe inserts or wedges placed under the cleat of the cycling shoe have been used to reduce medio-lateral deviation of the knee during cycling and thus reduce patellofemoral pain[50;144]. However, there are no known intervention studies to determine if inserts and wedges to correct leg length asymmetry reduce LBP in cyclists.

In summary, there is an association between inflexible hamstrings and LBP in the general population[61]. However, a similar association has not yet been studied in cyclists. Furthermore, correction of a leg length difference has been shown to reduce LBP in the general population[34], but again this association has yet to be investigated in cyclists.

2.7 SUMMARY AND CONCLUSION

- The epidemiology of injuries in cycling has not been well studied.
- In particular, there are few reports where overuse injuries in cycling, and specifically lower back pain, have been studied.

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- Reports do however indicate that LBP is a common cycling injury and its prevalence is likely to be underestimated.

- The cyclist's position on the bicycle results in the spine being placed in a non-physiological flexed position for an extended period of time.

- In cycling the prolonged flexed position potentially places a greater load on the spine which may increase the possibility of developing LBP.

- The importance of the selection of the correct bicycle frame to match the individual, as well as the correct bicycle set-up have been highlighted as an important factors in ensuring an optimum position to reduce the strain on the lower back region.

- The significant adjustable parameters on the bicycle are, seat height, reach and saddle set-back, handle bar height and saddle angle.

- A number of pathomechanical hypotheses for the development of LBP in cyclists have been proposed and include the: flexion–relaxation hypothesis, muscle fatigue hypothesis, over-activation of spinal extensor muscles hypothesis, altered motor control hypothesis, mechanical creep hypothesis, and disc ischaemia hypothesis.

- The flexion–relaxation hypothesis[22;23;70;112;114] suggests that a deactivation of the paravertebral spinal muscles may occur as the spine maintains a flexed position during cycling. The load may then be shifted to the passive structures such as the ligaments and possibly deeper muscles, subjecting these structures to increased strain and damage[23;44;73;95;112]. A review of studies to identify if the FR response occurred in the seated cycling position revealed only one study in which the FR response of the erector spinae muscles occurred in the flexed racing position. However, this study was limited by a small sample size.

- The muscle fatigue hypothesis[132] suggests that the deactivation of spinal extensors is a sign of muscle fatigue rather than a manifestation of the flexion relaxation response. This theory was supported by one case control study in which results showed higher muscle fatigue in the erector spinae of the LBP group when compared to their controls.

- The over-activation of spinal extensor muscles hypothesis[99;133;140;149], suggests that over-activation of the spinal extensors may cause muscle contracture and increased

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tissue strain across the lumbar spine in cyclists[99;133;140;141;149]. An isolated study showed an increased level of activity in the spinal extensors proportional to pedalling intensity. Although this high level of activity may lead to muscle spasm and strain of the lumbar spine, further studies are needed to support this theory.

- The altered motor control hypothesis suggests that an imbalance of activity of the paravertebral spinal muscles on either side of the spine may also be a mechanism for the development of LBP in cyclists. The results of two studies showed altered motor control of both the lumbar erector spinae and multifidus muscles, respectively, which supports this theory for the development of LBP in cyclists.

- The mechanical creep hypothesis suggests that mechanical creep may occur, due to prolonged forward flexion, and that this results in accumulated micro-damage in the soft tissue structures such as the spinal ligaments and the posterior annulus leading to lower back pain[136;148]. No studies on cyclists have shown evidence of mechanical creep, although a study on non-cyclists showed manifestations of creep in a position of short static lumbar flexion.

- The disc ischaemia hypothesisis proposes that ischaemic pain may originate from the lumbar disc[128]. The lumbar disc is predominantly avascular. By maintaining the lower back in a stretched, static position, discal movement that is necessary for nutrients to enter the disc and metabolic waste to move out is eliminated.

- It is possible that these hypotheses represent a continuum of the same phenomenon, and do not explain the development of LBP in cyclists in isolation or exclusively. It is important to note that in all the studies that investigate the possible pathomechanics of LBP in cyclists, researchers monitored the behaviour of muscles and spinal kinematics in cyclists for time periods short of an hour[22;132;140]. It is possible, that by only beginning to record motor patterns after an hour of cycling has already elapsed, and thereafter continuing to record over a longer period, more accurate information on the pathomechanics of LBP in cyclists will be obtained. In most instances cycling sessions and races far exceed one hour.

- A broader hypothetical model for the pathomechanics of LBP has therefore been proposed in this review. Of the individual aetiological components comprising the proposed hypothesis, the lack of co-contraction of the lumbar multifidi as a cause for

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LBP in cyclists, has received the most validation in research studies, although this is also limited.

- Risk factors for LBP in cyclists can include extrinsic and intrinsic risk factors.
- Extrinsic risk factors for LBP in cyclists have not been studied well but include increased distance cycled and training errors such as excessive low gear usage.
- Intrinsic risk factors for LBP in cyclists include muscle dysfunction factors such as: asymmetrical firing of paravertebral spinal muscles and weakness of hip flexors and abductors. Anthropometric factors which are associated risk factors include: the cyclist/bicycle fit, in particular, a reduced anterior pelvic tilt position due to an incorrect bicycle set-up of the saddle angle[126]. Inflexibile hamstring muscles have been shown to be associated with LBP in the general population, but this association requires investigation in cyclists.
- The extrinsic and intrinsic risk factors for LBP in cyclists have not been studied well and this is the basis for the research studies in this thesis.

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CHAPTER 3 - THE EPIDEMIOLOGY OF LOWER BACK PAIN IN CYCLISTS - A CROSS SECTIONAL SURVEY

3.1 ABSTRACT

Background: Lower back pain (LBP) appears to be a common overuse cycling injury but there are no known reports on the life-time prevalence of LBP in cyclists. There are few studies on the aetiology and risk factors associated with LBP in cycling. Factors such as time and distance cycled, hilly terrain, bicycle set-up and gear selection, have all been suggested as factors which may be associated with LBP in cycling. These and other possible risk factors have received little investigation and therefore require further research. *Aims of the study:* The aims of this descriptive cross-sectional research study are to investigate 1) the epidemiology of LBP in cyclists, 2) the nature of LBP in cyclists, and to 3) identify factors that are associated with LBP in cyclists. *Methods:* Cyclists were recruited in a random fashion at the registration for a 109km cycling race and asked to complete a questionnaire pertaining to 1) personal demographics, 2) training history, and 3) low back pain and general injury history. 460 of the questionnaires were analysed. Comparisons and frequencies between LBP subjects and asymptomatic subjects (NP group) were performed using independent t-tests. *Results:* The self reported annual incidence of LBP in cyclists was 42.9%, and the lifetime prevalence was 50.7%. LBP in cyclists occurred on average 1.38 hours after cycling commenced. Cyclists in the LBP group weighed significantly more (p=0.039) and were significantly taller than those in the NP group (p=0.011), but the BMI's were similar. Cyclists in the LBP group cycled a significantly greater distance per week than those in the NP group (p=0.010). The average race time for this 109km race in the previous year tended to be faster for the LBP group (p=0.084). *Conclusion:* LBP in cyclists is a common overuse injury that is associated with prolonged cycling, and an increased height and body weight. Further research studies to document intrinsic risk factors that may be associated with LBP in cyclists are required.

Keywords: Lower back pain, epidemiology, lifetime prevalence, annual incidence, cyclists, risk factors

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3.2 INTRODUCTION

Although cycling is not associated with high repetitive joint impacts associated with other sports[59;149] there is however, still a risk for sustaining acute traumatic as well as overuse injuries[24;27;36;76;98;118].

There have been limited studies on the epidemiology of overuse cycling injuries[14;79;127;149;151] and these studies have been reviewed (Chapter 2, section 2.3). The precise pattern of overuse injuries in cycling is therefore not understood, and this does not enable the health practitioner, coach or the cyclist to correct or prevent errors in bicycle set-up, training or biomechanics with any confidence. Lower back pain (LBP) appears to be a common overuse cycling injury, although the reported incidence varies between 2.7 - 60%[14;24;79;81;139;149;151]. There is also no known study in which life-time prevalence of LBP in cyclists has been reported.

In cycling, the lower back maintains a sustained flexed posture for long periods and this may predispose the lumbar spine to mechanical strain. It has been documented by various researchers that there is an association between prolonged sitting with the lumbar spine in a flexed position[6;10;88;89;152]. Spinal flexion is also associated with increased discal pressures[104] (Chapter 2, section 2.4) These mechanisms for the development of lumbar pain could possibly be applied to cyclists who spend extended periods in a flexed position. However, it has not been documented when LBP develops during cycling, and what factors may be associated with the development of LBP.

Training methods and their possible association with LBP in cyclists have also received little attention. Factors such as terrain, use of appropriate gear ratios and the intensity and frequency of cycling during training or in races, have not been investigated. In one study an association between neck pain and windy conditions, hilly terrain, or cycling a longer distance was documented[37]. In another survey, cyclists reported that LBP was aggravated by increased distance cycled per week, use of lower gears and less years of cycling[151]. There are no known published studies which have investigated regular stretching (flexibility training) as part of the cycling training programme to avoid the onset of LBP. In one cross sectional study of 225 runners, asymptomatic runners were significantly more likely to stretch prior to training ($p=0.028$) and racing ($p=0.003$) compared to runners who suffered from lower back pain[83].

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The aims of this descriptive cross-sectional research study were therefore to investigate 1) the epidemiology of LBP in cyclists, 2) the nature of LBP in cyclists, and to 3) identify factors that are associated with LBP in cyclists.

3.3 METHODOLOGY

3.3.1 EXPERIMENTAL DESIGN

The study design is a descriptive cross- sectional survey.

3.3.2 SUBJECT SELECTION AND EXPERIMENTAL PROCEDURE

All the approximately 30 000 cyclists participating in a 109 km cycle race that is held annually in Cape Town (Argus cycle tour) were considered potential volunteers for this study. After ethical clearance for the study was provided by the Ethics and Research Committee of the University of Cape Town and permission was obtained from the race organisers, a special research area was identified within the hall where registration for the race takes place for 3 days prior to the race. About 500 cyclists were randomly approached (every third cyclist that passed the research area) and were given an information sheet about the study (Subject Information Sheet – Appendix 1). In total 468 cyclists volunteered to participate in the research study by completing an informed consent form (Appendix 2). Inclusion criteria were that the cyclists had to ride a road bicycle and not a hybrid or mountain bicycle. Subjects included competitive and recreational cyclists. Thereafter, all the subjects completed a previously validated questionnaire (Appendix 3) that consisted of three main sections:

1. Personal Demographics

   The aim of this section was to determine age, weight, height and sex for possible associations with lower back pain (LBP). Data from this section were also used to select a sub-group of subjects for the laboratory study (next chapter).

2. Training history

   The section was to determine the training methods and stretching history of the cyclists.

3. Low back pain and general injury history

   This section focused on the nature of the lower back pain related to cycling. The intensity of LBP experienced by cyclists was also recorded using a Visual Analogue

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Scale (0-10, where 1 was no pain, and 10 severe pain). Only cyclists who experienced back pain were requested to complete this section.

A total of 460 questionnaires (out of the 468 subjects that were recruited) (male=390, female=70), were completed by the subjects and were analyzed. A few subjects failed to complete every question. In such cases, the true population sample (n) will be reported where necessary in the figures and tables. Not all the data obtained from the questionnaire (Appendix 3) will be included in this study. Only those data that were specifically related to the focus of this study were extracted from the questionnaire .

Based on a question in the "Lower back pain and general injury" section of the questionnaire (Section 3), subjects were divided into a group that reported suffering from lower back pain in the past 12 months (LBP group) or no history of lower back pain in the past 12 months (NP group).

3.3.3 STATISTICAL ANALYSIS

The statistical tests were performed on the data using the Statistica 8.0 software package (StatSoft Inc, Tulsa, OK, USA). Comparisons and frequencies between LBP subjects and NP subjects were performed using Independent t-tests, and Chi-square frequency tests for parametric data respectively. All data was expressed as mean ± standard deviation. Statistical significance was accepted as $P<0.05$.

3.4 RESULTS

3.4.1 EPIDEMIOLOGY (ANNUAL INCIDENCE AND LIFETIME PREVALENCE) OF LBP IN CYCLISTS

The retrospective self reported annual incidence of LBP (defined as cyclists who reported LBP in the last 12 months of cycling) was 42.9% (n=197). The lifetime prevalence of LBP in this group of cyclists (defined as the number of cyclists who have experienced LBP at some time in their cycling career) was 50.7% (n=233).

As previously mentioned, the annual incidence data (last 12 months) were used to categorize cyclists as those with LBP (LBP group=197) and those with no LBP (NP group=263) (Table 3.1). The majority (88.3%) of the 197 LBP cyclists were males, but 84.7% of the entire group of 460 subjects were males. The frequency of males in our sample was similar to that of the

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entire finishers of the race (80.7% males) (22 179 males out of 27 470 finishers- Data obtained from the race oragnizers but not shown).

Table 3.1 Gender distribution of cyclists in the LBP and NP groups (values in brackets are %)

	LBP group	NP group	Total cyclists
Male	174 (88.3)	216 (82.1)	390
Female	23 (11.7)	47 (17.9)	70
All	197 (42.9)	263 (57.1)	460

3.4.2 NATURE OF LBP IN CYCLISTS

Cyclists in the LBP group reported cycling for an average of 1.38 hours (±58.6 min) before they experienced pain. Alternatively cyclists reported cycling a distance of 51.96km (±29.6km) before experiencing low back pain.

The intensity of pain usually experienced by the LBP cyclists (n=174) while cycling was recorded from a Visual Analogue Scale (VAS). The mean pain intensity reported by cyclists in the LBP group was 4.4 ± 1.9. Most cyclists (47.8%) experienced pain during cycling which did not affect their cycling, others (23.9%) experienced pain during and after cycling which did not affect their cycling, and 26.1% of cyclists experienced pain during and after cycling which did affect their cycling. Only a small percentage of cyclists (2.2%) experienced pain which prevented them from cycling.

3.4.3 DESCRIPTIVE CHARACTERISTICS OF THE LBP AND NP GROUPS

The general characteristics of the subjects in the LBP and the NP groups are presented in Table 3.2. Cyclists in the LBP group weighed significantly more (p=0.039) and were significantly taller than the NP group (p=0.011). However, there was significant difference in the BMI between the two groups.

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Table 3.2 General characteristics (age, height, weight, BMI) of subjects in the LBP and NP groups (values are mean ± SD)

	LBP group	n	NP group	n	P Value
Age (years)	37.8 ± 11.4	197	36.3 ± 12.1	263	0.181
Height (m)	1.77 ± 0.08	191	1.75 ± 0.08	257	0.011*
Weight (kg)	77.1 ± 13.1	195	74.6 ± 12.2	262	0.039 *
BMI (kg.m²)	24.1 ± 4.1	191	24.1 ± 3.7	257	0.878

* Significant difference between the LBP and NP groups.

3.4.4 EXTRINSIC RISK FACTORS ASSOCIATED WITH LBP IN CYCLISTS

3.4.4.1 TRAINING AND RACING FACTORS

A. VOLUME OF CYCLING

The training history (volume of cycling in distance per week, days cycled per week, and hours cycled per week) is reported in Table 3.3. There was a significantly greater distance cycled per week in the LBP group compared with the NP group (p=0.010). There were no significant differences in the hours cycled per week (p=0.403), or in the number of days cycled per week between the LBP and NP group (p=0.228).

Table 3.3. The training history of cyclists in the LBP and NP groups (values are mean ± SD)

	LBP group	n	NP group	n	P value
Training history					
Distance/week (km)	175.8 ± 106.9	195	149.8 ± 104.8	255	0.010*
Days cycled/week	3.7 ± 1.3	195	3.6 ± 1.4	253	0.228
Hours/week (hours)	6.7 ± 3.7	193	6.4 ± 3.9	253	0.403

* Significant difference between the LBP and NP groups

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There was a tendency (p=0.084) for the average reported race time for this 109 km race in the previous year to be faster for the LBP group (248.4 ± 55.03 min) relative to the NP group (259.9 ± 55.99 min).

B. GEAR SELECTION

In response to a question on gear selection, there was no significant difference between the predominant use of low or high gears between both groups (p=0.409). Of the LBP cyclists 39.9% used predominantly low gears relative to 36.08% of the NP group. The use of high gears was more frequent in both groups, with 60.1% for the LBP group, and 63.9% for the NP group reporting the predominant use of high gears.

C. ENVIRONMENTAL, TERRAIN AND VARIOUS ASSOCIATED TRAINING FACTORS

The response of the LBP group of cyclists to a list of possible aggravating factors that are associated with cycling related LBP is represented in Table 3.4.

Table 3.4 Aggravating factors that are associated with LBP in the LBP group

	No. of cyclists (n = 174)	% cyclists
Hilly terrain	81	41.1
Distance	73	37.1
Low gear usage	35	17.8
Wind	35	17.8
Speed training	14	7.1
Combining cycling with other sports	12	6.1

D. STRETCHING HABITS

The stretching habits of the LBP and the NP groups are represented in Table 3.5. The response to whether or not the cyclists performed general body stretches pre and post cycling was very similar. The most significant finding from the stretching data was that a higher percentage of the LBP group stretched the lower back compared to the NP group (p=0.005). Few cyclists in both groups performed general body stretches prior to cycling (p=0.955). More cyclists stretched after cycling in both groups, but the numbers were similar between both groups (p=0.555). The average length of time of a stretching session (p= 0.214) and the

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holding time for each stretch (p=0.673) was also similar between groups. The different areas of the body that the cyclists stretched were similar for both groups - the hamstrings, quadriceps and calf muscles being the most stretched areas. The gluteal muscles were stretched more by the NP group but the results were not significantly different. There was a tendency (p=0.067), although not significant for more LBP cyclists to stretch at other times during the week compared to NP cyclists. Stretching session times and the duration of each stretch were similar.

Table 3.5. The stretching habits of cyclists in the LBP and NP groups (values are mean ± SD)

	LBP group	n	NP group	n	P value
Stretching (pre and post cycling)					
Number of cyclists (pre-cycle)	63 (32.3)	197	84 (32.6)	262	0.955
Number of cyclists (post cycle)	104 (54.2)	197	132 (51.4)	262	0.555
Duration of stretch session (min)	8.3 ± 5.6	197	9.54 ± 9.1	262	0.214
Duration of each stretch (sec)	24.2 ±15.5	197	23.37 ± 16.1	262	0.673
Stretching (in a week)					
Number of cyclists	101 (54.9)	197	115 (46.0)	262	0.067
Duration of each stretch (sec)	24.4 ± 16.5	197	23.0 ± 13.8	262	0.533

* Significant difference between the LBP and NP group

E. KNOWLEDGE OF THE BICYCLE SET-UP

A large percentage of cyclists, with similar representation between groups (p=0.344), reported that they had received advice about the bicycle set-up (LBP group = 76.8%, NP group = 72.9%). There was also no significant difference between groups as to the source of their bicycle set-up advice. The majority of cyclists (similar between groups) (p=0.153) received advice on bicycle set-up from the cycle shops (LBP group = 59.9%, NP group = 53.2%). A second less popular source of advice on bicycle set-up was from cycling books (LBP group = 22.8%, NP group = 22.8%) (p=0.994 between groups).

F. OTHER SPORTS PARTICIPATION

A similar proportion of cyclists in the LBP group (58.3%) and NP group (59.1%) participated in other sports (p=0.775).

3.5 DISCUSSION

The three main aims of this research study were to investigate 1) the epidemiology of LBP in cyclists, 2) the nature of LBP in cyclists, and to 3) identify possible risk factors that are associated with LBP in cyclists.

3.5.1 EPIDEMIOLOGY OF LBP IN CYCLISTS

The first main finding of this descriptive study was that cyclists participating in a 109km cycle race have a high self-reported annual incidence of LBP of 42.9% and a lifetime prevalence of LBP of 50.7%.

This is the only known study to report a lifetime prevalence of LBP in cyclists. The lifetime prevalence does however compare well with the lifetime prevalence of LBP reported in the general population (60 – 90%)[111;139].

The annual incidence of LBP in cyclists in our study is similar to previously reported data in the literature. However, in previous studies, a very large range of incidence figures have been reported (2.7 – 60%)[14;24;38;59;79;99;149]. Two previous epidemiological studies, with the largest sample sizes relative to other published studies, indicate that the results for this study fall within the range for LBP in cyclists reported in these studies of 30% (n=518)[151], and 60% (n= 500)[24]. The annual incidence reported in this study also compares favourably with the annual incidence of LBP in the general population (2%[139], 37%[117], 64%[81]).

3.5.2 NATURE OF LBP IN CYCLISTS

The second main finding from this study was that 1) cyclists who experienced LBP in the preceding 12 months reported cycling on average for 1.38 hours before experiencing LBP and 2) that LBP was aggravated by cycling on hilly terrain (41%) and during distance training (37%).

Increased cycling distance has been previously reported as a factor associated with LBP in cylists[151], but hilly terrain has not been previously reported. The reasons why these two factors are reported to aggravate pain are speculative but could be related to increased magnitude of

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loads (stronger muscle contraction in hill training) and increased frequency of loading (increased distance).

Furthermore, cyclists experienced moderate LBP pain during cycling which most often did not affect their cycling.

The cyclists also reported that pain usually started only after a period of cycling (mean of 1.38 hours of cycling, or a mean distance of 52 km). This time period before the pain manifests has important clinical implications for future analytical and intervention studies to determine the aetiology of LBP in cyclists. It is clear that in future research studies, a longer cycling time needs to be considered to effectively study the behaviour of back muscles and other visco-elastic passive structures during cycling. It is of note that in previous studies on LBP, as well as studies on muscle activity patterns in cycling, subjects were studied during and after much shorter cycling periods that ranged from a few minutes to a maximum of 54 minutes[18;22;140].

3.5.3 DESCRIPTIVE CHARACTERISTICS OF THE LBP CYCLISTS

The third main finding in this study was that cyclists with LBP were taller and weighed more but had a similar BMI to cyclists with no LBP.

The fact that the LBP group were significantly taller than the cyclists in the NP group may indicate that they require longer reach from the saddle to the handle bars depending on relative upper body length. Cyclists in the LBP group also weighed more, although BMI's were similar between groups. A relative increase in body weight may indicate an increased work rate during cycling, and this may place increased mechanical strain on the body.

3.5.4 EXTRINSIC RISK FACTORS ASSOCIATED WITH LBP IN CYCLISTS

3.5.4.1 TRAINING AND RACING FACTORS

The fourth main group of findings in this study related to training factors as possible extrinsic risk factors for developing LBP in cyclists. It was found that: 1) cyclists with LBP reported a greater training distance per week, 2) the average race time in the previous year was faster for the cyclists with LBP than the NP group, 3) cyclists with LBP stretched the lower back area more than asymptomatic cyclists, and 4) time periods for holding stretches were less than the generally recommended time for holding stretches for both groups. Other factors that were not associated with LBP in cyclists are the use of low or high gears, knowledge of bicycle set-up or combining cycling with other sports.

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The most significant training factor that was associated with LBP in cyclists was a greater cycling distance per week. However, the reported hours of cycling per week were not different between the groups. The likely reason for this is that cyclists in the LBP group train at a faster cycling speed, and this was confirmed by the observation that there was a tendency for the race time to be faster in cyclists in the LBP group compared with cyclists in the NP group.

A previous study showed that a greater percentage of male cyclists experienced LBP compared to female cyclists, and that these males also cycled a significantly greater distance than females per week[151]. Epidemiological studies of runners have shown that increased mileage is the most common factor associated with risk for overuse injury[65;75]. The average race time in the previous year showed a tendency to be faster in the LBP than the NP group. This, when combined with the increased distance cycled per week may indicate a greater intensity during cycling in the LBP group, possibly causing increased mechanical strain on the body with greater potential for overuse injury.

It was interesting to note that in both groups, a small percentage of cyclists stretched after cycling and even fewer cyclists stretched before they cycle. However, cyclists in the LBP group reported stretching of the lower back more frequently than cyclist in the NP group. Increased stretching may be as a result of the LBP, and therefore further research is required to determine if this was a cause or an effect. Therefore, whether stretching is not effective in relieving LBP, or if cyclists with LBP did not stretch with an adequate amount of frequency or hold the stretches long enough requires further research through intervention studies. In both groups in this study, stretches were held for less than the recommended 30 seconds required for an effective stretch[60].

3.5.5 STRENGTHS AND LIMITATIONS OF THIS STUDY

The main strengths of this study were that a large sample of cyclists was investigated, and that the sample obtained was random. However, the study population was confined to cyclists that entered a 109km race, which may limit the application of our findings to other recreational cyclists. A further limitation of this study was that data were self-reported, and recall bias could therefore not be eliminated.

3.6 SUMMARY AND CONCLUSION

In summary, this study showed that LBP is common in cyclists with a self-reported annual incidence of over 40%. The nature of the LBP is that it only occurs after prolonged cycling (on

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average >90min), and that hill cycling and distance training appear to aggravate LBP. The main extrinsic risk factor that is associated with LBP in cyclists is increased weekly cycling distance. Cyclists with LBP were also significantly taller and had increased body weight. Cyclists with LBP also report stretching the lower back more frequently, but this is likely to be as a result of LBP rather that an aetiological factor.

It therefore appears from this study, that prolonged cycling predisposes taller and heavier individuals to LBP. As previously reviewed (Section 2.5) the prolonged flexed position during cycling is likely to be related to the aetiology of LBP in cyclists. Furthermore, during prolonged cycling an incorrect match between the anthropometry of the cyclists and the adjustments of the bicycle (bicycle set-up) may increase the risk of LBP in cyclists. The relationship between antropometic variables as well as bicycle set-up and LBP in cyclists therefore requires further investigation.

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CHAPTER 4 - ANTHROPOMETRIC AND BICYLCE SET-UP PARAMETERS AS INTRINSIC RISK FACTORS FOR LOWER BACK PAIN IN CYCLISTS

4.1 ABSTRACT

Background: The prolonged flexed position of the spine during cycling may result in increased mechanical strain on the lumbar spine, thereby increasing the risk of lower back pain (LBP). LBP in cyclists has been reduced by changing the saddle angle[126]. It has been suggested that additional parameters of the bicycle set-up may be altered to prevent and alleviate LBP in cyclists. The anthropometric measurements of the cyclist may also influence the biomechanical interaction between the cyclist and the bicycle. Aims of the study: The aims of this case control study were to investigate the association between LBP in cyclists and 1) flexibility measurements 2) anthropometric measurements, and 3) bicycle set-up parameters. Methods: Twenty subjects with LBP and 20 asymptomatic subjects (control group) were recruited as subjects. Anthropometric measurements and flexibility tests were conducted on the subjects. Various parameters of the bicycle set-up were measured relative to the anthropometrics of the cyclist. Results: Right and left hamstring flexibility was significantly less in the LBP group compared with the NP group (left, p=0.001; right, p=0.001). Right leg hip flexion range of motion (ROM) was significantly less in the LBP group (p=0.026), and left hip flexion ROM tended to be less flexible in the LBP group compared with the NP group (p=0.063). Right ankle plantar flexion ROM was significantly less in the LBP group (p=0.034), and the left plantar flexion ROM tended to be less in the LBP group compared with the NP group (p=0.059). There were no significant differences in spinal (p= 0.351) and lumbar flexibility (p=0.180) between the groups. There was a significant difference in the reach ratio [total upper body length (upper body + arm) / total reach (diagonal reach from saddle to handle bars)] between the LBP and the NP group. There were no differences between groups with respect to the saddle set-back, saddle height and the saddle angle. Conclusion: Lower back pain in cyclists is associated with a reduced hamstring muscle length. In general, the lower limbs of LBP cyclists appear to have reduced flexibility compared to asymptomatic cyclists, as hip flexion and ankle plantar flexion flexibility were also reduced. Low back pain in cyclists may be prevented by increasing flexibility of the hamstring and lower limb muscles, as well as diagonal reach distance from saddle to handle bars.

Keywords: Lower back pain, cyclists, anthropometric measurements, bicycle set-up, hamstring flexibility, reach ratio, diagonal reach distance.

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4.2 INTRODUCTION

It has been reported that the annual incidence of LBP in cyclists is as high as 43 - 60%. The lifetime prevalence of LBP in cyclists has also been reported as 51% (chapter 3). Despite the high annual incidence of LBP in cyclists, there is a paucity of research to identify possible intrinsic risk factors that may be associated with LBP in cyclists (chapter 2).

Cycling is associated with a sustained flexed posture, and this may place the cyclist at risk for developing LBP[22;126;132]. It has been well documented that there is an association between LBP and prolonged sitting with the lumbar spine in a flexed position[6;10;89;152]. Spinal flexion is associated with increased discal pressures[104], and the development of LBP in cyclists could possibly be related to prolonged sitting in a flexed position. However, in contrast to unsupported open chain sitting in a flexed position that is often encountered in occupational settings, a portion of the body mass of the cyclist is supported on the handlebars. A variety of anthropometric factors in the cyclist as well as the construction of the bicycle may also influence the forces that are applied to the cyclist during cycling. This biomechanical interaction between the cyclist and the bicycle is therefore unique, and this is known as the bicycle set-up.

It has been suggested that an optimal bicycle set-up, which results in ideal positioning of the cyclist on the bicycle, would minimise mechanical strain on the spine of the cyclist [20;33;126;130]. The optimal bicycle set-up should match the individual anthropometrics of the cyclist and the various parameters of the bicycle set-up (such as length of the upper body with the reach distance from the saddle to handle bars). This matching should create a balance between power and efficiency, as well as ensuring comfort and injury prevention.

There have only been very few studies that have investigated factors that may be associated with LBP in cyclists, and only one published study where the role of the bicycle set-up and LBP has been studied. In this controlled clinical trial is was shown that by changing the saddle angle, the incidence of LBP in cyclists was reduced[126]. There is no known published research which has investigated a possible association between LBP and a number of parameters of the bicycle set-up.

The aim of this study was to investigate the association between LBP in cyclists and 1) various anthropometric measurements, 2) flexibility measurements, and 3) bicycle set-up parameters.

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4.3 METHODOLOGY

4.3.1 EXPERIMENTAL DESIGN

This study design is a case control study.

4.3.2 SUBJECT SELECTION

A total of 40 cyclists were recruited from 1) a sub–group from the epidemiological study in chapter 3 (n=28), 2) from physiotherapy practices (n=10) and 3) from a cycling gymnasium (n=2). Of the 40 cyclists, 20 had a history of LBP in the past 12 months (LBP group), and 20 were asymptomatic (NP group). The main inclusion criterion for the subjects in the LBP group was that they experienced pain in the lumbar area of the spine, which occurred while cycling in the past 12 months. Exclusion criteria for the subjects in the LBP group were: 1) acute neurological symptoms, including referred buttock and leg pain, and 2) a current acute episode of LBP which prevented them from sitting on the bicycle in the cycling position.

The two groups were matched for age, height, weight and gender. The descriptive characteristics of the cyclists are represented in Table 4.1. The level of pain experienced by the 20 cyclists in the LBP group while cycling in the last month was of a high intensity, with 40% (n=8) of cyclists reporting a baseline Visual Analogue Scale (VAS) of 7 out of 10. Twenty five percent (n=5) of the cyclists reported a VAS of 5 out of 10. The average time period before the cyclists in the LBP group experienced back pain during cycling was 1.48 hours.

Ethical clearance for the study was provided by the Ethics and Research Committee of the University of Cape Town and an informed consent was obtained from the subjects prior to testing (Appendix 4). An information sheet explaining the testing procedure was read by the subjects prior to testing (Appendix 1). All subjects completed a medical questionnaire to exclude 1) any serious medical conditions, and 2) current acute lower back pain. Both these parameters were exclusion criteria for participation in the study (Appendix 5).

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Table 4.1 Descriptive characteristics of LBP and NP group (values are mean + SD) (% in brackets)

	LBP group(n= 20)	NP group(n=20)	P value
Age (years)	44.1 ± 10.2	46.7 ± 7.9	0.374
Weight (Kg)	76.4 ± 8.8	73.3 ± 12.0	0.352
Height (m)	173.6 ± 6.7	173.2 ± 7.3	0.884
BMI (kg.m²)	25.4 ± 2.6	24.3 ± 2.8	0.219
Gender (male)	15 (75%)	13 (65%)	
Gender (female)	5 (25%)	7(35%)	

4.3.3 EXPERIMENTAL PROCEDURE

All the subjects were required to report to the biomechanics laboratory at the Sports Science Institute for assessment. The subjects were dressed in cycling clothes and shoes, and brought their own bicycles to the testing laboratory. Flexibility testing and anthropometric measurements were first conducted on the subjects.

4.3.3.1 FLEXIBILITY MEASUREMENTS

- The straight leg raise test was conducted bilaterally as a measure of hamstring flexibility with the subject in the supine on the plinth. The pelvis was placed in a posterior tilted position to allow the lumbar spine to come into contact with the plinth. This position was maintained using a belt around the anterior superior iliac spines and the plinth. The ankle joint was placed in neutral (90 degrees angle) and maintained in this position with a rigid hinge brace[60]. A flexometer (Leighton Flexometer, Inc., 3118 East Chaser Lane, Spokane, WA 99223, USA) was secured to the subject's thigh and the examiner raised the subject's leg passively until initial resistance was felt (as tested in a repeatability study)[60]. The examiner recorded the reading for hamstring flexibility[40;51;82].

- Hip flexion was measured in supine with a standard goniometer (Dynatronics goniometer, Dynatron Corporation, USA). The arms of the goniometer were placed on the line of the femur and mid-line of the trunk. The hip was passively flexed until initial resistance was felt. The subject was instructed to maintain the position by placing a hand on the knee without pulling the leg closer[4].

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- Ankle plantar flexion was measured with a standard goniometer. The arms of the goniometer were placed on the line of the fibula and the midline of the foot[4].

- Spinal flexibility was measured as the change in the distance between vertebra in the upright position and the fully flexed position, (measured in mm). There were two outcome variables, one measuring the flexibility of the lumbar spine and another measuring the flexibility of the entire spine. The "modified-modified" Schober technique[155] has been suggested as a reliable method for measuring spinal flexion. The method, originally described by Schober, made use of a tape measure held directly over the spine, and a mark was made 10cm proximal to the lumbar-sacral junction. The difference between this length in neutral standing and full spinal flexion was recorded and gave an indication of spinal flexion. For the purpose of this study, spinal and lumbar flexion was determined using a modification of the Schober technique. A reliability study confirmed the reliability of this modified method[83] .The following procedure was followed:

    - The distance between the spinous processes of the second sacral vertebra (S2) to the first lumbar vertebra (L1) and to the first thoracic vertebra (T1) was measured in mm using a rigid tape measure (MTS tapes, Matus Ltd, GMG Hardware,Panyi, Ningbo, China).

    - S2 was chosen as it is easy to palpate between the posterior superior iliac spines (PSIS's) of the pelvis. L1 was identified by palpating and counting the spinous processes cranially from S2.

    - The L1 spinous process is difficult to palpate, and the skin stretches and moves superiorly to the marked spinous processes during movement[155]. During the performance of this test, every effort was made to ensure that L1 was correctly identified by repeating the procedure identifying the lumbar vertebra after flexion.

    - The distance between the first thoracic vertebra and S2 was measured. The spinous process of the seventh cervical vertebra was located by fully flexing the neck. T1 was then identified by palpating the next spinous process caudally from C7.

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- Measurements were conducted with a rigid tape measure and compared between standing upright in the neutral position and full active flexion using the S2 spinous process as the reference point.

4.3.3.2 ANTHROPOMETRIC MEASUREMENTS

- Height and body weight were measured using a precision stadiometer and balance (Model 770, Seca, Bonn, Germany, accurate to 10g).
- Full leg length was measured bilaterally in standing from the top edge of the greater trochanter to the floor, and upper leg length to the knee joint line with a rigid tape measure.
- Foot length was measured with sliding calipers (Harpenden Anthropometer, Holtain Ltd.Crosswell, Crymych, SA41 3UF, UK).
- Arm length was measured bilaterally from the top of the acromion to the 2nd metacarpal of a fisted hand with a rigid tape measure.
- Upper body length was measured in the upright seated position (on a hard bench with the subject's feet touching the ground) from the manubrium to the bench with a rigid tape measure.

After the flexibility and athropometric measurements were completed the cyclists own bicycle was then mounted on a Computrainer cycle ergometer[32] and specific parameters of the bicycle set-up were measured (chapter 2, section 2.4.6.3). The cyclist was then asked to sit on their bicycle and the position of the cyclist on the bicycle was assessed by measuring specific parameters.

4.3.3.3 BICYCLE AND BICYCLE SET-UP MEASUREMENTS

The following measurements were recorded from the bicycle:

- Seat height - measured in line with the seat tube from the top of the seat to the pedal positioned at bottom dead centre[20].

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- Crank length - the length of the crank arm was measured.

- Saddle set-back position - two different measurements (saddle set-back 1 and 2) were taken for saddle set-back. Saddle set-back 1 - a plumb line was dropped from the front of the saddle and the distance from the bottom bracket to the plumb line was measured[21]. Saddle set-back 2 was measured with the cyclist on the bicycle as the distance from the back of the patella to the pedal spindle. Saddle set-back 2 takes into account the upper leg length of the cyclist. (If the cyclist has a long femur, they may need to move the seat back to reduce the flexion of the knee in the top dead centre (TDC) position of the crank arm during cycling).

- Saddle angle – one end of a spirit level (MTS levels, Matus Ltd, GMG Hardware, Ghangzou, China) was positioned on the seat of the saddle by an assistant and the other end was raised or lowered until horizontal was established. The angle of the saddle was then measured with one arm/axis of a goniometer on the line of the saddle and one arm on the line of the spirit level[20;21].

- Reach - the distance from the centre of the seat post to the transverse part of the handle bar was measured using a rigid tape measure[33]. Handle bar height or drop - the height from the ground to the top of the handle bars was measured, then the distance from the ground to the top of the seat was measured with a rigid tape measure. The difference between the two measurements was calculated to establish the drop.

- The Reach ratio – This ratio was calculated mathematically. The Reach ratio is the measurement, or ratio, of the total upper body length (torso length plus arm length – determined from the anthropometric measurements) divided by the diagonal reach distance from saddle to handle bars (calculated by using the vertical drop distance from saddle to handle bars, and the horizontal reach distance from saddle to handle bars as the other two sides of a hypotenuse triangle. The reach distance is the square root of the sum of the squares of the other two sides). This is depicted in Figure 4.1.

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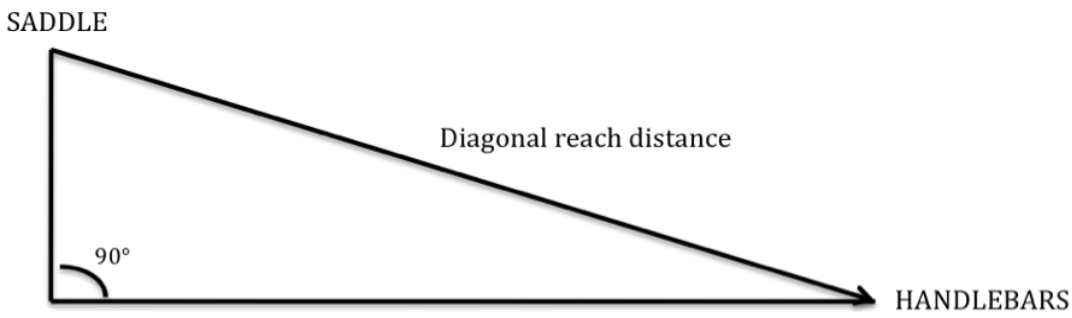

Figure 4.1: Calculation of diagonal reach distance

The following measurements recorded with the cyclist in a seated position on the bicycle (set-up measurements):

- Saddle set-back - the crank arm was placed in a horizontal forward position (toward the front of the bicycle). A plumb line was dropped from the posterior aspect of the patella to the mid- point of the pedal spindle. The distance from the pedal spindle was measured with a rigid tape measure. Zero was directly over the spindle, while a positive measurement was the distance in front of the pedal spindle and a negative measurement was the distance behind the pedal spindle[20;97].

- Knee angle in bottom dead centre (BDC) – The angle of the knee with the crank arm in the bottom vertical central position was measured (BDC position). The one arm of the goniometer was positioned along the line of the femur and the second arm on the midline of the lateral lower leg, the knee joint being the axis for movement[4]. This measurement is considered as a guideline for seat height[14;20;21;26;92].

- Plantar flexion in bottom dead centre (BDC) – the plantar flexion angle was measured in the BDC position. The stationary arm of the goniometer was positioned along the line of the fibula and the second arm along the mid-point of the line of the foot. The axis of movement was the ankle joint[4].

- Hip angle in top dead centre (TDC) - the hip angle was measured at the TDC position of the crank arm. The angle was measured with a standard goniometer (in degrees). The stationary arm was parallel to the long axis of the trunk in line with the greater trochanter while the moving arm is placed along the lateral midline of the femur (on a line between the greater trochanter and the lateral femoral condyle) towards the lateral

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epicondyle. One centimeter anterior and superior to the greater trochanter was taken as the axis of this measurement[4].

4.3.4 STATISTICAL ANALYSIS OF DATA

Appropriate statistical tests were performed on the data using the Statistica 8.0 software package (StatSoft Inc, Tulsa, OK, USA). Comparisons and frequencies between LBP subjects and NP subjects were performed using Independent t-tests, and Chi-square frequency tests for parametric data respectively. Non-parametric data was analysed using the Mann-Whitney U test. All data were expressed as mean ± standard deviation. Statistical significance was accepted as $P<0.05$.

4.4 RESULTS

4.4.1 FLEXIBILITY MEASUREMENTS

The results of the flexibility measurements in the LBP and the NP groups are presented in Table 4.2. The right and left hamstring flexibility was significantly less in the LBP group compared with the NP group (left, p=0.001; right, p=0.001). The right leg hip flexion was significantly less in the LBP group (p=0.026), and there was a tendency for the left hip flexion to be less flexible in the LBP group compared with the NP group (p=0.063). The right ankle plantar flexion range of motion (ROM) was significantly less in the LBP group (p=0.034), and there was a tendency for the left plantar flexion ROM to be less in the LBP group compared with the NP groups (p=0.059). On the bicycle, hip flexion ROM in the top dead centre (TDC) position of the crank arm was similar between groups (p=0.163), and ankle plantar flexion ROM with the crank arm in the bottom dead centre (BDC) position was very similar between groups (p=0.803). There were no significant differences in the measures of spinal and lumbar flexibility between the two groups.

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Table 4.2 Flexibility measurements in the LBP and NP groups (values are mean ± SD)

	LBP group (n=20)	NP group (n=20)	P value
Hamstring R (degrees)	51 ± 8	66 ± 14	0.001*
Hamstring L (degrees)	49 ± 10	62 ± 10	0.001*
Hip flexion R (degrees)	107 ± 6	113 ± 10	0.026*
Hip flexion L (degrees)	108 ± 9	114 ± 10	0.063#
Hip angle TDC (degrees)	113 ± 12	103 ± 21	0.163
Ankle PF R (degrees)	40 ± 6	44 ± 6	0.034*
Ankle PF L (degrees)	40 ± 6	44 ± 7	0.059#
Ankle PF in BDC (degrees)	19 ± 7	18 ± 7	0.803
Lumbar flexion (S2-L1) (cm)	4.3 ± 0.9	4.7 ± 1.1	0.180
Spinal flexion (S2-T1) (cm)	8.6 ± 1.7	8.1 ± 1.0	0.351

Abbreviations : L – left, R – right, TDC – top dead centre position of pedal, PF – plantar flexion, BDC – bottom dead centre position of pedal, S2 – second sacral level, L1 –first lumbar vertebra, T1 – first thoracic vertebra.* Indicates a significant difference between the LBP and NP groups. # indicates a tendency that there is a significant difference between the groups (0.05<p<0.1)

4.4.2 ANTHROPOMETRIC MEASUREMENTS

The results of the anthropometric measurements are presented in Table 4.3. The NP group showed a significant leg length difference relative to the LBP group (p=0.03). The right upper leg length of the LBP group was significantly shorter than the NP group (p=0.016) and there was a tendency for it to be shorter on the left (p=0.072). There were no significant differences between the two groups with respect to foot length, arm length and upper body length.

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Table 4.3 Anthropometric measurements in the LBP and the NP groups (Values are mean ± SD)

	LBP group (n=20)	NP group(n=20)	P value
Leg length R (cm)	92.2 ± 4.7	94.2 ± 4.0	0.158
Leg length L (cm)	92.2 ± 4.2	93.3 ± 3.9	0.407
Mean leg length (cm)	92.2 ± 4.4	93.8 ± 3.9	0.252
Leg length diff. (mm)	0.5 ± 1.4	9.0 ± 1.1	0.030*
Upper leg length R (cm)	42.9 ± 2.8	44.9 ± 2.0	0.016*
Upper leg length L (cm)	42.8 ± 2.2	43.9 ± 1.7	0.072#
Foot length R (mm)	261±14	264±15	0.68
Foot length L (mm)	263±15	264±14	0.86
Mean arm length (cm)	67.6 ± 3.0	67.6 ± 3.1	0.983
Upper body length (cm)	60.8 ± 2.6	59.6 ± 2.7	0.141
Total upper length (cm)[1]	128.4 ± 5.1	127.2 ± 4.9	0.425

* Indicates significant difference between the LBP and NP groups ($p<0.05$)
\# Indicates a tendency that there is a significant difference between the groups ($0.05<p<0.1$).[1]
Mean arm length plus upper body length.

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4.4.3 BICYCLE SET-UP CHARACTERISTICS RELATED TO CYCLIST ANTHROPOMETRICS'

The bicycle set-up measurements (reach and saddle set-back) in the LBP and the NP groups are presented in Table 4.4. A significant difference was found between groups in the *reach ratio* measurement (p=0.021) (described in section 4.3.2.3). There was no significant difference between groups the groups for saddle set-back 1 (p=0.903), saddle saddle set-back 2 (p=0.273). The saddle angle measurement was similar between the LBP and the NP group (p=0.848). A negative value for saddle angle indicates a downward tilt of the nose of the saddle.

Table 4.4. The bicycle set-up measurements (reach and saddle set-back) relative to cyclist anthropometrics' (values are mean ± SD)

	LBP group (n=20)	NP group (n=20)	P value
Upper body length (cm)	60.8 ± 2.6	59.6 ± 2.7	0.141
Mean arm length (cm)	67.6 ± 3.0	67.6 ± 3.1	0.983
Total upper length (cm)[1]	128.4 ± 5.1	127.2 ± 4.9	0.425
Drop (cm)	5.1 ± 4.22	5.9 ± 3.3	0.495
Reach (cm)	64.2 ± 3.4	65.2 ± 1.0	0.364
Total reach (cm)[2]	64.5 ± 3.6	65.5 ± 3.6	0.375
Reach ratio[3]	1.9 ± 0.1	1.9 ± 0.1	0.021*
Saddle set-back 1 (cm)	5.9 ± 2.1	5.9 ± 2.3	0.903
Saddle set-back 2 (cm)	2.6 ± 1.1	2.2 ± 2.0	0.273

[1] Total upper length = upper body length + mean arm length,[2] Total reach = diagonal distance from saddle to handle bars,[3] Reach ratio = Total upper length/ total reach.
*: Indicates significant difference between the LBP and NP groups ($p<0.05$)

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The bicycle set-up measurements (leg lengths) and their relationship to the bicycle set-up in the LBP and the NP groups is depicted in Table 4.5. There was no significant difference in the total saddle height (saddle height plus crank length - calculated as a percentage of trochanteric leg length) between the two groups. The knee angle measurement in the bottom dead centre position (BDC) of the crank arm, which is a relative measure of saddle height, was also similar for both groups ($p=0.375$). The recommended value for knee flexion in the BDC is between 25- 30°.

Table 4.5.The bicycle set-up measurements (leg lengths) and their relationship to the bicycle set-up in the LBP and the NP groups (values are mean + SD)

	LBP group (n=20)	NP group (n=20)	P value
Leg length R (cm)	92.2 ± 4.7	94.2 ± 3.9	0.158
Leg length L (cm)	92.2 ± 4.2	93.3 ± 3.9	0.407
Mean leg length (cm)	92.2 ± 4.4	93.8 ± 3.9	0.252
Leg length diff. (mm)	0.5 ± 1.4	9.0 ± 1.1	0.030*
Upper leg length R (cm)	42.9 ± 2.8	44.9 ± 2.0	0.016*
Upper leg length L (cm)	42.8 ± 2.2	43.9 ± 1.7	0.072
Total saddle height[1](cm)	90.4 ± 4.5	90.9 ± 4.3	0.685
Total saddle ht[1]/ leg length (%)	97.9 ±2.7	96.9 ± 1.8	0.172

*: Indicates significant difference between the LBP and NP group ($p<0.05$). [1] Total saddle height =saddle height+ crank length

4.5 DISCUSSION

The aim of this study was to investigate the association between LBP in cyclists and various flexibility measurements, anthropometric measurements and bicycle set-up parameters.

The main finding of this study was that low back pain in cyclists was associated with decreased hamstring flexibility, and limited hip flexion and ankle plantar flexion range of movement. In addition, LBP in cyclists was also found to be associated with an increased reach ratio (total upper body length / total diagonal reach from saddle to handle bars), but not with other bicycle set-up variables such as the saddle angle and seat height.

The hamstring muscles in the LBP group were significantly less flexible than the NP group.[17] The hamstring muscle group originates from the ischial tuberosity of the pelvis and therefore has the ability to pull the pelvis into a posterior pelvic tilt position which accentuates flexion of the lumbar spine. Prolonged flexion of the lumbar spine is associated with increased mechanical strain of the spine[6;10;89;152]. Cyclists in the LBP group were also generally less flexible than the NP group in the lower limb – specifically, hip flexion and ankle plantar flexion range of movement (ROM) was less in the LBP group. However, when hip and ankle ROM was measured on the bicycle in the TDC and BDC positions of cycling respectively, there were no significant differences between the groups. This may be due to the fact that full range of

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motion in these joints is not required in these positions. Although limited hip flexion in the LBP group was not demonstrated on the bicycle, the limited range may still be an indication of reduced flexibility in the posterior pelvic, sacro-iliac and hip structures, and this may create a dynamic resistance to smooth through range movement in the repetitive hip flexion- extension motion in cycling. This increased dynamic resistance may lead to mechanical strain of posterior lumbar–sacral structures. Flexibility of the lumbar region and the entire spine was similar between groups. The possible reasons for this are that in these cyclists, reduced hamstring flexibility has resulted in increased hypermobility of the lumbar spine as a compensatory mechanism. However, the measuring system that was used to determine spinal mobility, although validated by a repeatability study, may also not be sensitive enough to detect actual distance between vertebrae. Radiographic measurements would be a more accurate method to measure spinal flexibility and could be considered in future studies.

The sub-group of cyclists in this case control study were well matched for height and yet the LBP cyclists showed a significant difference in the reach ratio [ratio of upper body length plus arm length (total upper length)] relative to the diagonal distance from the seat to the handle bars (total reach). This indicates that cyclists in the LBP group had a decreased diagonal reach distance compared with cyclists in the NP group. The diagonal reach distance may be increased by 1) increasing the drop from the seat to the handle bars or 2) increasing the horizontal distance from the seat to the handle bars, or 3) a combination of 1) and 2). It has been suggested that the reach distance should be decreased in cyclists with LBP because this would result in a posterior pelvic tilt position during cycling[98;99;127;130]. However, more recent literature supports the idea of increasing reach distance to reduce LBP as this would facilitate an anterior pelvic tilt position thereby limiting lumbar flexion[20;21;33]. Furthermore, by increasing the reach distance, the cyclist would assume a more flattened position of the trunk, thereby reducing aerodynamic drag and improving efficiency and performance in cycling. In one study, angling the nose of the saddle downwards increased anterior tilt of the pelvis and this decreased LBP in more than 70% of cyclists[126]. However, in the current study, an association between the saddle angle and LBP in cyclists was not shown. The reasons for this are not clear. And require further investigation.

Leg length differences, or asymmetry, have been associated with LBP in the general population[34]. In our study, cyclists in the NP group had a significantly greater leg length difference of 0.9cm compared to cyclists in the LBP group. This finding is unexpected, but may indicate that there is a ‘possible protective effect’ for cyclists with a minimal leg length

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difference. A leg length difference of greater than 1cm is considered common in the general population[28]. The reasons for this finding are not clear and would require further investigation.

The main limitation of any case control study design is that no cause-effect relationship can be demonstrated. Therefore, in this study only associations between possible risk factors and LBP in cyclists could be determined. It should also be pointed out that the measurement techniques used in this study were largely clinical measurements. Although these measurement techniques have been validated, these measurements could be limited in their validity and repeatability. Therefore, intervention studies are necessary to analyse the effect on LBP in cyclists by changing various parameters of bicycle set-up, in particular total reach distance. Intervention studies which assess the effect of a hamstring stretching programme on LBP in cyclists would also be of value.

4.6 SUMMARY AND CONCLUSION

In this case control study, LPB in cyclists was associated with reduced hamstring muscle flexibility and a decreased diagonal reach distance from the saddle to the handle bars. Cyclists with LBP may therefore benefit from 1) a flexibility training program to increase hamstring and hip flexion flexibility, and 2) increasing the diagonal reach distance from saddle to handle bars. Both hamstring flexibility and increased diagonal reach distance may facilitate increased anterior tilting of the pelvis during cycling, and allow a more extended position of the trunk. Both these positions will reduce lumbar flexion and thereby indicate a plausible biomechanical intervention to decrease the risk of developing lower back pain. However, this hypothesis requires testing through intervention studies.

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CHAPTER 5 – SUMMARY AND CONCLUSION

5.1 SUMMARY AND CONCLUSION

The main aims of this thesis were 1) to review the current literature on the epidemiology and risk factors associated with LBP in cyclists, and 2) to identify extrinsic and intrinsic risk factors that may be associated with lower back pain in cyclists

In summary the literature review revealed the following:

- Lower back pain appears to be a common overuse cycling injury - however the epidemiology of LBP in cyclists has not been well studied.

- The sustained flexed posture that the cyclist maintains during cycling may create increased strain on posterior active and passive support structures[20;33;127;130]. This may be an important factor contributing to the development of LBP.

- The selection of the correct bicycle frame to match the individual, as well as the correct bicycle set-up could minimise abnormal mechanical loads on the spine while still optimising power and efficiency[20;33].

- The reach distance is the distance from the saddle to the handle bars. It has been suggested that a shortened reach distance results in an increase in lumbar flexion which may result in a posterior tilt of the pelvis[33]. The resultant position of the spine and pelvis may place increased mechanical strain on the posterior spinal structures such as the ligaments and discs[33].

- There are varied hypotheses for the pathomechanics of LBP[22;99;140;149] which may even seem opposing. In all the studies which have contributed to the development of these hypotheses spinal kinematics and muscle activity in cyclists were monitored for less than 1 hour during cycling[22;132;140].

- A broader hypothetical model for the pathomechanics of LBP (section 2.5) has therefore been proposed in this review. It is possible that the previous hypotheses do not occur in isolation, but are part of a continuum, which may only become evident if cyclists are monitored for time periods exceeding 1 hour of cycling.

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- Extrinsic and intrinsic risk factors associated with LBP in cyclists have been scarcely researched. These are summarised in Table 2.2 of this thesis.

- Extrinsic risk factors which have been shown to have a positive association with LBP in cyclists include the training and racing factors of 1) increased distance cycled[151] and 2) low gear usage[151].

- Intrinsic risk factors which have been shown to have a positive association with LBP in cyclists include: muscle dysfunction factors, and the anthropometric match between the saddle angle and the pelvic tilt[126].

Following the review of the literature, two main research studies were identified that formed the basis of the research components of this thesis: 1) a cross sectional research survey which investigated the prevalence and aetiology of LBP in cyclists, and identified extrinsic risk factors, 2) a case control study which investigated intrinsic risk factors associated with LBP in cyclists.

The cross sectional survey revealed that LBP is common in cyclists with a self-reported annual incidence of over 40%. This was the first study to record a life-time prevalence of LBP in cyclists, which was 50.7%. It was found that LBP only occurs after prolonged cycling (on average >90min) which has important clinical implications for future analytical and intervention studies to determine the aetiology of LBP in cyclists.

Additional extrinsic and intrinsic factors were revealed in the two research studies. Therefore, the main findings of the research components of this thesis increase the current understanding of the risk factors associated with LBP in cyclists. Thus, a revision of Table 2.2 (Extrinsic and Intrinsic Risk Factors for LBP in cyclists) highlights the added knowledge and results gained from the current studies in this thesis (Table 5.1)

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Table 5.1: Extrinsic and Intrinsic Risk Factors for LBP in cyclists (level of evidence according to evidence based medicine (EBM) criteria).

Risk factors		Study details and reference	Level of evidence (I-IV)[115]
Extrinsic risk factors	**Training and racing factors:**		
	Increased distance cycled	Positive association: cross sectional survey[151]	III
		Positive association*: cross sectional survey[91]	III
	Low gear usage	Positive association: cross sectional survey[151]	III
		No association*: cross sectional survey[91]	III
	Hill cycling	Positive association*: cross sectional survey[91]	III
Intrinsic risk factors	**Muscle dysfunction:**		
	Asymmetrical spinal muscle firing patterns	Positive association: case control[22;132]	III
	Imbalance of trunk muscles	No association: case series[140]	IV
	Weak hip flexors and abductors	Positive association: case series[85]	IV
	Flexibility:		
	Lumbo-pelvic inflexibility	No association: case control[17]	III
		No association*: case control[90]	III
	Hamstring inflexibility	Positive association*: case control[90]	III
	Anthropometry :		
	Cyclist / bicycle fit:		
	- Pelvic tilt / saddle angle	Positive association: prospective cohort [126]	I
		No association:* case control[90]	III
	- Reach ratio[1]	Positive association:* case control[90]	III
	Increased height	Positive association:* cross sectional survey[91]	III
	Increased body weight	Positive association:* cross sectional survey[91]	III

*Evidence from studies in this thesis; [1] reach ratio= [total upper body length (arm ength + torso length) / diagonal reach to handle bars]

In summary the main extrinsic risk factors that are associated with LBP in cyclists include increased weekly cycling distance and hill cycling.

The main intrinsic factors that are associated with LBP in cyclists include reduced hamstring muscle flexibility and a decreased reach ratio [total upper body length (trunk length + arm length)/diagonal reach distance from the saddle to the handle bars]. Reduced hip flexion, and ankle plantar flexion, range of movement are also associated with LBP in cyclists. Cyclists with LBP are also significantly taller and have increased body weight.

It therefore appears that prolonged cycling in a sustained flexed posture places taller, heavier cyclists at risk of developing LBP. In addition, the incorrect match between the individual anthropometrics of the cyclist and the adjustments of the bicycle (bicycle set-up) may increase this risk. Reduced hamstring flexibility may increase the posterior tilt of the pelvis which could place additional strain on posterior pelvic and spinal active and passive structures, again increasing the risk of LBP.

This study has shown that cyclists with LBP may benefit from 1) a stretching program to increase hamstring and hip flexion flexibility, and 2) increasing the diagonal reach distance from saddle to handle bars.

Increased hamstring flexibility and an increased reach distance may both facilitate the attainment of an anterior pelvic tilt and a more extended position of the lumbar spine during cycling. The resultant reduction in lumbar flexion may reduce the risk of developing LBP in cyclists. However, this hypothesis requires further investigation through intervention studies.

The knowledge gained from this study provides a basis for future research. It is important to ensure the correct match between the anthropometry of the cyclist and the bicycle set-up before necessary studies on the pathomechanics of LBP (including muscle dysfunction and spinal kinematics) are conducted.

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APPENDIX 1

SUBJECT INFORMATION

Dear Cyclist

Thank you for the interest you have shown in the research trial on lower back pain in cycling. The aim of this study is to determine how common lower back pain is amongst cyclists and what factors may be associated with lower back pain in cycling. This will provide information about a possible link between factors such as training, the individual's flexibility and strength, and the bicycle set-up, and lower back pain. Appropriate interventions can then be made to alleviate back pain during cycling.

Step one

You will be required to complete a questionnaire on cycling related lower back pain. This will help to identify the factors which may increase your injury.

Step two

You may be requested to come to the Sports Science Institute of South Africa as a test subject in this study. On arrival you will be requested to give a brief medical history to eliminate any risk factors for testing. You will bring your bicycle with you to the testing room. Various measurements will be taken of your bicycle set-up, and your weight, height and flexibility will be measured.

You will benefit from participation in this study by receiving information on the correct bicycle set-up and the possible factors associated with lower back pain in cycling. This will enable you to make the appropriate adjustments to eliminate your lower back pain.

Yours faithfully

Mandy Marsden

University of Cape Town

APPENDIX 2

INFORMED CONSENT

Study: The prevalence and aetiology of lower back pain in cyclists

This study attempts to establish the prevalence of lower back pain in cyclists and determine the possible associated factors and causes of lower back pain.

I,……., have been fully informed about the nature of this research project and hereby give consent to act as a subject for the research.

I am fully aware of the procedures involved:

Section 1:

I will complete a questionnaire on cycling training, cycling related back pain, as well as a general medical history questionnaire.

	Name	Signature	Date
Subject			
Researcher			
Witness			

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APPENDIX 3

QUESTIONNAIRE

Official Use

Date: / / 200

Cycle race .....

- Distance .....

1. Flat **2. Hilly**

- Terrain ....

- Finish time .....

Argus Expo. .....

Cycle gym .....

Cycle training track .....

Cycle shops _____

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Do you ride a road bike? If the answer is YES please complete the questionnaire.

SECTION 1: Personal demographics

Name: _____

Height: _____ m or _____ feet

Sex. **Please tick (√) the appropriate box:**

M	F

Age _____ years

Weight _____ kg

City of residence. **Please tick (√) the appropriate box:**

Cape Town	Other

What posture do you spend most of your working day in? **Please tick (√) the appropriate box.**. You may tick a maximum of 2 postures.

Standing	Sitting	Driving
Manual Work	Walking	Running
Other (Specify):		

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SECTION 2: Training

1. How many days a week do you cycle? _____ days/week

2. What distance do you cycle in an average week? _____ km/week

3. How many hours a week do you cycle? _____ hours/week

4. How long have you been cycling? _____ months

   _____ years (intermittent with 1-3 month breaks

   _____ years (throughout the year)

5. What is the intensity of your average training cycle? **Please tick (√) the appropriate box:**

a. Easy	b. Mild	c. Moderate	d. Hard	e. Very Hard

6. What is your average training speed? **Please tick (√) the appropriate box:**

a. 10-15km/hr	b. 15-25km/hr	c. 25-35km/hr	d. 35-45km/hr	e. tick here if you don't know

7. Do you cycle more often in a heavier gear (which requires more power and strength) or in a lighter gear (which allows you to spin more). **Please tick (√) the appropriate box:**

Heavy gear	Light gear

8. Do you stretch ***prior*** to cycling?

Yes	No

9. Do you stretch ***after*** cycling?

Yes	No

10. If yes to either Question 8 or 9, how long is your full stretching session? _____ minutes

11. How long do you hold each individual stretch for? _____ seconds

12. Which areas do you stretch? **Tick (√)** the appropriate box.

a. Thigh (back) – hamstring		b. Thigh (front) – quadriceps	
c. Inner thigh – (abductors)		d. Buttocks - (gluteals)	
e. Calf muscles		f. Neck	

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g. Upper back ☐ h. Lower back ☐

13. Do you stretch at other times during the week? **Yes** **No**
14. If **Yes** how long is each full stretching session? ..... minutes ..... hours
15. How long do you hold each individual stretch for? ..... seconds
16. Have you received any advice on the correct bicycle set-up? **Yes** **No**
17. From where? Tick **(√)** the appropriate source.

a. Cycle shop	☐	b. Cycling books	☐
c. Cycling gymnasium	☐	d. Physiotherapist	☐
e. Biokineticist	☐	f. Other, specify	☐

18. Do you do any other sports?

SPORT	HOURS/WEEK
a.	
b.	
c.	

19. What was your time for :

- The Argus **2001** ..... Hours ..... Minutes

2002 ..... Hours ..... Minutes

- Giro Event **2001** ..... Hours ..... Minutes

2002 ..... Hours ..... Minutes

- Your latest's race ..... Hours ..... minutes ..... Distance

Would you be prepared to participate in a study on cycling related lower back pain at the Sports Science Institute? You will receive guidelines on the correct bicycle set-up and information on the possible factors associated with lower back pain in cyclists. We would require approximately 1 hour of your time **Yes** **No**

How can we contact you? Telephone (w) _____

(h) _____

Cell _____

Please turn the page

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SECTION 3: Injury History questionaire

1. Have you ever experienced any cycling related lower back pain? (during cycling and/or within 2 hours after cycling)

Yes	No

2. Have you experienced any lower back pain in the last 12 months from cycling?

Yes	No

3. If you answered **YES** to either 1 or 2, complete the remainder of questionnaire.

---

4. In the last ten times you have cycled (10 training sessions and 10 races) how many times have you experienced back pain (during or within 2 hours of cycling)? Circle the appropriate amount.

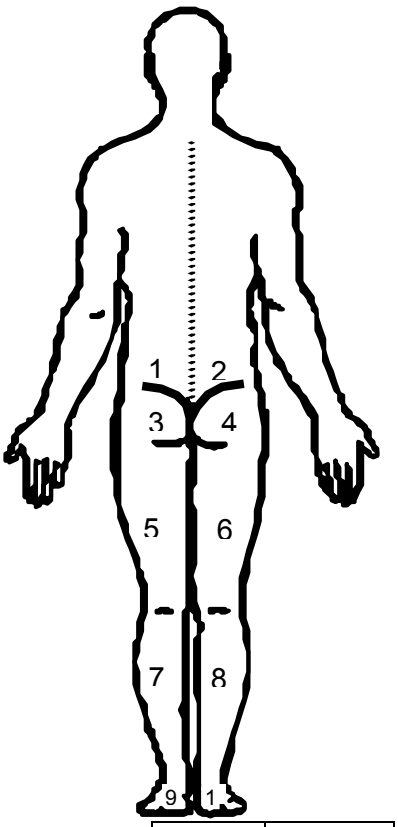
Training related:	1	2	3	4	5	6	7	8	9	10
Race related:	1	2	3	4	5	6	7	8	9	10

5. When did your back pain start? ..... weeks ago

..... months ago

..... years ago

6. Where is your main pain on this picture?
Circle the corresponding number in the picture.
(You may circle more than one area)



7. Do you experience any other symptoms besides pain in your back or legs/feet?
Tick **(√)** the appropriate box

Yes	No

8. If **Yes,** tick **(√)** the appropriate box.

1. Pins and needles	2. Loss of sensation	3. Tingling	4. Weakness in legs

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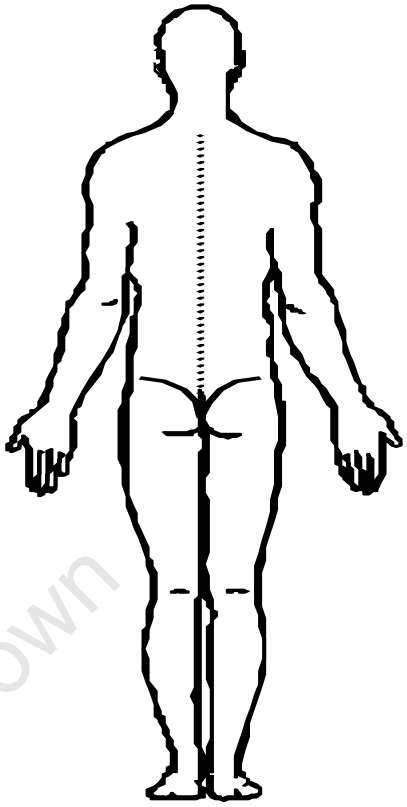
9. Mark on the picture right, with the appropriate number in the relevant area, where you experience any of the above symptoms.
e.g.: If you experience **Tingling** in the **lower left side** of the back, put a **3** in that area. You may mark more than one area.



10. When do you experience cycling-related lower back pain?
Tick **(√)** the appropriate box.

Cycling	
Pain during cycling which does not affect your cycling	
Pain during and after cycling which does not affect your cycling	
Pain during and after cycling which affects your cycling	
Pain (at times) preventing you from cycling	

11. Please indicate the severity of your cycling related back pain in the last month (either during or within 2 hours after cycling)
Mark with a cross anywhere on the line.

0	1	2	3	4	5	6	7	8	9	10
no pain					average					severe pain

12. If you experience lower back pain while cycling, how long does it take to come on?

..... minutes ..... hours

OR What distance do you ride before you experience pain? ..... km

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13. If you experience lower back pain after cycling, how long does it last for?

..... minutes _____ hours ..... days

14. What aggravates your pain? Tick **(√)** the appropriate responses.

Hill training		High gear ratios	
Speed training		Distance training	
Wind		Combining cycling with other sport	
Other, specify			

15. Do you lose training days in the week due to lower back pain?	**Yes**	**No**
16. If **Yes**, how many	days	
17. Does your pain get worse as you cycle for a longer period of time?	**Yes**	**No**
18. Have you ever injured your back in a sudden/ single incident?	**Yes**	**No**
19. Have you ever consulted a medical professional with regard to your lower back pain?	**Yes**	**No**

20. If **Yes,** please indicate who by ticking **(√)** in the appropriate box

1. Physiotherapist	**2. Chiropractor**	**3. G P**	**4. Specialist**	**5. Other, Specify**

21. What diagnosis did they give? Tick **(√)** the appropriate box.

1. Slipped disc	**2. Joint/facet joint problem**	**3. Nerve root pain**
4. Muscle spasm	**5. Spondylolisthesis**	**6. Scoliosis**
7. Stress fracture	**8. Arthritis**	**9. Other, specify**

22. Have you had any other injuries within the last year or do you have any other injuries now?	**Yes**	**No**

23. What?

Thank you for completing the questionnaire!

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APPENDIX 4

INFORMED CONSENT

Study: The prevalence and aetiology of lower back pain in cyclists

This study attempts to establish the prevalence of lower back pain in cyclists and determine the possible associated factors and causes of lower back pain.

I,……., have been fully informed about the nature of this research project and hereby give consent to act as a subject for the research.

I am fully aware of the procedures involved:

Section 1:

I will complete a questionnaire on cycling training, cycling related back pain, as well as a general medical history questionnaire.

Section 2:

Part A

- Body measurement tests which will be conducted on me, including the marking of points on my skin with a washable body marker.
- Measurement of bicycle parameters which will in no way alter my existing bicycle set-up

Part B

- My bicycle will be fitted to the Computrainer ergometer.
- I understand that I may experience back pain during the testing I am aware that appropriate medical care will be available in the unlikely event of an injury during the testing.

I am aware that I will be free to withdraw from the study at any time and that I will not be subjected to any pressure whatsoever to remain in the trial. I understand that the data collected may be used for scientific purposes and publications in a scientific manner, and that

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all individual data will be treated confidentially. I understand the implications of my consent and that questions I had have been answered to my satisfaction.

The researcher will arrange treatment for any adverse or untoward events arising from participation in this research study.

	Name	**Signature**	**Date**
Subject			
Researcher			
Witness			

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APPENDIX 5

MEDICAL QUESTIONAIRE

Part A: Lower back pain Questionnaire

1. Have you experienced acute, incapacitating, lower back pain in the last week which has limited you from cycling? **Please tick (√) the appropriate box:**

Yes	No

2. Have you had referred pain into your buttocks and/or leg in the last week which has limited you from cycling? **Please tick (√) the appropriate box:**

Yes	No

Part B: Physical Activity Readiness Questionnaire (PAR-Q)

Please tick (√) the appropriate box:

1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?

Yes	No

2. Do you feel pain in your chest when you do physical activity?

Yes	No

3. In the past month, have you had chest pain when you were not doing physical activity?

Yes	No

4. Do you lose your balance because of dizziness or do you ever lose consciousness?

Yes	No

5. Do you have a bone or joint problem that could be made worse by a change in your physical activity?

Yes	No

6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?

Yes	No

7. Do you know of any other reason why you should not do physical activity?

Yes	No

(American College of Sports Medicine, 2000)

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