A RANDOMISED CONTROL TRIAL FOR THE RESTORATION OF FUNCTIONAL ABILITY IN PATIENTS POST TOTAL KNEE ARTHROPLASTY:

ECCENTRIC VERSUS CONCENTRIC CYCLING ERGOMETRY

By

SANDHYA PRAKASH SILAL

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Division of Physiotherapy
Department of Health and Rehabilitation Sciences
Faculty of Health Science
UNIVERSITY OF CAPE TOWN

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Supervisors:

Yumna Albertus, ***BSc (Med.) Hons, PhD***
Division of Exercise Science and Sports Medicine, Department of Human Biology, Faculty of Health Sciences, University of Cape Town

Nicholas Tam, ***BSc (Med.) Hons, MSc (Med.), PhD***
Department of Physiology, Faculty of Medicine and Nursing, University of the Basque Country UPV/EHU

Michael Posthumus ***BSc (Med.) Hons (Med.), PhD***
Division of Exercise Science and Sports Medicine, Department of Human Biology, Faculty of Health Sciences, University of Cape Town

DECLARATION

I, **Sandhya Prakash Silal,** 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.

Signed by candidate

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(Signature)

8 December 2018

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(Date)

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ॐ श्री राम

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LIST OF ABBREVIATIONS

ACL	**:**	Anterior cruciate ligament
ADL	**:**	Activities of daily living
BF	**:**	*Biceps femoris*
CON	**:**	Concentric
DOMS	**:**	Delayed-onset of muscle soreness
ECC	**:**	Eccentric
EMG	**:**	Electromyography
HR	**:**	Heart Rate
KAM	**:**	Knee adduction moment
LH	**:**	*Lateral hamstring*
LG	**:**	*Gastrocnemius lateralis*
MG	**:**	*Medial gastrocnemius*
OA	**:**	Osteoarthritis
PAR-Q	**:**	Physical Activity Readiness Questionnaire
Q/H	**:**	quadriceps/hamstrings
QOL	**:**	Quality of life
RF	**:**	*Rectus femoris*
ROM	**:**	Range of movement
RPE	**:**	Rating of Perceived Exertion
SCT	**:**	Stair climb test
SF-36	**:**	Short Form Health Survey
TA	**:**	*Tibialis anterior*
THA	**:**	Total hip arthroplasty
TKA	**:**	Total knee arthroplasty
TUG	**:**	Timed up-and-go test
VAS	**:**	Visual analogue scale
VL	**:**	*Vastus lateralis*
VM	**:**	*Vastus medialis*
6MW	**:**	6-minute walk

ABSTRACT

Introduction: While the total knee arthroplasty procedure improves joint-specific outcomes, including pain and range of movement, functional deficits post-surgery has been noted. Movement abnormalities and quadriceps weakness of the operated limb, as well as a decrease in strength on the non-operated have been widely reported. Recovery of strength and function to normal levels is also rare, thereby predisposing patients to future disability with increasing age.

The purpose of this study was to determine the effects of an eight-week eccentric cycling ergometry exercise intervention versus a concentric cycling ergometry exercise intervention in total knee arthroplasty recipients three to nine months post-surgery. This study aimed to a) investigate the change in joint kinetics, kinematics and muscle activity during the phases of gait, between the eccentric and concentric groups over time and b) To determine if an eccentric cycling exercise intervention produces greater improvements in knee function when compared to concentric cycling exercise.

Methods: Eighteen participants, three to nine months post total knee arthroplasty were recruited and randomly assigned to either an eccentric or concentric cycling exercise intervention group. Participants performed three exercise sessions weekly over a progressive eight-week period on the Grucox Isokinetic Ergometer. Walking gait analyses and functional outcomes, as measured by the six-minute walk test and validated knee scores (Knee Injury and Osteoarthritis Outcome Score, SF-36 Health Survey and Tegner Activity Scale) were recorded pre- and post-intervention.

Results: The concentric group knee flexion range of movement increased significantly during the swing phase of gait (p=0.021) post-intervention together with a significant increase in the peak knee flexion angle during swing (p=0.038). The concentric group showed significant differences between pre and post-rehabilitation in knee flexion range of movement during the swing phase of gait (p=0.030). Significant correlations between knee joint stiffness and the quadriceps:hamstring co-activation ratio were observed in the concentric intervention group pre-intervention: during the pre-activation phase of gait between knee joint stiffness and *vastus medialis / biceps femoris* (r=-0.68; p=0.042) and during load acceptance phase of gait between knee joint stiffness and *vastus lateralis / biceps femoris* (r=0.07; p=0.036).

The eccentric group recorded neuromuscular changes post-intervention with a significant decrease in the muscle activity of the *biceps femoris* during load acceptance phase of gait (p=0.021). The eccentric group had significantly better functional outcomes in the overall score of Knee injury and Osteoarthritis Outcome post-intervention (p=0.008) with a significant increase in function seen in the Sports and Recreation subgroup (p=0.008) and a significant increase in the level of activity as measure by the Tegner Activity Scale post-intervention (p=0.028), despite not showing any significant changes in the knee joint kinetics and kinematics. The concentric group only reported a significant increase in the overall score of the of the SF-36 Health Survey (p=0.011) with significant increases in three of the subgroups post-intervention: Bodily pains had improved (p=0.042), the role limitations due to physical heath had improved (p=0.028) and the role limitations due to emotional health had also improved (p=0.009). The concentric group also showed significant improvement in the emotional health over the intervention in comparison to the eccentric intervention group (p=0.020). Both intervention groups reported a similar significant increase in the distance covered during the six-minute walk test post-intervention (p=0.038).

Conclusion: The results of this exploratory study did not find the eccentric cycling rehabilitation intervention exclusively more effective than the concentric cycling intervention in the restoration of functional ability in patients post-TKA. The eccentric intervention did however result in neuromuscular adaptations consistent with a move towards a more typical asymptomatic gait pattern and participants reported greater functional improvements on validated knee functional assessments and levels of activity scores. The concentric intervention yielded kinematic changes and participants reported improvements in their emotional and physical health post-intervention. Eccentric training and its role in early stage post-operative rehabilitation is limited. Based on the findings from this exploratory study, the benefit of eccentric training as an adjunct to rehabilitation and its role in contributing to greater improvements in the restoration of functional ability post-TKA needs to be further explored.

CHAPTER 1

INTRODUCTION AND SCOPE OF THESIS

Total knee arthroplasty (TKA) is a universally performed surgical procedure in which the weight-bearing surfaces of the knee joint are replaced in an attempt to relieve or alleviate joint pain and disability. This procedure is currently the international standard of care in the treatment of degenerative and rheumatological knee joint disease (Kurtz et al., 2011). Despite patient satisfaction exceeding 75% post-TKA, it is however less clear whether TKA improves overall physical function (Franklin et al., 2008; George et al., 2008). Movement abnormalities and quadriceps weakness of the operated limb, as well as a decrease in strength on the non-operated limb, may contribute to the functional deficits noted post-TKA (Mizner et al., 2005; Mizner and Snyder-Mackler, 2005; Farquhar and Snyder-Mackler, 2010).

The aim of a TKA is to mechanically correct knee alignment and optimize knee loading, thereby improving gait biomechanics and ultimately knee function. Improving the tibiofemoral loading reduces the frontal plane mal-alignment that is typically seen in knee OA. Research has shown that a shortened stride length and limited knee excursion during the weight acceptance phase in gait occurs after TKA (Berman et al., 1991; Bolanos et al., 1998; Chao et al., 1980; Chen et al., 1991; Ouellet & Moffet, 2002). Other observed marked locomotor deficits two months post-TKA included; 20% reduction in gait speed, 29% increase in stair ascent duration, timed up and go (TUG) duration was 30% longer and the distance walked at the six minute walk (6MW) test was 19% less than before surgery. In addition, quadriceps and hamstrings weakness and co-activation are present post-TKA and may impair functional performance. (Thomas et al., 2014).

The greatest improvement observed in TKA recipients has been seen within the first three to six months after surgery, with more gradual improvements occurring up to two years after surgery (Jones et al., 2003). A systematic review and meta-analysis of randomised controlled trials looking at the effectiveness of physiotherapy rehabilitation post-TKA reported short-term benefits of a structured TKA rehabilitation programme, while no long-term benefits were recorded (Minns Lowe et al., 2007). Several other studies emphasize that current rehabilitation methods do not effectively restore patients to the level of their healthy peers. With persistent impairments and functional limitations experienced six months post-operatively, a more intensive therapeutic approach may be required to restore function and improve the quality of life of TKA recipients to match those of health adults (Mizner and Stevens, 2003; Mizner et al., 2005; Mizner et al., 2005; Bade et al., 2010).

Eccentric muscle contractions have received much less experimental attention than both isometric and concentric muscle contractions, especially in the field of rehabilitation. However, recent research has suggested that eccentric muscle contractions may elicit further improvements in strength gains and can be safely implemented in rehabilitation (LaStayo et al., 2009; Lastayo et al., 2015). Many frail or exercise-limited patients recovering from chronic cardiovascular, metabolic or neurological illnesses or post-operative orthopaedic conditions, lack the ability to produce sufficient muscle force during rehabilitation to maintain or improve their muscle mass and function. Without sufficient load on the muscles, muscle mass and strength gains are often not met, thereby affecting function (Lastayo et al., 2015). Thus, eccentric training is an ideal intervention that allows for greater force production at a reduced metabolic cost that would be of great benefit to this population group and serve as a novel adjunctive to rehabilitation.

Many institutions, centres and clinics provide outpatient therapy to patients following TKA surgery. Despite this, a best-practice outpatient rehabilitation approach has not been published (Marcus et al, 2011). Gait analyses investigating loading rate, range of movement (ROM) and forces through the knee as well as electromyography (EMG) activity pre and post-exercise intervention following TKA are lacking. It was our intention to add to the growing bank of evidence-based research investigating the effects of various rehabilitation interventions in the restoration of functional ability in patients post-TKA.

In preparation for this exploratory randomised clinical trial, a comprehensive literature review of the functional ability and rehabilitation in patients post-TKA will be presented in Chapter 2 together with the aims and objective of the study. The study design, methodology and intervention will be elaborated upon in Chapter 3, followed by the kinematic and kinetic findings, the EMG activity of the involved leg and the functional outcomes results (Chapter 4). The gait analyses and functional outcomes of this clinical trial will be discussed in Chapter 5. The summary and conclusion section will complete this thesis (Chapter 6).

CHAPTER 2

LITERATURE REVIEW OF FUNCTIONAL ABILITY AND REHABILITATION IN PATIENTS POST TOTAL KNEE ARTHROPLASTY

2.1 INTRODUCTION

More than 647 000 TKA are performed each year in United States, with the projected number to increase to over 2 million TKA surgeries being conducted by 2030 (Kurtz et al., 2007). It is estimated that osteoarthritis (OA) of the knee joint results in disabling knee symptoms in 10% of people over the age of 55 years (Peat et al., 2001) and is the commonest cause of disability affecting the elderly with over 80% of patients experiencing some degree of limitations in performing activities of daily living, such as household chores, mobility outside the home and work duties (Fautrel et al., 2005).

2.2 FUNCTIONAL OUTCOMES POST TOTAL KNEE ARTHROPLASTY

It is reported that more than one-third of the TKA recipients experience sub-optimal physical function following TKA surgery (Dickstein et al., 1998; Jones et al., 2000; Brander et al., 2003; Franklin et al., 2008). Further, almost all TKA recipients report levels of physical function that are below age-matched normative levels (Singh & Sloan, 2008) with their performance based physical function scores rarely matching those levels of healthy controls (Yoshida et al., 2008). Walking speeds were up to one-third slower (Bolanos et al., 1998), the time to negotiate stairs were two-times slower (Walsh et al., 1998) and the distance walked in six minutes was 20% shorter (Moffet et al., 2004) than control participants.

Both self-reported studies and those reporting performance-based measures have reported sub-optimal knee function post-TKA. In general, self-reported functional questionnaires, including the Western Ontario and McMaster Universities Osteoarthritis Index and the Medical Outcome Study 36-Itemed Short Form Health Survey (SF-36), have been successful in tracking knee function and health-related quality of life (QOL) outcomes post-TKA. These self-reported questionnaires have yielded varying results. Health-related QOL after joint replacement surgery improved on most scales of the SF-36 but physical function and bodily pain scores remained significantly worse than the population norm (March et al., 1999).

Large improvements were reported for pain and function after joint replacement surgery, while small to moderate changes were seen in other areas related to QOL (Jones et al., 2000). Patients experienced dramatic improvements in bodily pain and physical function after joint replacement, however a physical decline in function occurred 1 month post-surgery (Fitzgerald et al., 2004). However, significant improvements in QOL measures in all of the SF-36 subscales, as well as a change in health was noted in all arthroplasty patients from six months, one year, and two years after surgery (Ritter et al., 1995). Similarly, Singh et al., (2008) evaluated the health-related QOL in veterans with prevalent TKA or total hip arthroplasty (THA) and compared them with age and gender-matched controls. Results revealed a profound physical health-related QOL deficit that existed in veterans with TKA or/and THA when compared with age and gender – matched controls.

Further, several self-reported studies revealed various functional impairments following TKA. One third of the patients in a self-appraisal study expressed dissatisfaction from the operation linked to pain in both the operated and non-operated knees that resulted in functional limitations (the use of stairs) (Dickstein et al., 1998). Results from a large cohort study conducted by Jones et al. (2000) showed small to moderate changes in physical function and quality of life where 64% of all recipients reported having moderate to extreme difficulty in participating in heavy domestic duties while 60% of the recipients reported moderate to extreme difficulty descending stairs (Jones et al., 2000). A comparative study between TKA patients and participants with no history of knee pain, concluded that 52% of the TKA patients still experienced substantial functional impairment compared with their age and gender-matched peers one year post operatively, especially when performing biomechanically demanding activities, like squatting, kneeling and gardening (Noble et al., 2005). Results from these studies suggest that despite the dramatic improvements in pain and perceived function, individuals who had undergone TKA for advanced knee OA experienced substantial functional impairment when compared to healthy age-matched individuals.

In comparison to self-reported measures, performance-based measures like the 6-minute walk test (6MW) and the stair climb test (SCT) depicted moderate improvements following TKA, with substantial deficits that persisted when compared with age and gender matched healthy comparison groups (Bade et al., 2010; Walsh et al., 1998). Results showed marked physical impairments and functional ability one-year post-TKA. Walking speeds at normal and fast pace as well as stair climbing ability were compromised when compared to the control group (Walsh et al., 1998). Similarly, patients post-TKA performed significantly worse for all measures (SCT, 6MW test and TUG), when compared to a control group consisting of healthy adults. Patients demonstrated 63% longer TUG times, 105% longer SCT times, and 28% less distance walked on the 6MW test (Bade et al., 2010).

Two recent studies evaluated patient outcomes after TKA by examining changes in both self-report measures and performance measures pre and post-operatively (Stevens-Lapsley et al. 2011) (Mizner et al. 2011). Results from both studies showed significant improvement in self-reported measures and in the performance measures at 3, 6 and 12 months after TKA when compared with pre-operative values. These results emphasize the importance of including performance measures when tracking recovery after TKA as opposed to solely relying on self-reported measures (Stevens-Lapsley et al. 2011). These functional performance findings in recipients post-TKA are consistent with chronic quadriceps muscle weakness (Noble et al., 2005; Walsh et al., 1998).

2.3 QUADRICEPS STRENGTH POST TOTAL KNEE ARTHROPLASTY (TKA)

The predominant impairment for function following a TKA, is a distinctive reduction in quadriceps muscle strength that has been associated with a limitation of post-operative physical activity (Walsh et al., 1998; Berth et al., 2002; Silva et al., 2003; Mizner, Petterson, Stevens, et al., 2005a; Meier et al., 2008; Yoshida et al., 2008). Stevens-Lapsley et al. (2010) suggests the loss of quadriceps strength after TKA could be a result of a combination of various factors including: pre-existing quadriceps weakness characteristic of knee OA, surgical trauma during TKA and age-related limitations in the recovery of muscle function.

The Effect of Surgery

The most common surgical approach during a TKA procedure involves an incision through the extensor mechanism. This anterior approach possibly compounds pre-operative strength deficits as patients produce less than half of their pre-operative torque values when tested one month after surgery (Mizner and Stevens, 2003; Stevens et al., 2003; Mizner, Petterson and Snyder-Mackler, 2005; Mizner, et al., 2005).

The Effect of Muscle Atrophy

Sarcopenia, the progressive loss of muscle mass with aging, is a fundamental contributor to disability and impaired function in the elderly population (Volpi et al., 2004). A combination of quadriceps muscle atrophy and neuromuscular activation deficits may also contribute to residual strength impairments in this patient population (Mizner et al., 2005). Berth et al., (2002) is of the similar opinion. The average isometric extension peak torque values in patients who underwent TKA were reduced by up to 30.7% when compared with healthy controls (Silva et al., 2003). Relatively greater quadriceps strength was associated with a better functional score while higher body mass index (BMI) was associated with relative quadriceps weakness. These findings are consistent with Berth et al. (2002) who earlier found that patients who underwent TKA had 83% of the quadriceps muscle strength of the contralateral knee at minimum 2 years post-surgery. These results suggest that specific quadriceps strengthening, as part of the rehabilitation after TKA, would improve functional outcomes.

Further studies investigating the role of quadriceps muscle strength loss after TKA, concluded that quadriceps strength showed greatest decline of all the physical measures assessed and could not match the strength of the uninvolved limb (Mizner and Stevens, 2003; Mizner and Snyder-Mackler, 2005; Mizner *et al.*, 2005). All performance measures underwent significant improvements one-month following TKA, while quadriceps strength was the most highly correlated measure associated with functional performance at all testing sessions. This considerable quadriceps femoris muscle inhibition and strength deficit after TKA surgery has several implications for recovery. Results from these studies suggest that early interventions focused on improving quadriceps muscle voluntary activation and strength, may improve efforts to restore muscle force and improve functional outcomes post-operatively.

While quadriceps strength has shown to improve steadily post-operatively, significant changes in strength start tapering off from 6 to 12 months following TKA surgery (Meier et al., 2008). Despite improvements in isometric quadriceps strength 10% to 20% from pre-operative levels following TKA (85-95 Nm), strength rarely ever reaches the value of age-matched healthy individuals (105-137 Nm) or the potential isometric or isokinetic strength levels of the non-operative knee extensor muscles (87-232 Nm) (Meier et al., 2005). One long-term follow-up study on TKA recipients revealed that quadriceps muscle weakness persists even 6 to 13 years after surgery (Huangh et al., 1996). A strengthening programme focused on improving quadriceps muscle activation and strength may improve functional and performance-based outcome measures post-operatively and in turn improve the QOL of TKA recipients.

2.4 GAIT KINEMATICS AND KINETICS

Gait abnormalities and increased joint loading have been associated with the degenerative changes seen in patients with OA of the knee, where symptoms often worsen over time as the disease progresses (Hurwitz et al., 2000; Levinger et al., 2013; Metcalfe et al., 2013). The most noted gait abnormalities in knee OA are frontal plane joint kinematics (joint motion) and kinetics (joint moments) as they have been linked to disease progression (Chang et al., 2004). These abnormalities include a) higher knee adduction moment (KAM) and b) increased incidence of abnormal varus-valgus motion when compared to healthy knees (Astephen et al., 2008; Baliunas et al., 2002; Chang et al., 2010) These abnormal gait biomechanics observed pre-operatively may persist following TKA and may contribute to sub-optimal knee function.

Gait Abnormalities Post Total Knee Arthroplasty

Two abnormal moment patterns that have been identified in TKA recipients, where patients either maintain a knee flexor moment (flexor pattern) or a knee extensor moment (extensor pattern) throughout the stance phase of gait. This compensatory mechanism is performed instead of alternating between the two directions (biphasic pattern), which is typically associated with normal gait (Andriacchi et al., 1982). In addition, research has shown that a shortened stride length and limited knee excursion during the weight acceptance phase in gait occurs after TKA (Berman et al., 1991; Bolanos et al., 1998; Chao et al., 1980; Chen et al., 1991; Ouellet & Moffet, 2002). Other observed marked locomotor deficit two months post-TKA included; 20% reduction in gait speed, 29% increase in stair ascent duration, TUG duration was 30% longer and the distance walked at the 6MW was 19% less than before surgery. The TKA recipients also used higher hip and knee moments in the uninvolved leg compared to the involved leg to stand (Ouellet & Moffet, 2002; Su et al., 1998). The cause of quadriceps weakness, persistent disability and altered movement patterns in TKA recipients, is still unclear.

Mizner & Snyder-Mackler (2005) hypothesized that quadriceps strength affects performance by altering loading and movement patterns during functional tasks. The study showed that functional performance was significantly related to the quadriceps strength of both legs, but was more strongly related to the uninvolved limb strength (involved rho=-0.43 with TUG; -0.65 with SCT; 0.64 with 6MW) (uninvolved rho=-0.63 with TUG; -0.68 with SCT; 0.77 with 6MW). The asymmetry in quadriceps strength was correlated to asymmetry in knee excursion during the weight acceptance phase of gait, where TKA patients adopted a pattern of movement that allowed the uninvolved limb to compensate for quadriceps weakness in the involved limb during functional tasks, thereby inhibiting the recruitment of the involved quadriceps. Yoshida et al., (2008) also demonstrated that quadriceps strength was positively correlated with faster times on the TUG and SCT and greater distances during the 6MW test, over a 12-month period following TKA.

Gait analyses focusing on both the sagittal and frontal planes of the knee joint need to be explored to fully understand knee biomechanics post-TKA. Three systematic reviews have been conducted in the last 10 years investigating gait biomechanics following TKA: two studies compared a cross-section of post-operative sagittal plane biomechanics of TKA recipients to a healthy control group (McClelland et al., 2007; Milner, 2009) while the third study evaluated changes in 3-dimensional gait analysis with a focus on frontal plane biomechanics, following TKA (Sosdian et al., 2014).

The systematic review by McClelland et al. (2007) found that TKA recipients walked with less total range of knee movement than the healthy controls. They also walked with less knee flexion during the swing phase and stance phase of gait when compared with healthy controls. These kinetic findings indicate that TKA recipients walked with a sagittal moment pattern about the knee that is different to healthy controls. It was reported that 64% to 80% of TKA recipients did not demonstrate the biphasic moment pattern that was seen in over 80% of the healthy controls. The most consistent finding of the systematic review was the absence of a normal sagittal plane moment and it has been suggested that reasons for this are multifactorial. Possible reasons have been considered including: the absence of the anterior cruciate ligament and reduction in knee proprioception (Andriacchi and Hurwitz, 1997), the abnormal gait pattern that might be residual from pre-operative gait, despite one third of the recipients in this study did not demonstrate this abnormal pattern pre-operatively (Smith et al., 2004) and lastly, abnormal muscle function may contribute to the abnormal sagittal gait pattern. These observations could impact on the rehabilitation protocols pre-operatively, that would ultimately affect functional abilities post-TKA.

Milner (2009), systematically reviewed studies examining whether gait mechanics were normal following TKA. The study found that peak knee flexion moment and knee flexion excursion during the weight acceptance phase, were smaller in the operated knee following TKA when compared to healthy controls. It was reported that the reduced knee flexion moment could be a consequence of a quadriceps avoidance gait that is common in the presence of knee pain and could be residual from pre-operative gait. This was shown by Smith et al. (2004) where pre-operative gait patterns were retained for up to 18 months post-surgery. The review also suggested there may be a smaller peak knee flexion moment post TKA when compared to healthy controls, as most studies reported lower knee flexion angles and consequently smaller peak external knee flexion moments. This however was not conclusive. Hatfield et al. (2011) showed similar findings where investigators showed how TKA alters knee motion and loading during gait. Results revealed an overall and mid-stance decrease in the KAM with an overall increase in knee flexion angle due to an increase during the swing phase. Increases in the early stance knee flexion moment and late stance knee extension moment were also found, indicating improvement in push off due to the impact attenuation, resulting in improved knee function. Most changes indicated a shift toward an asymptomatic gait pattern following TKA.

The most recent systematic review aimed to evaluate longitudinal changes in 3-dimentional gait analysis following TKA (Sosdian et al., 2014). Researchers evaluated knee kinematics and kinetics in the stance phase of gait where frontal and sagittal post-operative gait parameters where compared to healthy controls. The main findings highlighted a decreased peak KAM and maximum knee adduction angle and an increased peak knee flexion moment after TKA. There were inconsistent findings in the maximum knee flexion angle.

Normal biomechanical functioning of the knee may not be fully restored following TKA (McClelland et al., 2007; Milner, 2009) however early identification of factors that predict abnormal knee biomechanics post-operatively is important to improve physical and functional outcomes following surgery (Levinger et al., 2012). This may also assist therapists in designing and implementing specific rehabilitation protocols pre-operatively that would ultimately affect physical and functional abilities post TKA, thereby improving quality of life.

2.5 NEUROMUSCULAR CHANGES IN GAIT

As established, despite experiencing significant reductions in pain, many TKA patients do not achieve normal joint function during walking following surgery when compared to age-matched peers (McClelland et al., 2007; Milner, 2009; Ouellet & Moffet, 2002) and while improved function has been reported post-TKA based on participant reports (Yoshida et al., 2008), understanding the changes in neuromuscular control during fundamental tasks and how they affect normal joint functioning following TKA, needs to be explored.

Neuromuscular Changes Observed in the Presence of Osteoarthritis

Firstly, the neuromuscular changes observed in patients who present with OA in the knee needs to be explored to fully understand the changes that occur post TKA. Changes in neuromuscular control during walking have been shown in patients with mild to moderate OA of the knee as well as in those with severe OA (Hubley-Kozey et al., 2006; Hubley-Kozey et al., 2008).

The subtle change in neuromuscular control observed in the quadriceps, hamstrings and gastrocnemius muscles in the moderate OA group, favoured the idea that the lateral musculature around the knee produces higher forces to compensate for the high medial joint loading often found in those with OA (Hubley-Kozey et al., 2006). An increase in quadriceps activity just prior to and during the loading phase of the gait cycle was observed where scores demonstrated a higher *vastus lateralis* (VL) recruitment when compared to controls. The VL score for the controls was significantly lower than the VL for the OA group ($p < 0.003$). Similarly, *vastus medialis* (VM) recruitment amplitudes between groups were also elevated, which could be attributed to a typical response to decreased medial joint loading. Despite *rectus femoris* (RF) recruitment being low in both groups an increase was observed during late stance which may be compensating for the reduced activity noted in the *medial gastrocnemius* (MG) before toe-off. Results of the principal pattern scores for the quadriceps provided evidence that those with OA had higher lateral site amplitudes during initial loading with prolonged activity during mid to late stance and a slightly altered role for the VM and RF during late stance and early swing.

Similarly, hamstring muscle activity in the moderate OA group was noted with peaked muscle activity prior to heel contact. This occurs to decelerate knee extension and in preparation for initial loading (Ivanenko et al., 2004). In the OA group, *lateral hamstring* (LH) recruitment was higher than in the control while *medial hamstring* (MH) recruitment was the same in both groups. Prolonged activity of the LH was also captured during stance phase. Hubley-Kozey et al. (2006) hypothesized this could be an attempt to increase stability through antagonist co-activity since the VL and RF were also activated during this phase. Once again, a similar recruitment strategy for the OA group was seen with higher lateral site amplitudes that appeared to be consistent with attempts to decrease medial joint loading during initial contact.

In contrast, the EMG profiles of the group with severe OA was quite different, where increased activity of all seven muscles (*lateral gastrocnemius, medial gastrocnemius, vastus lateralis*, *vastus medialis*, *rectus femoris, lateral hamstring and medial hamstring*) over the majority of the stance phase was seen as opposed to having on/off timings throughout the gait cycle (Hubley-Kozey et al., 2008). The higher LH activity observed after heel strike compared to MH supports the theory that the lateral muscles attempt to increase lateral forces to decrease medial joint loading (Andriacchi, 1994). This is similar for those with moderate knee OA (Hubley-Kozey et al., 2006).

Neuromuscular Changes Observed Post-Total Knee Arthroplasty

Research is limited where we identified three studies that examined knee muscle activity during walking following TKA surgery that reported prolonged muscular co-contraction during stance phase of gait, despite patients having excellent clinical scores (Benedetti et al., 2003; Kramers-de Quervain et al., 1997; Wilson et al., 1996). A fourth study examined neuromuscular alterations one year post TKA and reported changes that were consistent with a move towards a typical asymptomatic gait pattern despite not matching asymptomatic controls (Hubley-Kozey et al., 2010). Decreased muscle activity during mid-stance for quadriceps and hamstrings was noted in the TKA recipients and is consistent with re-establishing soft tissue tension and passive joint stability, reducing the need for active muscle stiffness during single-leg stance (Hubley-Kozey et al., 2010). Also noted was a reduction in overall LH activity during prolonged mid-stance activity leaning towards a more balanced activation between the medial and lateral sites. This return to more typical neuromuscular responses may reflect the restoration of joint sensation and improved proprioception found following TKA surgery (Swanik et al., 2004).

A study noted gender-specific differences in knee joint biomechanics and neuromuscular control in patients before and post-TKA where women had higher quadriceps and gastrocnemius activity than men during stance phase, for both pre and post-TKA (Astephen Wilson et al., 2015). This may indicate a higher level of co-activation in early to mid-stance, possibly to improve joint stability. Despite there being a trend towards a more asymptomatic gait pattern post-TKA for both genders, this study highlighted women lagged behind their male counterparts in presenting with a less asymptomatic gait pattern post-TKA.

Quadriceps/Hamstring Co-activation

Co-activation refers to the simultaneous recruitment of synergistic muscles (Sirin & Patla, 1987), where synergistic muscles are all muscles that participate in producing moments of force around a particular joint during dynamic tasks (Nigg et al., 2003). Abnormal phasing of quadriceps and hamstring muscle activity may occur with knee stiffening pattern during walking, possibly leading to altered kinematics and joint loading (Andriacchi, 1993). Quadriceps and hamstrings weakness and co-activation are present post-TKA and may impair functional performance (Thomas et al., 2014).

Increased quadriceps/hamstrings (Q/H) co-activation have been reported frequently in patients with knee OA when compared with healthy adults and may be related to dysfunction in these muscle groups (Rudolph et al., 2007; Schmitt & Rudolph, 2008).

Two studies demonstrated differing co-activation muscle patterns between patients with moderate and severe OA respectively. (Hubley-Kozey et al., 2006; Hubley-Kozey et al., 2008). The moderate OA group had high VL and LH co-activation in early stance but also recorded higher amplitudes and prolonged activity of the LH during the stance phase when compared to the control group. This could possibly be an attempt to increase stability through antagonist co-activity since the VL and RF were also activated during stance phase (Hubley-Kozey et al., 2006). The study concluded that the lateral muscle sites produced higher forces to counteract the high medial joint loading often found in those with OA. The severe OA group exhibited a relationship between the VL, VM and LH, when compared to the other lower limb muscle sites. They concluded, it was most likely that this co-activation between agonists and antagonists present throughout the gait cycle possibly occurred to provide stability of the knee joint in the case of severe OA where function is limited by pain and altered biomechanics.

The results of these studies provide compelling evidence that neuromuscular control of the lower limb is altered in this population where changes are noted with the onset of OA. Despite gait patterns leaning towards an asymptomatic pattern post-TKA, altered neuromuscular control around the knee is still seen throughout the phases of the gait cycle.

2.6 REHABILITATION FOLLOWING TOTAL KNEE ARTHROPLASTY

The greatest improvement observed in TKA recipients has been seen within the first three to six months after surgery, with more gradual improvements occurring up to two years after surgery (Jones et al. 2003). The standard rehabilitation generally implemented post-TKA comprises a three-phase progressive exercise programme. The acute, sub-acute and end-stage rehabilitation phases focus on improvements in knee range of movement (ROM) and muscle strength, a decrease in pain level and improvements in independence with activities of daily living. (LaStayo et al., 2000; Moffet et al., 2004; Mizner et al., 2005; Minns Lowe et al., 2007; Meier et al., 2008). Despite the importance to incorporate these post-operative goals in the process of rehabilitation, a best-practice rehabilitation protocol post TKA has yet to be established. There are also no clinical practice guidelines in South Africa for rehabilitation post TKA (Wood, 2010).

Standard Physiotherapy Rehabilitation

Minns Lowe et al. (2007) conducted a systematic review and meta-analysis of randomised controlled trials looking at the effectiveness of physiotherapy exercise after arthroplasty. They reported short-term benefits of a structured TKA rehabilitation programme, while no long-term benefits were recorded. Small to moderate weighted mean differences in favour of the functional exercise interventions were seen for range of knee joint motion (2.9 (0.61 to 5.2)) and quality of life (1.66 (−1 to 4.3)) 3 to 4 months post-operatively.

All trials included a standard post-TKA rehabilitation programme that incorporated a combination of ROM exercises (continuous passive movements and manual mobilization of the joints of the lower limb), strengthening exercises for the lower limb (a graduated quadriceps, hamstring and hip abductors muscle strengthening programme) as well as stretching and gait re-education exercises (Minns Lowe et al., 2007). Physiotherapy exercise interventions included outpatient physiotherapy sessions and functional physiotherapy programmes based on functional activities. Usual or standard care referred to the continuation of home exercise programmes provided to patients post-surgery while in hospital which usually consist of isometric or simple strengthening exercises and stretches to help regain ROM.

The intervention groups varied in each of the trials. Frost et al. (2002) showed that traditional home exercise and functional home exercise after discharge did not yield significantly different outcomes, as did study by Kramer et al. (2003) who looked at a home-based exercise group versus the individual clinical based treatment group. Two other large trials, Mockford & Beverland (2004) (n=150) and Rajan et al., (2004)(n=120) both investigated outpatient physiotherapy versus the control group of usual care with no outpatient physiotherapy, using knee ROM as an outcomes measure. Mockford & Beverland (2004) showed a significant difference in knee ROM favouring the intervention group, while no significant differences were noted between the groups by Rajan et al. (2004). Conversely, Codine et al. (2004), showed a significant difference, for knee ROM for knee extension only, in the eccentric isokinetic strength training group when compared to the usual care group.

A study by Moffet et al. (2004) showed a significant difference in walking distance for the functional group when compared to the usual care (control) two months post-operatively. The functional group reported less pain, stiffness and difficulty performing activities of daily living at the second and fourth month follow-up sessions but not at the one-year follow-up session. These results demonstrate that an intensive and functional rehabilitation programme can lead to significantly better short and mid-term function when compared with a standard intervention. It also highlights that further research needs to be conducted to improve long-term function post TKA. Interestingly, the rehabilitation programme focused on ‘functional task-oriented exercises’, the majority of which were closed chain quadriceps strengthening exercises.

Piva et al. (2010) recently investigated whether this same functional task-oriented exercise programme supplemented with a balance exercise programme could improve knee function when compared with the functional exercise programme alone. Results from their pilot demonstrated clinically important improvements in lower-extremity functional status in both groups, however the degree of improvement seemed higher for gait speed, single-leg stance time, and stiffness in the intervention group.

It must be noted, that of the five rehabilitation trials discussed in the meta-analysis, only one included a direct measure of muscle strength as an outcome measure (Codine et al., 2004), despite previous literature having emphasized the predominant impairment to function following a TKA was a distinctive reduction in quadriceps muscle strength associated with limitation of post-operative physical activity (Berth et al., 2002)(Meier et al., 2008)(Mizner et al. 2005a)(Silva et al., 2003)(Walsh et al., 1998)(Yoshida et al., 2008). It also highlights the need for further clinical trials focusing on muscle strength as an objective measure.

Bade et al. (2010) implemented a standardized rehabilitation programme following TKA, measured outcomes before and after TKA and matched them with health adults. TKA patients demonstrated significant impairments and limitations one month post-surgery that exceeded those recorded pre-operatively, despite the implementation of a standardized rehabilitation programme after surgery. Patients lost 24.0° of active knee flexion (95% CI:19.2, 28.8), lost 2.6° of active knee extension (95% CI:0.4, 4.8), took 49.0% longer on the TUG (95% CI:36.2, 61.8), had 87.9% longer SCT times (95% CI:59.5, 116.3), walked 38.5% less distance on the 6MW (95% CI:30.1, 46.9), and decreased in SLS time by 25.2% (95% CI:2.4, 48) ($p<0.05$). Although TKA patients reached pre-operative levels six months post-surgery, patients still experienced the same limitations they did prior to surgery when compared to healthy adults where TKA patients had 40.9% ±23.1% less quadriceps torque, 26.3° ±7.5° less active knee flexion, 2.6° ±4.6° less active knee extension. Patients took 62.9% ±35.1% longer on the TUG, showed 105.0% ±87.7% longer SCT times, and walked 27.9% ±15.8% less distance during the 6MWT ($p<0.05$).

Bade & Stevens-Lapsley (2011), also demonstrated that a high-intensity programme leads to better short and long-term strength and functional performance outcomes when compared to a lower intensity rehabilitation programme, where the high-intensity rehabilitation intervention group yielded better functional performance and quadriceps strength ($p<0.05$) and continued to demonstrate better functional performance ($p<0.05$) with greater quadriceps strength ($p=0.08$) after a year. In addition, Lowe et al., (2012) demonstrated that TKA patients who received two additional home visits with individualized physiotherapy fared better on functional and pain scores when compared to the control group.

These various studies emphasize that current rehabilitation methods do not effectively restore patients to the level of their healthy peers. With persistent impairments and functional limitations experienced six months post-operatively, a more intensive therapeutic approach may be required to restore function and improve the quality of life of TKA recipients to match those of health adults (Mizner and Stevens, 2003; Mizner *et al*., 2005; Mizner *et al.*, 2005; Bade et al., 2010).

Stationery cycling is a low impact sport with little risk of prosthetic wear, dislocation, and periprosthetic fracture that may increase with high-impact sports, therefore stationary cycling has been recommended and widely used in rehabilitation after knee joint surgery and in various dysfunctions of the lower limb (McLeod & Blackburn, 1980). A study evaluating the three-dimensional knee joint kinematics during sports activity after TKA compared two low impact activities: a golf swing and stationary cycling (Hamai et al., 2008). During stationary cycling, axial rotation (6.78°) was within the ranges of the prosthetic articulating surfaces where the femur also exhibited progressive internal rotation relative to the tibia with knee extension compared to the average golf swing axial rotation (18.7°). The results suggested that stationary cycling be recommended to patients post-TKA as it allows the individual to maintain a functional knee through low impact physical activity while protecting the knee from high impact forces thereby preserving the integrity of the prosthesis.

2.7 ECCENTRIC REHABILITATION

Eccentric (ECC) type muscle contractions is the active lengthening of a muscle and can produce two to three times the force production of a typical isometric or concentric (CON) muscle contraction (Komi & Buskirk, 1972; Lindstedt et al., 2001). In addition to the increased force production, eccentric muscle contractions require less metabolic cost or a reduced oxygen requirement when compared to a concentric muscle contraction, for example where sub-maximal eccentric cycling is only 1/6 - 1/7 of that for concentric cycling at the same workload (Abbott et al., 1952; Bigland-Ritchie & Woods, 1976).

Many frail or exercises-limited patients recovering from chronic cardiovascular, metabolic or neurological illnesses or post-operative orthopaedic conditions, lack the ability to produce sufficient muscle force during rehabilitation to maintain or improve their muscle mass and function. They may also lack the energy required to produce these gains. Generally elderly individuals with cardiovascular disease also have difficulty exercising at intensities sufficient enough to provoke improvement in skeletal muscle mass and function (Braith, 1998; Brown et al., 1995). Without sufficient load on the muscles, muscle mass and strength gains are often not met, thereby affecting function (Lastayo et al., 2015). Thus, an ideal intervention that allows for greater force production at a reduced metabolic cost would be of great benefit to this population group and serve as a novel adjunctive to rehabilitation.

There is a common perception that due to their high tension capabilities, eccentric muscle contractions cause muscle pain and injury (Evans et al., 1986; Fridén et al., 1983). However, evidence reveals that muscle soreness, injury and damage to muscles as the result of high intensity eccentric training are transient and the muscles seem to adapt to the eccentric stress by becoming more ‘‘resistant’’ to it (Armstrong, 1986; Ebbeling and Clarkson, 1990; Clarkson et al., 1992) Performance of one bout of eccentric exercise induces an adaptation in the muscle that allows it to be less vulnerable to a subsequent bout of eccentric exercise (Clarkson & Hubal, 2002). Several theories have explained this to possibly be due to the repeated bout effect, including altered motor unit recruitment, an increase in sarcomeres in series, a blunted inflammatory response, and a reduction in stress-susceptible fibres, however, there is no general consensus as to its cause (Clarkson & Hubal, 2002).

Standard protocol strengthening exercises involve predominantly muscle-shortening contractions, referred to as a concentric muscle contraction. These types of muscle contractions remain the predominant mode of muscle contraction in rehabilitation programmes. Typically, the standard post-operative TKA end-phase rehabilitation involves home based concentric muscle contraction exercises. However, recent research has suggested that eccentric muscle contractions may elicit further improvements in strength gains and can be safely implemented in rehabilitation (LaStayo et al., 2009; Lastayo et al., 2015)

A systematic review with a meta-analysis conducted to determine the effects of eccentric versus concentric resistance training on muscle strength and mass in healthy adults, showed that eccentric exercise performed at higher intensities than concentric intensity resulted in a significant increase of 4.24 N.m (95% CI:0.24, 8.24; p=0.04; n=313) in total strength and eccentric strength when compared with concentric training (Roig et al., 2009). A significantly greater increase in eccentric peak torque of was also shown in those training at higher eccentric than concentric intensity (13.71 N.m (95% CI:5.56, 21.86; p=0.001; n=294) and 1 RM of 4.11 kg (95% CI:1.47, 6.76; p=0.002; n=38). High intensity eccentric training was shown to be more effective than concentric exercise in promoting increases in muscle mass measured as muscle girth with a positive trend towards a greater improvement in the muscle cross-sectional area among participants who performed eccentric exercise at higher intensities.

LaStayo et al. (2000) conducted several studies over the last decade in the field of eccentric training and its role in rehabilitation. The first clinical study compared the structural and functional locomotor muscle responses of eccentric versus concentric cycle ergometry performed at an identical measure of oxygen uptake (LaStayo et al., 2000). Results showed that isometric leg strength increased significantly in the eccentrically trained group by 36% while the cross-sectional area of the muscle fibre increased by 52%, whereas the muscle ultra-structure remained unchanged. No changes in the fibre size, composition, or isometric strength were recorded in the concentrically trained group. The study concluded that the responses of muscle to eccentric training appear to be similar to resistance training.

A second clinical trial investigated if a chronic eccentric training intervention could limit or even reverse sarcopenia and its related impairments and functional limitations and decrease falls risk in a frail elderly population (LaStayo et al., 2003). Following 11 weeks of lower extremity resistance training on a high-force eccentric cycle ergometer, a significant increase in muscle fibre cross-sectional area (ECC = 60%, Control = 41%) was noted where only the ECC group experienced significant improvements in strength (60%), balance (7%), and stair descent (21%) abilities. The TUG task improved in both groups, with only the ECC group went from a high to a low fall risk. These results demonstrate that eccentric resistance training can significantly improve muscle structure and function in those with limited exercise tolerance, resulting in improved balance, stair descent and fall risk. Interestingly, all participants (mean age, 80 years) in the experimental eccentric completed the study and reported the training to be relatively effortless with minimal and transient muscle soreness.

Similarly, results of a pilot study investigating resistance exercise via negative eccentrically-induced work demonstrated increases in muscle size, strength and power with improved mobility (LaStayo et al., 2011). The efficacy of a high-force, low perceived exertion exercise suggests that resistance exercise via negative eccentrically-induced work may be suited to older individuals and this intervention may be useful for those individuals who are otherwise unable to achieve high muscle forces with traditional resistance exercise, like the TKA population.

The effects of progressive eccentric exercise on thigh muscle structure three weeks post anterior cruciate ligament (ACL) reconstruction was investigated following a 12-week programme of eccentric ergometry (Gerber et al., 2007a). Structural changes in the quadriceps and gluteus maximus muscles were observed in the eccentric group and greatly exceeded those achieved with a standard rehabilitation protocol. Isokinetic strength testing showed the overall quadriceps strength index was significantly greater in the eccentric-exercise group than in the standard-rehabilitation group (p=0.030). At the one-year follow-up, the magnitude of improvement in quadriceps muscle isokinetic strength was approximately 33% in the eccentric exercise group and 9% in the standard rehabilitation group. This highlights the need to investigate the role of eccentric resistance training in the TKA population and its effects both short term and long term in strength and functional improvements.

Although these studies demonstrate the benefits of an eccentric based programme to be superior in muscle strength gains when compared to a concentric based programme, however the muscle damage associated with eccentric contractions have overshadowed the benefits (Lastayo et al., 2015). Muscle damage or the delayed-onset of muscle soreness (DOMS), is often experienced following unaccustomed muscular exertion (Armstrong, 1984). The symptoms of discomfort, stiffness or pain in the skeletal muscle normally increase in intensity 24 hours post exercise and last up to 72 hours, after which they subside. This damage could be attributed to the high forces generated by muscles during an eccentric contraction. Thus, the strong association of eccentric muscle contractions with “muscle injury or damage” (Armstrong, 1984; Ebbeling and Clarkson, 1989).

Eccentric Rehabilitation following Total Knee Arthroplasty

The two unique characteristics of eccentric muscles contractions that are known are (1) the force production is uniquely high, and (2) the energy cost to produce the high force is uniquely low (Lastayo et al., 2015). The foremost concern during post-operative rehabilitation is implementing interventions that preserve and maintain the stability of surgical procedure.

There are only three clinical trials published that have investigated the role of eccentric resistance training following TKA, which further highlights the gap in post-TKA rehabilitation research. The first study demonstrated an increase in muscle size, strength and an improvement in levels of mobility after 12 weeks of ECC resistance exercise in older individuals, 1 to 4 years post TKA when compared with the traditional resistance training control group (LaStayo et al., 2009). The ECC group recorded an increase in quadriceps muscle size by 11% (p<0.001) and knee extension muscle strength by 15% (p=0.005), while the control group did not. There was a collective improvement of 20% in all of the mobility tasks i.e. timed-up-and-go (p=0.010), 6-minute walk (p=0.048), stair ascent (p=0.001), and stair descent (p=0.001). This also suggests that long-term muscle and mobility impairments are reversible with resistance exercise.

The second clinical study investigated the effects of an eccentrically-based rehabilitation programme three weeks after TKA (Marcus et al., 2011). Results showed eccentric exercise restored knee function to near-normal values. Sixty minutes of eccentrically induced exercise twice weekly for six weeks on the Eccentron (a recumbent eccentric stepper), resulted in significant improvements in physical function, muscle strength and power and knee ROM. Increases were noted in the following: SF-36 physical component (59%), Lower Extremity Functional Scale (55%) six-minute walk test (47%), Stair Climb Test (47%) and Gait Speed (30%) with knee extension strength (107%) and power (93%). The results of this study demonstrate that eccentrically biased exercise can be safely and effectively applied during the first three months following TKA surgery and does not adversely impact joint or muscle responses, despite the fivefold increase in eccentric work over the six-week rehabilitation period.

In addition, Codine et al. (2004) investigated the use of eccentric exercises for increasing tendon- muscular extensibility in attaining full knee extension after TKA. The experimental ECC group achieved a significantly better knee extension ROM while no differences were noted with ROM in flexion or quadriceps and hamstrings strength. Training was well tolerated without inflammatory reaction or hamstrings muscle pain. The study highlighted the safe and effective application of eccentric training, where eccentric training may be prescribed for improving range of movement following TKA.

Although these studies have demonstrated the safe and beneficial application of ECC training post-TKA with gains in muscles strength, knee mobility and ultimately ADLs, gait analyses pre and post an exercise intervention has yet to be investigated.

This risk of muscle damage has been of concern when implementing an eccentrically based rehabilitation programme, especially in an older population like the TKA population, however recent evidence has shown that muscle damage is neither inevitable or necessary for muscle rehabilitation (Lastayo et al., 2015). Firstly, studies have shown that eccentric exercise can be used safely and effectively in rehabilitation (Gerber et al., 2007b; Dibble et al., 2009; Lastayo et al., 2010). The key to avoiding or reducing muscle damage or injury is the dosage of exercise. Higher eccentric forces generated in a muscle will almost certainly result in muscle damage, however if the magnitude and duration of the force produced is gradually increased over time, no symptoms of muscle damage or injury may be recorded (Lastayo et al., 1999; LaStayo et al., 2003). Secondly, an increase in muscle size and strength can be achieved independent of any symptoms of muscle inflammation or injury (Flann et al., 2011). Therefore, the implementation of a graduated high-force eccentric based programme during rehabilitation, with no symptoms of muscle damage, may be perfectly suited to the elderly exercise intolerant individuals, like the TKA population (Hortobágyi, 2003).

2.8 SUMMARY

Although TKA effectively relieves arthritis pain, improvement in physical function varies (Franklin et al., 2008). Several clinical trials and observational studies have demonstrated that the TKA procedure improves joint-specific outcomes, including pain and range of movement, with levels of patient satisfaction exceeding 75%, however, it is less clear whether TKA improves overall physical function (George et al., 2008). In addition, recovery of strength and function to normal levels is rare, thereby predisposing patients to future disability with increasing age (Noble et al., 2005; Silva et al., 2003; Walsh et al., 1998).

Many institutions, centres and clinics provide outpatient therapy to patients following TKA surgery. Despite this, a best-practice outpatient rehabilitation approach has not been published (Marcus et al, 2011). Studies investigating “standard rehabilitation techniques” have emphasized the effectiveness of physiotherapy exercise after arthroplasty. They however, reported only short-term small to moderate benefits of a structured TKA rehabilitation programme in favour of more functional exercises, where minimal improvements in joint range of motion and quality of life were seen. The safety and efficacy of eccentric rehabilitation in the older population has been established with minimal or no adverse muscle damage or injury, provided the magnitude and duration of the eccentric force produced is gradually increased over time (Hortobágyi, 2003; Lastayo et al., 2015). This has also been shown in the TKA population (Codine et al., 2004; LaStayo et al., 2009; Marcus et al., 2011). Gait analyses investigating loading rate, ROM and forces through the knee as well as EMG activity pre and post-exercise intervention following TKA has yet to be seen.

As demonstrated by McLeod and Blackburn, (1980), stationary cycling has been recommended and widely used successfully in rehabilitation after knee joint surgery, which allows TKA recipients to maintain a functional knee through low impact physical activity while protecting the knee from high impact forces thereby preserving the integrity of the prosthesis. It was our intention to add to the growing bank of evidence-based research investigating the effects of eccentric and concentric cycling rehabilitation interventions in the restoration of functional ability in patients post-TKA.

Purpose

The purpose of this study was to investigate and compare the effects of an eight-week eccentric and concentric cycling rehabilitation intervention in TKA recipients three months post-surgery at the end stage of rehabilitation. This exploratory study aimed to investigate the changes in joint kinetics and kinematics; muscle activity during the phases of walking gait, as well as knee function and quality of life.

Aims and objectives

1) To investigate any changes in kinematics of the involved TKA knee joint by measuring range of movement during walking gait analysis, between the eccentric and concentric intervention groups, pre and post-intervention. We hypothesised that the eccentric rehabilitation intervention will result in increased knee range of movement during the swing phase in comparison to the concentric rehabilitation intervention.

2) To investigate any changes in kinetics of the involved TKA knee joint during walking gait analysis, between the eccentric and concentric intervention groups, pre and post-intervention. We hypothesised that the eccentric rehabilitation intervention will result in decreased sagittal and frontal knee joint moments in comparison to the concentric rehabilitation intervention.

3) To investigate any changes in knee joint stiffness of the involved TKA during walking gait analysis, between the eccentric and concentric intervention groups, pre and post-intervention. We hypothesised that the eccentric rehabilitation intervention will produce greater knee joint stiffness during walking gait in comparison to the concentric rehabilitation intervention.

4) To investigate any changes in the vertical ground reaction force of the involved TKA knee during walking gait analysis, between the eccentric and concentric intervention groups, pre and post-intervention. We hypothesised that the eccentric rehabilitation intervention will result in decreased vertical ground reaction force in comparison to the concentric rehabilitation intervention.

5) To identify any variations in muscle activity (electromyography) of the vastus medialis, vastus lateralis and biceps femoris muscles during walking gait analysis between the eccentric and concentric intervention groups, pre and post-intervention. The hypothesis is that the eccentric rehabilitation intervention will result in greater reductions in muscle activity of the vastus medialis, vastus lateralis and biceps femoris muscles in comparison to the concentric rehabilitation intervention.

6) To determine if the eccentric rehabilitation intervention produces greater improvements in knee functional outcomes, as measured by the validated knee scores and other functional assessments, namely the Knee injury and Osteoarthritis Outcome Score, the Tegner Activity Scale and the 6-minute walk test, between the eccentric and concentric intervention groups, pre and post-intervention. We hypothesised that the eccentric rehabilitation intervention will produces greater improvements in the knee functional outcomes.

7) To determine if the eccentric rehabilitation intervention produces greater improvements in health-related quality of life and overall well-being, as measured by the SF-36 Health Survey, between the eccentric and concentric intervention groups, pre and post-intervention. We hypothesised that the eccentric rehabilitation intervention will produces greater improvements in health-related quality of life and overall well-being.

CHAPTER 3

METHODOLOGY

3.1 PARTICIPANTS AND INCLUSION CRITERIA

Twenty-one patients between the ages of 30 and 80 years old, with a body mass index (BMI) less than 40 $kg.m^{-2}$ who had undergone unilateral TKA surgery participated in this randomised, single blinded, control trial (Figure 3.1).

Patients who had undergone a unilateral TKA at the Sports Science Orthopaedic Clinic in the preceding three to nine months were identified and requested to participate in this randomized control trial. The orthopaedic knee specialists Dr Willem van der Merwe, Dr Hayden Hobbs and Dr Dion O'Cuinneagain, as well as the investigators, confirmed the inclusion and exclusion criteria. Thereafter, the investigators contacted the participants and arranged a face-to-face meeting where the study was explained in detail and participants had the opportunity to voice any concerns with regards to the exercise intervention.

Patients had to be deemed medically fit to proceed with this end stage rehabilitation exercise intervention and completed the Physical Activity Readiness Questionnaire (PAR-Q; Appendix C) (Thomas S, Reading J, 1992). To ensure all participants were at a similar functional level at the time of enrolment, the Knee Injury and osteoarthritis Outcome score (KOOS; Appendix D) (Roos et al., 1998) was used as an inclusion criterion. Participants were required to achieve a score of greater than 60% on the KOOS activities of daily living sub-scale. To maintain a homogeneous population, we did not include patients already over 90% for this sub-scale. Once participants were satisfied with the requirements of the study and met the inclusion criteria, they were enrolled for the study.

Patients who had indicated "yes" for any of the 10 PAR-Q questions and had not been cleared by a qualified physician to partake in an exercise programme, were excluded from participating in this trial. Those patients who presented with excessive knee pain, involving either the involved or uninvolved limb during activities of daily living, had taken pain medication in the 2 weeks prior to recruitment, or had a corticosteroid injection in either knee since the TKA surgery, were not included in the study. Those who presented with a moderate or large effusion, a surgical scar that had not completely healed, a current deep vein thrombosis and rheumatoid arthritis or other rheumatological pathology in either the involved or uninvolved limbs, were also not included in the study.

Twenty patients made the inclusion criteria, with one patient excluded for not achieving >60% on the KOOS activities of daily living sub-scale. The 20 participants who completed the pre-intervention testing were randomised into either the Eccentric (ECC) or Concentric (CON) cycling exercise intervention programmes. Two participants, one from each intervention group, dropped out during the intervention due to the intervention being too physically demanding.

The study was performed in accordance with the principles of the Declaration of Helsinki (Seoul, 2008) and ethical approval was granted by the Human Research Ethics Committee of the University of Cape Town (HREC REF: 101/2012) (Appendix A)

Inclusion Criteria:

- 3 to 9 months post TKA
- Participant is between 30 and 80 years old.
- The patient is willing to complete an 8-week training protocol.
- BMI should be < 40 $kg.m^{-2}$
- KOOS score between 60% and 90% on the ADL sub-scale.
- Medically fit to proceed to end stage rehabilitation. Patients completed a Physical Activity Readiness Questionnaire (PAR-Q; Appendix C) to assess if they were medically fit to undergo the required testing and training. If any flags are noted, a qualified physician will assess the specific risk factor to evaluate if the patient may complete an exercise program.
- Range of motion should be >110 degrees in full active flexion and <10 degrees of flexion in full active extension.

Exclusion Criteria:

- Patient indicated “yes” for any of the 10 PAR-Q questions and has not been cleared by a qualified physician to partake in an exercise programme.
- A moderate or large effusion.
- Wound not completely healed.
- A current Deep Vein Thrombosis.
- Bilateral TKA surgery.

- A symptomatic contralateral (unaffected) knee (or leg) that limits activities of daily living (ADL).
- Excessive pain in the involved knee during ADL.
- A corticosteroid injection in either knee since the TKA surgery.
- Current (last 2 weeks) pain medication usage.
- Any contra-indication to exercise.
- Rheumatoid arthritis or other rheumatological pathology in either the involved or uninvolved limbs.

3.2 SAMPLE SIZE DETERMINATION

The sample size was based on a previously published study results where 13 participants showed improvements in quadriceps strength and volume resulting from a 12-week eccentric resistance training programme as the primary outcome measure (Gerber et al., 2007a). It was calculated that with the effect size shown, we would require nine patients in each group to achieve a level of 80% power and with 5% significance.

The study design was a single blind randomized design where participants were randomly assigned to either an eccentric or a concentric rehabilitation group. Sequenced numbered, sealed envelopes containing the intervention rehabilitation group name was used to determine the allocation of the 20 participants who had made the inclusion criteria.

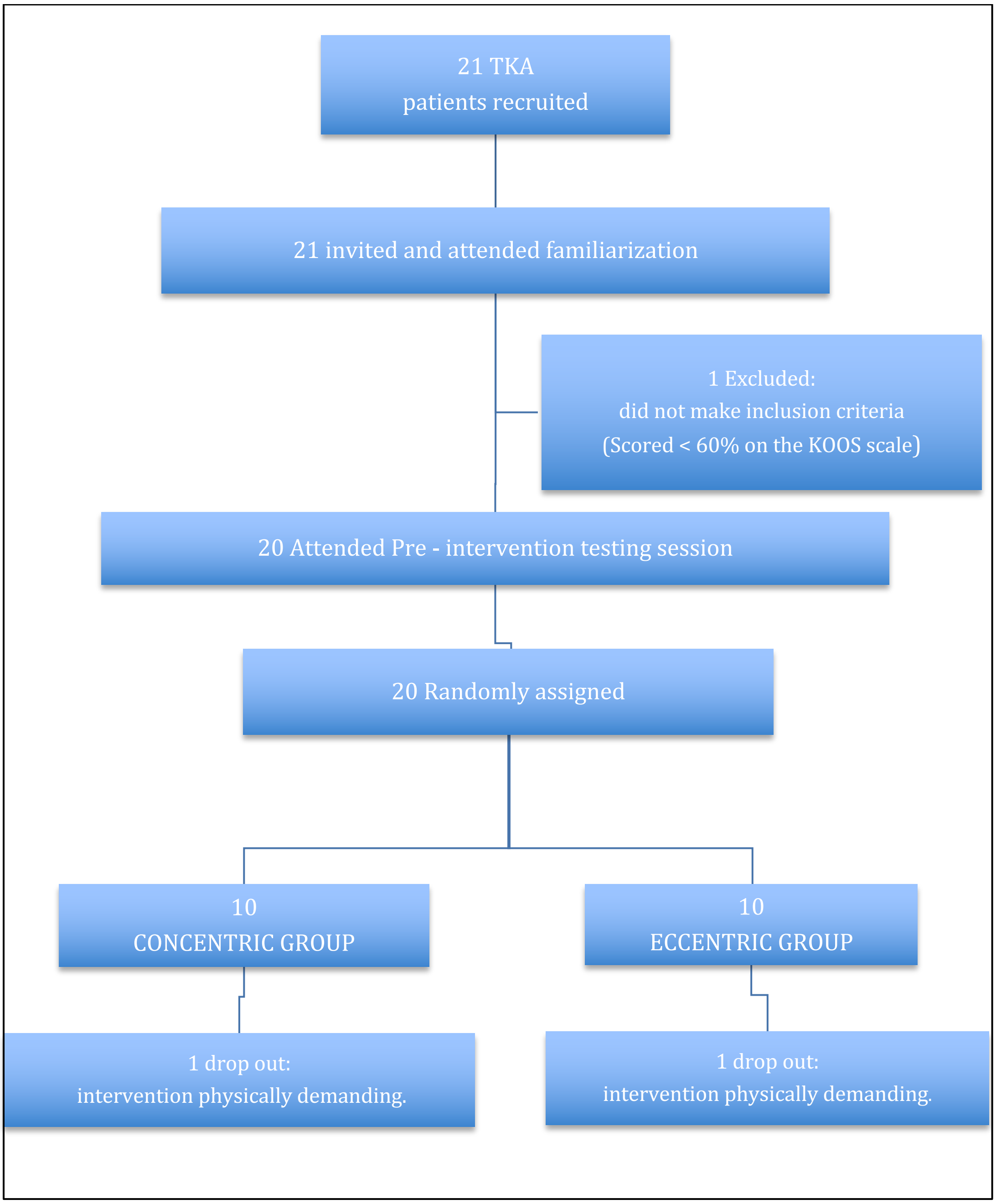


Figure 3.1 Study Recruitment Process

3.3 OVERVIEW OF TRIAL PROCEDURES

Participants were required to visit the biomechanics laboratory on 2 occasions for pre-intervention and post-intervention testing (Figure 3.2). At the pre-intervention visit participants completed a questionnaire of demographics, medical and knee injury history (Appendix B) and basic anthropometry measurements were recorded. Participants 3 questionnaires: The Knee Injury and osteoarthritis Outcome score (KOOS) (Appendix D), the SF-36 Health Survey (Appendix E) and the Tegner Activity Level Scale (Appendix F). Walking gait analysis was then recorded where participants were required to walk at a self-selected speed over a force platform where the kinetics and kinematics of the involved knee and electromyography (EMG) of the lower limb muscles were recorded. Lastly the 6-minute walk test was undertaken at a self-selected "fast" pace around a 70m indoor track.

The exercise intervention required participants to perform a progressive eight-week ergometric exercise programme on the Grucox Isokinetic Ergometer. Participants in both the ECC group (n=9) performed the eccentric exercise intervention while those in the CON group (n=9) performed the concentric exercise intervention. Participants in both groups performed 3 exercise sessions per week, each lasting 20 minutes. Following the completion of the 8-week exercise intervention participants were required to visit the biomechanics laboratory to complete the post-intervention testing: the three questionnaires, the walking gait analysis and the 6-minute walk test.

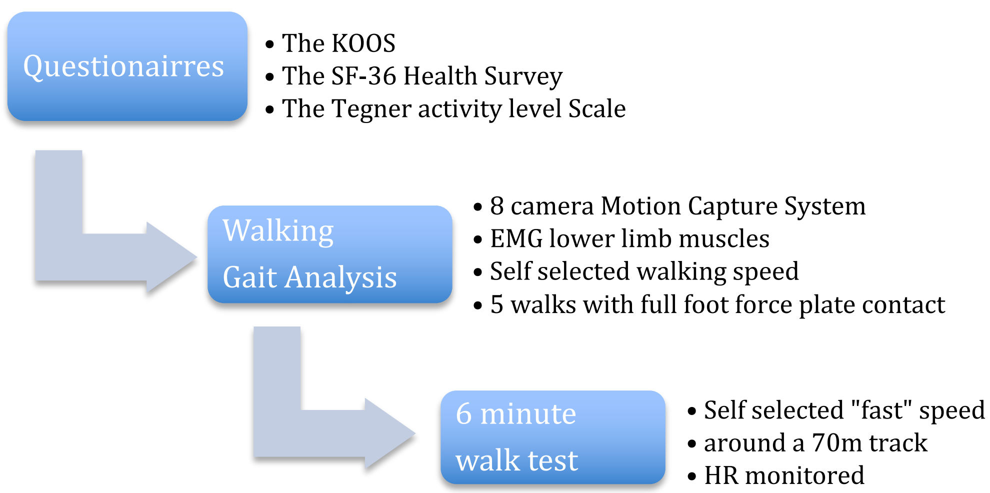


Figure 3.2: A summary of the pre-intervention and post-intervention testing protocol

3.3.1 Personal Details and Medical History Questionnaire

Participants completed a questionnaire of demographics, medical and knee injury history that included details on the TKA procedure. (Appendix B)

3.3.2 Anthropometry Measurements

Basic anthropometry measurements: height (cm), body mass (kg) and leg length (cm) were recorded in the standing position. Bilateral leg length was measured from the anterior superior iliac spine to the medial malleolus using a standard tape measure. Body mass index (BMI) was calculated (BMI = body mass (kg)/ height $(m)^2$).

3.3.3 Health Questionnaires and Surveys

The Knee Injury and Osteoarthritis Outcome score, the SF-36 Health Survey and Tegner activity scale, were documented prior to the exercise intervention, as well as after the eight-week exercise intervention.

Knee Injury and Osteoarthritis Outcome Score (KOOS)

The KOOS (Appendix F) was developed with the intention to evaluate short-term and long-term symptoms and function in patients/participants with knee injury and osteoarthritis (Roos et al. 1998). It has been validated for various orthopaedic interventions including anterior cruciate ligament reconstruction, meniscectomy and TKA studies.

This score consists of 5 subscales; (1) Pain, (2) Other Symptoms, (3) Function in daily living (ADL), (4) Function in sport and recreational activities and (5) Quality of life (QOL). The last week was taken into consideration in the answering of the questions. Standardized answer options were given (5 Likert boxes) and each question was scored from 0 to 4. A normalized score (100 indicating no symptoms and 0 indicating extreme symptoms) was calculated for each subscale. KOOS has high test-retest reproducibility (ICC>0.75; Roos & Lohmander, 2003).

The SF-36 Health Survey

The SF-36 (Appendix E) is a multi-purpose, short-form health survey with 36 questions. It yields an 8-scale profile of functional health and well-being scores as well as psychometrically based physical and mental health summary measures and a preference-based health utility index (Ware Jr., 1999).

This multi-item scale was constructed using the Likert method of summated ratings and measures the following health concepts: (1) physical functioning; (2) role limitations because of physical health problems; (3) role limitations because of emotional problems; (4) vitality (energy/fatigue); (5) emotional well-being; (6) social functioning; bodily pain; (7) and (8) general health perceptions.

Each of the eight-scaled scores, which are the weighted sums of the questions in their section are directly transformed into a 0-100 scale on the assumption that each question carries equal weight. The lower the score the more disability. The higher the score the less disability i.e., a score of zero is equivalent to maximum disability and a score of 100 is equivalent to no disability.

The Tegner Activity Scale

The Tegner activity scale (Appendix D) is a measure of physical activity were participants had to select the level of participation that best describes their current level of activity (Tegner & Lysholm, 1985). The questionnaire provides a standardized method of grading activities of daily living, physical work and recreational and competitive sporting activities. The score varies from level 0-10, were level 0 denotes "sick leave or disability", while level 10 represents competitive sports at an elite level.

3.3.4 Walking Gait Analysis

Walking trials were conducted in the University of Cape Town Biomechanics laboratory. Participants were required to walk along a 6m walkway at a self-selected walking speed while the biomechanics of the involved TKA limb was recorded.

Kinematics and Kinetics

Three-dimensional marker trajectories during gait were captured using an 8-camera Vicon motion capture system (Oxford Metrics Ltd, Oxford, UK) while kinetic data were collected using a 900 x 600mm force platforms (AMTI, Watertown, MA, USA). Marker trajectories were recorded at 250Hz and kinetic data (ground reaction force) were recorded at 2000Hz. A modified Helen Hayes marker set was used and applied to determine joint kinematics and kinetics (Kadaba, 1990). Specifically, reflective markers were attached bilaterally on the anterior iliac spine, the posterior superior iliac spine, the lateral distal third of the femur, lateral aspect of the sagittal axis of the knee, on the distal third of the lower leg, the lateral malleolus, the posterior calcaneus and the base of the second metatarsal head.

Electromyography

Electromyography (EMG) of the involved lower limb muscles were measured during gait trials. Five lower limb muscles were measured: *Vastus medialis* (VM), *Vastus lateralis* (VL), *Biceps femoris* (BF), *Gastrocnemius lateralis* (LG) and *Tibialis anterior* (TA). An additional reference electrode was placed on the anterior superior iliac spine (ASIS) of the pelvis. Two bipolar surface EMG electrodes (Blue Sensor SP-00-S/50, Ambu, Medicotest, Denmark) electrodes were placed on the belly of the listed muscles in accordance with the SENIAM recommendations (Hermens et al., 2000). Prior to the application, the skin area located for electrode placement was shaved and cleaned with ethanol swabs. Data was sampled at 2000Hz (Noraxon 2400T G2, Noraxon, Arizona, USA) and synchronized with the kinematic and kinetic data. All lead and pre-amplifiers connected to the electrodes were securely fastened with medical tape to ensure no interference during the walking trial. The transmitter unit was placed in a halter strapped to the participant's back; this technique contributed to minimizing the movement artefact of EMG signal.

Walking Trial Procedure

Participants were instructed to walk along a 6m walkway at a self-selected walking speed through the capture volume of the cameras and over the force plate. The position of the force plate in the centre of the walkway remained hidden to the participant thereby ensuring participants maintained a walk as close to their normal stride. Participants repeated the process until at least 5 strikes were recorded with the involved foot. During the walking trials marker trajectories and force platform data were synchronized and recorded with the VICON Nexus (VICON, Oxford Metrics, Oxford, UK). A manual synch was used to trigger EMG data collection (Myoresearch XP, Noraxon etc.) at the same time. A trial was deemed successful where all markers were visible to the camera and when the participant cleanly struck the force plate with the foot fully weight bearing on the force platform i.e. heel strike and toe-off with no visual evidence of targeting the force platform.

3.3.5 The 6-minute Walk Test (6MW)

The 6MW test is a validated test for the assessment of functional capacity in clinical populations where a maximal distance is covered walking at a self- selected speed during six minutes (Parent & Moffet, 2002). Participants were instructed to walk as fast as he/she could in six minutes around a 70m indoor track. In order to determine the maximum distance covered by each individual in the six minutes, the number of laps covered was recorded as well as any additional distance covered in meters, during the test. Heart Rate (HR) was also recorded during the entire 6MW test. The test was used for functional performance and not as a measure of cardiovascular fitness.

3.3.6 The Exercise Intervention

The exercise intervention required participants to perform a progressive eight-week ergometric rehabilitation intervention on the Grucox Isokinetic Ergometer. Participants were randomised into the eccentric ECC group (n=9) performed the eccentric exercise intervention while those in the CON group (n=9) performed the concentric exercise intervention. Participants in both groups performed three exercise sessions per week, each lasting 20 minutes.

The Grucox Isokinetic Ergometer

Both the ECC and CON intervention groups performed the rehabilitation exercise intervention on a Grucox Isokinetic Ergometer (Figure 3.3). The Grucox Isokinetic Ergometer is an upright ergometer and is equipped with a 230 Volt, 900 Watt (W) servo-drive system that drives the ergometer pedals via a geared drive train, in either a forward or reverse direction. The pedal speed and maximal motor torque was set on the ergometer display. Eccentric work was created by resisting against the driven pedals, with the aim of stopping the pedals. Concentric work was created when the participant exerted a force in the same direction of the driven pedals. Power (W) and work (Joules) was recorded during each intervention session.

Figure 3.3 The Grucox Isokinetic Ergometer

Concentric and Eccentric Exercise Intervention

The exercise intervention protocol entailed a progressive eight-week cycle ergometry programme performed on the Grucox Isokinetic Ergometer (Figure 3.4). During each exercise session, participants performed a 20-minute exercise protocol focusing on either ECC or CON work, performed in both the forwards and reverse directions. Participants in the ECC group were instructed to slow down the pedals of the Grucox Isokinetic Ergometer by resisting against the pedals, in both the forward and reverse directions. Participants performing the CON exercise intervention protocol were instructed to exert a force in the direction of the pedals, in both the forward and reverse directions.

Table 3.1: The Eccentric and Concentric Exercise Intervention Protocol

Eccentric Group (ECC)		**Concentric Group (CON)**	
Direction of Grucox Bike – Reverse		Direction of Grucox Bike – Reverse	
2 min	Continuous Passive Movement	2 min	Continuous Passive Movement
8 mins	Eccentric work	8 mins	Concentric work
Direction of Grucox Bike – Forwards		Direction of Grucox Bike – Forwards	
1 min	Continuous Passive Movement	1 min	Continuous Passive Movement
8 mins	Eccentric work	8 mins	Concentric work
1 mins	Cool down	1 mins	Cool down

Participants were positioned on the Grucox Isokinetic Ergometer, with the seat height adjusted allowing for approximately 30 degrees of knee flexion when the leg was fully extended, minimizing the possibility of a hyperextension injury to the knee. The intensity of the exercise was based on the Borg Rating of Perceived Exertion (RPE) scale (Figure 3.5).

Heart Rate (HR) and perceived pain recorded on a visual analogue scale (VAS) and reported RPE scores were recorded at 0, 1, 5, 9, 10, 14 and 18 minutes during the exercise session (Appendix G). The rate of work (watts) and cadence (pedal rate) displayed on the computer monitor, were electronically recorded in files downloadable after each exercise session. Power output (watts) was also recorded as an average for each leg, as well as a maximum. The pedal speed and torque of the cycle ergometer was self-selected according to comfort and fitness levels of the participants at the first session and thereafter progressed. Pedal speed ranged from 20 to 40 revolutions per minute and torque ranged according to desired RPE prescribed during each exercise session.

Table 3.2 The Borg Rating of Perceived Exertion Scale

6	No exertion at all
7	Extremely light
8	Very light
9	
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

The first session was a familiarization session at an "extremely light" intensity according to the Borg rating of perceived exertion. If a participant had an absence of exacerbation of pain or effusion, he or she was allowed to gradually progress to a "hard" intensity in the 8 weeks. The specific prescribed intensities and guidelines for progression of the intervention are outlined (Figure 3.6). Participants were required to complete a minimum of 80% of the exercise sessions to be included in the analysis of the study. A trained physiotherapist or biokineticist was present to instruct and record the required information during each training session and ensured the participant's safe use of equipment.

Table 3.3: The eccentric and concentric exercise intervention guidelines

Training week	Exercise session	Intensity Rate of Perceived Exertion	Duration (minutes)
1	1	Familiarization	20
	2	7 (Extremely light)	20
	3	9 (Very light)	20
2	4	9 (Very light)	20
	5 – 6	11 (Light)	20
3-4	7-12	13 (Somewhat hard)	20
5-6	13 - 18	13 (Somewhat hard)	20
7-8	19 - 24	15 (Hard)	20

3.4 DATA ANALYSIS

3.4.1. Kinematic and Kinetic Data and Electromyography Analysis

The marker trajectory and force platform data were filtered using a low-pass fourth-order Butterworth filter with a cut-off frequency at 25Hz and 100Hz, respectively. The lower body PlugInGait model (VICON, Oxford Metrics, Oxford, UK) was used to calculate three-dimensional lower extremity joint angles and joint moments using a Newton-Euler inverse dynamics approach. Joint angles were described using the joint coordination system (Grood & Suntay, 1983) while the three-dimensional joint moments were expressed as external moments normalized to body mass ($Nm.kg^{-1}$). Each walking trial was analysed for one complete gait cycle.

Joint angles and moments of the involved knee were extracted for statistical analysis using a customized MATLAB (MAthworks Inc., Natrick, USA) code. The data for each participant's involved limb were averaged over 3 walking trials. Discrete sagittal and frontal plane knee angles (degrees) and moments ($Nm.kg^{-1}$) were extracted for the different phases of gait: foot strike, peak during swing and stance, range of movement during swing and stance. Further, peak vertical ground reaction force (BW) and initial vertical loading rate ($BW.s^{1}$) were extracted. Sagittal plane knee joint stiffness was calculated as a change of maximum knee moment during stance and the initial ground contact divided by the change of maximum knee flexion angle over the same points (Hamill et al., 2012) (Figure 3.4).

$$\text{Joint stiffness} = \frac{\Delta \text{ Moment}}{\Delta \text{ Angle}}$$

Figure 3.4: Joint Stiffness Calculation

The raw digital EMG signal was processed using Noraxon's Myoresearch XP software (Version 1.8.07). The raw EMG data was filtered using a 50 Hz notch filter to remove any electrical interference from external sources and filtered a second time using a 15-500 Hz band pass filter. This allows noise or movement interference below 15 Hz and other non-physiological signals above 500 Hz to be removed. Data was smoothed using root mean squared analysis, calculated at 50ms moving window (Albertus-Kajee et al., 2011). Average EMG activity was analysed for the pre-activation, load acceptance and ground contact phases of walking, reported in micro-volts/second ($\mu V.s^{-1}$). Pre-activation was defined as the EMG activity during the 100ms before ground contact with load acceptance defined as the EMG activity from initial ground contact (foot strike) to 0.05s after foot strike. While ground contact was defined as EMG activity from foot strike to toe-off. The quadriceps (*vastus medialis* and *vastus lateralis*) / hamstring (*biceps femoris*) co-activation ratio in the involved knee during the pre-activation, load acceptance and ground contact phases was also computed and average values calculated for each phase (Kellis et al., 2011). Agonist:antagonist (VM:BF and VL:BF) EMG ratios of 1.0 indicate equal activation of the 2 antagonistic muscles, whereas co-activation ratios greater than 1.0 indicate increased agonist (VM or VL) activation compared with the antagonist (BF) muscles and vice versa. Ratios less than one indicate high activity of the antagonist relative to the agonist muscles. Further the correlation between joint stiffness and the quadriceps/hamstring co-activation ratio was analysed.

3.4.2. Health Survey and Questionnaires

Knee Injury and Osteoarthritis Outcome Score

The 5 subscales; (1) Pain, (2) Other Symptoms, (3) Function in daily living (ADL), (4) Function in sport and recreational activities and (5) Quality of life (QOL); of the KOOS were analysed. Standardized answer options were given (5 Likert boxes) and each question was scored from 0 to 4. A normalized score (100 indicating no symptoms and 0 indicating extreme symptoms) was calculated for each subscale.

The SF-36 Health Survey

Each of the eight-scaled scores was analysed as suggested by Ware Jr., (1999) :(1) physical functioning; (2) role limitations because of physical health problems; (3) role limitations because of emotional problems; (4) vitality (energy/fatigue); (5) emotional well-being;(6) social functioning; bodily pain; (7) and (8) general health perceptions. **T**he weighted sums of the questions in their section were directly transformed into a 0-100 scale on the assumption that each question carries equal weight. The lower the score the more disability. The higher the score the less disability i.e., a score of zero is equivalent to maximum disability and a score of 100 is equivalent to no disability.

The Tegner Activity Scale

The scoring of the Tegner Activity Scale varies from level 0-10, were level 0 denotes “sick leave or disability”, while level 10 represents competitive sports at an elite level.

3.5 STATISTICAL ANALYSIS

Statistical analyses were performed using Stata 12 software programme (StataCorp. 2011. College Station, TX, USA). Data were screened for normality of distribution and homogeneity of variances. The Kolomogorov-Smirnov test for normality showed unequal distribution while the F-test showed unequal variances of the data therefore non-parametric statistical tests were performed on the data sets. The Wilcoxon signed-rank test was performed to compare data pre-intervention and post-intervention data within the CON and ECC groups. A change in differences (post-intervention – pre-intervention) between the CON and ECC groups was calculated using the Wilcoxon rank-sum test. The non-parametric Spearman’s rank correlation coefficient was used to analyze the relationship between joint stiffness and quadriceps/hamstring co-activation ratio. Statistical significance was set at $p<0.05$. Data are presented as medians (interquartile range).

CHAPTER 4

RESULTS

4.1 GROUP DESCRIPTIVE CHARACTERISTICS

The group descriptive characteristics are shown in Table 4.1. No significant observations were made between the groups or over the course of the intervention. Post-intervention weight and body mass index (BMI) remained unchanged from baseline data taken pre-intervention (pre-weight = post-weight, p=0.627) (Pre-BMI = Post-BMI, p=0.566).

TABLE 4.1: Descriptive characteristic between the Concentric and the Eccentric intervention groups.

	INTERVENTION GROUP		
	CON GROUP (n=9)	**ECC GROUP (n=9)**	**p[1]**
Variable:			
Age (Years)	64 (59 – 74)	62 (49 - 68)	0.331
Sex (% of Male)	66.67	44.44	0.357
Height (m)	1.73 (1.67 – 1.80)	1.68 (1.62 – 1.83)	0.508
Pre Weight (kg)	78.75 (75.76 – 94.27)	86.75 (75.20 – 102.65)	0.627
Post Weight (kg)	79.50 (77.55 – 96.70)	86.70 (75.20 – 102.75))	0.627
Pre BMI ($kg.m^2$)	27.16 (25.23 – 30.57)	30.53 (25.77 – 34.36)	0.566
Post BMI ($kg.m^2$)	27.68 (26.44 – 30.59)	31.14 (26.17 – 34.34)	0.566

P[1]=p-value, Abbreviations: CON, concentric intervention group; ECC, eccentric intervention group; n, number; Pre, pre-intervention testing battery; BMI, body mass index; m, metres; kg, kilograms; %, percentage; * - significant difference (*p<0.05)

4.2 KNEE KINEMATICS AND KINETICS

Knee Joint Kinematics

Table 4.2 shows the knee joint kinematics for the ECC group and CON group after 8-weeks of the rehabilitation intervention. In the sagittal plane, significant increases were observed with two variables in the CON group post-intervention: in knee flexion ROM during the swing phase of gait (CON Pre 51.14 (45.18-55.25) and Post 56.39 (52.92-57.11); p^1=0.021) and in the peak knee flexion angle during swing (CON Pre 60.48 (48.24-63.96) and Post 64.40 (59.91-68.05); p^1=0.038). No significant changes were noted in the ECC group post-intervention.

The CON and ECC intervention groups showed a significant change in knee flexion ROM during the swing phase of gait pre and post intervention, (CON Pre 51.14 (45.18-55.25) and Post 56.39 (52.92-57.11); p^1=0.021 and ECC Pre 48.61(47.13-53.96) and Post 46.43 (45.04-53.35); p^2=0.260), where the CON group had a greater change in difference (p^3=0.030).

No changes were found in knee flexion ROM at initial ground contact or the during stance phase in either intervention group or in the change in the group differences over time.

In the frontal plane, no significant changes were observed during knee ROM or in the peak knee angle during stance, in either intervention group or in the change in the change in group differences over time

Knee Joint Kinetics

No significant changes were observed in the sagittal plane knee flexion moment at initial ground contact or at peak stance, within either group or the change in group differences over time. Similarly, no significant changes were observed in frontal plane KAM during the stance phase, in either intervention group or in the change in group differences over time.

Knee Joint Stiffness

No significant changes were observed in sagittal plane knee joint stiffness, in either intervention group or in the change in group differences over time

Vertical Ground Reaction Forces

No significant changes were observed in the vertical ground reaction forces, in either intervention group or in the change in group differences over time.

TABLE 4.2: Kinematics and Kinetics of the Involved Total Knee Arthroplasty Knee in the Concentric and the Eccentric Groups Pre and Post-Exercise Intervention.

	CON group			ECC group			Dx
	Pre (n=9)	**Post (n=9)**	**p^1**	**Pre (n=9)**	**Post (n=9)**	**p^2**	**p^3**
***Joint angle* (°)**							
Sagittal Plane:							
Initial ground contact	10.08 (2.41-14.47)	11.14 (6.44 -13.85)	0.515	10.55(7.68-13.46)	11.98 (8.84-14.07)	0.314	0.825
Peak Swing	60.48 (48.24-63.96)	64.40 (59.91-68.05)	**0.038***	58.39 (55.03-63.66)	56.14 (48.95-64.35)	0.594	0.070
ROM stance	36.20 (32.55-43.71)	36.79 (33.43-39.88)	0.859	37.31 (32.88-38.73)	37.78 (36.56-42.19)	0.374	0.453
ROM swing	51.14 (45.18-55.25)	56.39 (52.92-57.11)	**0.021***	48.61(47.13-53.96)	46.43 (45.04-53.35)	0.260	**0.030***
Frontal Plane:							
Peak stance	-2.35 (-3.00-5.83)	-4.06 (-7.96-1.90)	0.260	-5.70 (-7.39-2.64)	-0.23 (-5.49-2.72)	0.953	0.508
ROM stance	11.90 (9.84-19.68)	11.00 (10.44-17.35)	0.859	11.97 (8.39-15.88)	12.17 (10.03-16.54)	0.515	0.627
Joint moment ($Nm.kg^{-1}$)							
Sagittal Plane:							
Initial ground contact	0.03 (-0.13-0.05)	0.02 (0.00-0.05)	0.441	-0.06 (-0.11- -0.04)	0.01 (-0.13-0.05)	0.441	0.895
Peak stance	0.59 (0.55-0.85)	0.67 (0.43-0.82)	0.953	0.70 (0.58-0.91)	0.65 (0.58-0.74)	0.173	0.354
Frontal Plane:							
Peak stance	0.33 (0.24-0.35)	0.31 (0.14-0.37)	0.678	0.22 (0.19-0.31)	0.20 (0.12-0.24)	0.767	0.965
Joint stiffness ($Nm.degrees^{-1}$)							
Sagittal plane	1.67 (1.14-1.90)	1.77 (0.78-1.96)	0.859	2.14 (1.32-2.34)	1.64 (1.03-2.06)	0.066	0.200
Vertical ground reaction force							
Initial Rate of Force (BW/s^{-1})	16.31 (11.66-26.28)	22.50 (17.37-24.56)	0.086	10.51 (9.34-20.41)	16.97 (8.59-26.52)	0.515	0.402
Peak vertical Force (BW)	1.02 (1.01-1.06)	1.05 (1.05-1.05)	0.086	1.04 (1.01-1.08)	1.03 (1.02-1.09)	0.767	0.200

P^1, Pre vs Post CON; P^2, Pre vs Post ECC; Dx P^3, The change in the differences between CON vs ECC over time. Pre, pre-intervention; Post, post-intervention group; ROM, range of movement; Sagittal plane: Positive values – flexion; Negative values - extension. Frontal plane: Positive values – adduction; Negative values – abduction. significant difference (*p<0.05)

4.3 NEUROMUSCULAR ACTIVITY

Electromyography activity of the involved knee was investigated during the pre-activation, load acceptance and ground contact phases of gait (Table 4.3). The selected lower limb muscles included: *biceps femoris, vastus medialis, vastus lateralis, gastrocnemius lateralis* and *tibialis anterior.*

The only significant finding observed was the decreased *biceps femoris muscle* activity during load acceptance phase of gait (ECC Pre 12.1 (11.4 - 15.1) and Post 8.1 (5.9 - 12.7); p^2 = 0.021) in the ECC group post-intervention. No further significant findings were observed within the CON group or in the change in the group differences over time.

TABLE 4.3: EMG activity of the involved Total Knee Arthroplasty knee in the concentric and the eccentric intervention groups during the phases of gait pre and post exercise intervention.

	CON group			ECC group			Dx
	Pre (n=9)	**Post (n=9)**	**p^1**	**Pre (n=9)**	**Post (n=9)**	**p^2**	**p^3**
PRE ACTIVATION (µV.s^{-1})							
Biceps femoris	19.74 (17.88-35.05)	18.62 (14.71-22.18)	0.314	18.27 (15.09-25.77)	19.11 (12.86-22.29)	0.051	0.895
Vastus medialis	11.49 (10.71-16.84)	14.26 (10.46-17.05)	0.953	15.09 (10.44-18.06)	14.67 (5.61-19.10)	0.314	0.627
Vastus lateralis	17.18 (15.21-22.01)	13.96 12.71-16.93)	0.086	16.77 (15.73-28.19)	18.18 (11.00-25.0)	0.441	0.825
Gastrocnemius lateralis	5.25 (2.62-13.97)	5.64 (3.29-10.64)	0.374	6.10 (2.82-9.32)	8.3 (3.14-12.12)	0.374	0.310
Tibialis anterior	11.93 (9.13-16.05)	12.57 (9.17-13.63)	0.953	16.64 (10.22-19.19)	11.83 (9.31-19.56)	0.594	0.627
LOAD ACCEPTANCE (µV.s^{-1})							
Biceps femoris	14.33 (8.48-15.62)	10.31 (5.85-14.30)	0.139	12.09 (11.41-15.07)	8.10 (5.85-12.67)	**0.021***	0.508
Vastus Medialis	10.58 (8.27-12.54)	11.50 (8.16-13.20)	0.594	8.68 (6.23-12.00)	10.22 (5.11-12.31)	0.859	0.895
Vastus lateralis	12.35 (10.08-14.45)	9.82 (9.32-13.42)	0.173	14.56 (11.08-17.57)	11.78 (7.92-15.07)	0.859	0.825
Gastrocnemius lateralis	5.85 (3.79-7.99)	6.08 (2.96-7.50)	0.859	5.79 (3.2-7.04)	5.86 (5.46-7.01)	0.678	0.825
Tibialis anterior	8.34 (7.34-8.74)	7.45 (5.57-8.73)	0.859	8.14 (6.60-10.12)	7.32 (3.37-8.00)	0.260	0.825
GROUND CONTACT (µV.s^{-1})							
Biceps femoris	118.10 (79.97-181.96)	75.32 (57.62-122.26)	0.214	99.96 (94.17-145.08)	110.10 (93.57-135.15)	0.594	0.453
Vastus Medialis	78.69 (50.01-95.62)	104.47 (47.73-111.43)	0.767	89.15 (66.02-121.22)	73.18 (37.20-113.78)	0.859	0.895
Vastus lateralis	77.39 (64.03-123.54)	81.22 (51.40-128.25)	0.314	101.7 (91.6-119.9)	77.72 (58.25-136.94)	0.767	0.627
Gastrocnemius lateralis	69.15 (64.55-117.96)	72.41 (51.63-108.07)	0.594	88.77 (82.89-115.07)	73.89(46.56-116.52)	0.214	0.757
Tibialis anterior	62.09 (46.87 – 80.51)	56.94 (50.21-82.52)	0.859	65.91 (57.44-87.96)	65.05 (51.78-73.40)	0.594	0.965

P[1], Pre vs Post CON; P[2], Pre vs Post ECC; Dx P[3], The change in the differences between CON vs ECC over time. Pre, pre-intervention; Post, post-intervention group; * - significant difference (*p<0.05)

The Quadriceps/Hamstring Co-activation Ratio

The quadriceps (*vastus medialis* and *vastus lateralis*) / hamstring (*biceps femoris*) co-activation ratio in the involved TKA knee during the phases of gait pre and post-intervention is presented in Table 4.4.

No significant changes were noted in either the CON and ECC groups or in the change in group differences over time.

TABLE 4.4: The quadriceps/ hamstring co-activation ratio in the involved Total Knee Arthroplasty knee in the concentric and the eccentric intervention groups during the phases of gait.

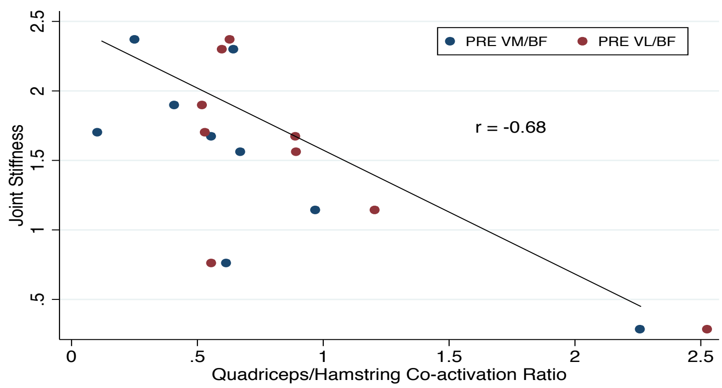
	CON group (n=9)			ECC group (n=9)			Dx
	Pre	**Post**	**P[1]**	**Pre**	**Post**	**P[2]**	**P[3]**
PRE-ACTIVATION							
Vastus medialis / Biceps femoris	0.61 (0.41-0.67)	0.77 (0.40-0.92)	0.214	0.8 (0.43 - 1.00)	0.77 (0.44 - 1.27)	0.515	0.757
Vastus lateralis / Biceps femoris	0.63 (0.55-0.89)	0.68 (0.60-0.91)	0.767	1.08 (0.74 - 1.09)	1.03 (0.95 - 1.27)	0.953	0.895
LOAD ACCEPTANCE							
Vastus medialis / Biceps femoris	0.96 (0.57-1.08)	1.10 (0.61-1.62)	0.110	0.79 (0.46 - 0.99)	0.95 (0.85 - 1.76)	0.214	0.895
Vastus lateralis / Biceps femoris	1.07 (0.84-1.14)	0.96 (0.69-1.78)	0.678	1.07 (0.74 - 1.37)	1.18 (0.98 - 2.43)	0.213	0.566
GROUND CONTACT							
Vastus medialis / Biceps femoris	0.82 (0.61-1.06)	0.91 (0.74-1.49)	0.173	0.67 (0.61 - 0.94)	0.68 (0.57 - 0.89)	0.953	0.354
Vastus lateralis / Biceps femoris	0.84 (0.63-1.05)	0.98 (0.78-1.05)	0.374	0.94 (0.66 - 1.06)	0.85 (0.60 - 1.24)	0.859	0.757

P[1], Pre vs Post CON; P[2], Pre vs Post ECC; Dx P[3], The change in the differences between CON vs ECC over time. Pre, pre-intervention; Post, post-intervention group; * - significant difference (*p<0.05)

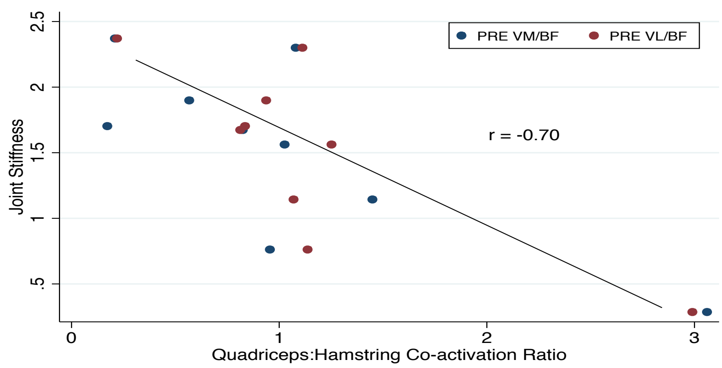
Correlation between Quadriceps:Hamstring Co-activation Ratio and Knee Joint Stiffness

Significant correlations pre-intervention were observed in the CON group during the pre-activation phase between VM:BF and knee joint stiffness (r=-0.68; p[1]=0.042) and during load acceptance between VL:BF and knee joint stiffness (r= 0.07; p[1]= 0.036).

No significant changes were noted in the ECC group. No significant changes were observed in the change in the group differences over time during all 3 phases of gait.



Graph A: Pre-activation Phase of Gait



Graph B: Load Acceptence Phase of Gait

Figure 4.1: Pre-intervention correlation between quadriceps/ hamstring co-activation ratio and knee joint stiffness in the involved TKA knee in the concentric intervention group during the (A) Pre-activation and (B) Load acceptance phases of gait.

4.4 FUNCTIONAL OUTCOMES

Knee Injury and osteoarthritis Outcome score (KOOS)

A comparison of the Knee injury and Osteoarthritis Outcome (KOOS) overall score and its subgroups between the CON and ECC intervention groups is shown in Table 4.5.

The ECC group reported a significant increase in the overall outcome score post-intervention (ECC Pre 73.5 (64.6 - 79.2) Post 79.5 (73.5 - 85.9); p=0.008) with no significant result observed in the CON group over time. No significant change in the group differences was observed over time.

The only significant increase in function was seen in the Sports and Recreation subscale (ECC Pre 40.0 (30.0- 60.0) Post 65.0 (45.0 - 75.0); p=0.008) which was reported by the ECC group post-intervention, showing a 21% increase in activity.

Table 4.5: A comparison of the Knee injury and Osteoarthritis Outcome overall score and subgroups between the concentric and the eccentric intervention groups.

	CON group (n=9)			ECC group (n=9)			Dx
	Pre	**Post**	**P^1**	**Pre**	**Post**	**P^2**	**P^3**
Knee Injury and osteoarthritis Outcome score (KOOS)							
Overall score (%)	64.8 (51.6 - 76.9)	73.8 (69.7 - 82.9)	0.051	73.5 (64.6 - 79.2)	79.5 (73.5 - 85.9)	**0.008***	0.964
Pain (%)	86.1 (75.0 - 91.7)	94.4 (77.8 - 94.4)	0.123	91.7 (86.1 - 97.2)	94.4 (91.7 - 97.2)	0.436	0.398
Symptoms (%)	75.0 (67.9 - 89.3)	82.1 (71.4 - 92.9)	0.545	82.1 (82.1 - 85.7)	85.7 (75.0 - 89.3)	0.404	0.689
ADLs (%)	85.3 (75.0 - 91.2)	86.8 (80.9 - 97.1)	0.260	92.6 (88.2 - 95.6)	94.1 (86.8 - 95.6)	0.188	0.399
Sports/Recreation (%)	35.0 (25.0 - 40.0)	50.0 (30.0 - 60.0)	0.075	40.0 (30.0- 60.0)	65.0 (45.0 - 75.0)	**0.008***	0.658
QOL (%)	50.0 (37.5 - 81.3)	62.5 (56.3 - 93.8)	0.150	62.5 (43.8 - 75.0)	68.8 (62.5 - 81.3)	0.084	0.894

P^1, Pre vs Post CON; P^2, Pre vs Post ECC; Dx P^3, The change in the differences between CON vs ECC over time. Pre, pre-intervention; Post, post-intervention group; ADLs, activities of daily living; QOL, quality of life; * - significant difference (*$p<0.05$)

SF-36 Health Survey

A comparison of the SF-36 Health Survey overall score and subgroups between the CON and ECC intervention groups is shown in Table 4.6.

The CON group reported a significant increase in the overall score (CON Pre 61.8 (51.9 - 70.4) Post 78.3 (68.8 - 87.6); p = 0.011) while none was seen in the ECC group over time. Significant increases were reported in 3 of the subgroups by the CON group post-intervention: Bodily pains had improved (CON Pre 52.0 (51.0 - 64.0) Post 72.0 (62.0 - 84.0); p=0.042), the role limitations due to physical heath had improved (CON Pre 25.0 (0.0 -100.0) Post 100.0 (25.0 - 100.0) p=0.028) and the role limitations due to emotional health also improved (CON Pre 66.7 (33.3 - 66.7) Post 100.00 (100.0 – 100.0); p=0.009).

A change in the group differences over time between the CON and ECC intervention groups reported a significant improvement in the role limitations due to emotional health in favour of the CON group (p=0.020).

Table 4.6: A comparison of the SF-36 Health Survey overall score and subgroups between the concentric and the eccentric intervention groups pre and post exercise intervention.

	CON group			ECC group			Dx
	Pre	Post	P[1]	Pre	Post	P[2]	P[3]
The SF-36 Health Survey							
Overall score	61.8 (51.9 - 70.4)	78.3 (68.8 - 87.6)	**0.011***	85.8 (75.1 - 88.9)	88.4 (86.6 - 90.4)	0.137	0.077
Physical functioning	60.0 (40.0 - 65.0)	65.0 (30.0 - 80.0)	0.553	75.0 (60.0 - 80.0)	85.0 (70.0 - 90.0)	0.152	0.626
Role functioning/physical	25.0 (0.0 -100.0)	100.0 (25.0 - 100.0)	**0.028***	100.0 (100.0 - 100.0)	100.0 (100.0 - 100.0)	0.157	0.392
Role functioning/emotional	66.7 (33.3 - 66.7)	100.0 (100.0 - 100.0)	**0.009***	100.0 (100.0 - 100.0)	100.0 (100.0 - 100.0)	0.157	**0.020***
Vitality	55.0 (45.0 - 60.0)	65.0 (60.0 - 80.0)	0.065	70.0 (60.0 - 80.0)	75.0 (75.0 - 80.0)	0.362	0.398
Emotional well-being	80.0 (76.0 - 84.0)	80.0 (76.0 - 92.0)	0.148	80.0 (76.0 - 92.0)	88.0 (84.0 - 92.0)	0.491	0.821
Social functioning	75.0 (62.5 - 100.0)	100.0 (75.0 - 100.0)	0.118	100.0 (100.0 – 100.0)	100.0 (87.5 - 100.0)	0.518	0.430
Bodily pains	52.0 (51.0 - 64.0)	72.0 (62.0 - 84.0)	**0.042***	84.0 (74.0 - 84.0)	84.0 (84.0 - 100.0)	0.085	0.432
General Health	82.0 (67.0 - 82.0)	72.0 (70.0 - 87.0)	0.951	82.0 (80.0 - 87.0)	82.0 (77.0 - 87.0)	0.895	0.890

P[1], Pre vs Post CON; P[2], Pre vs Post ECC; Dx P[3], The change in the differences between CON vs ECC over time. Pre, pre-intervention; Post, post-intervention group; * - significant difference (*p<0.05)

Tegner Activity Scale

The ECC group reported a significant increase in the level of activity post-intervention (ECC Pre 3.0 (2.00 – 3.0) Post 4.0 (3.0 – 4.); p=0.028) with no change noted in the CON group over time. (Figure 4.2). No significant changes were noted in the change in the group differences over time.

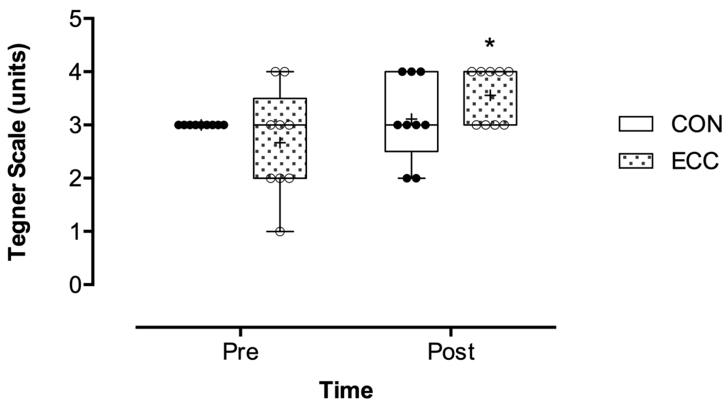


Figure 4.2: A comparison of the overall score of Tegner Activity Scale between the concentric and the eccentric group intervention groups pre and post-exercise intervention.

Six Minute Walk Test

Both intervention groups reported a significant increase in the distance covered post-intervention (CON Pre 554.60m (514.00-590.50) Post 596.00m (518.70-608.00); p=0.038 and ECC Pre 552.50m (521.00-616.50) Post 578.30m (550.00-686.50); p=0.038) with no significant changes noted in the change in the group differences over time. (Figure 4.3)

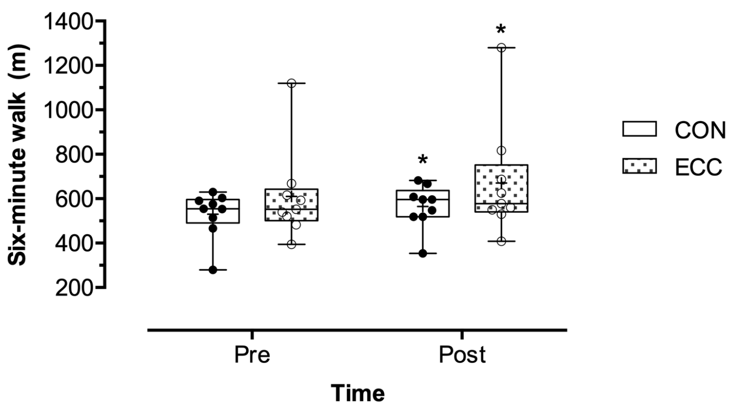


Figure 4.3: A comparison of the Six Minute Walk Test between the concentric and the eccentric group intervention groups pre and post-exercise intervention.

CHAPTER 5
DISCUSSION

The purpose of this study was to investigate and compare the effects of an eight-week eccentric and concentric cycling rehabilitation intervention in TKA recipients three months post-surgery at the end stage of rehabilitation. This exploratory study aimed to investigate the changes in joint kinematics, kinetics and muscle activity during the phases of walking gait. This study also assessed changes in knee function and health-related quality of life as measured by validated functional outcomes and other functional assessments.

5.1 THE EFFECT OF ECCENTRIC AND CONCENTRIC INTERVENTION ON KNEE KINEMATICS AND KINETICS

The study found significant changes in joint kinematics during gait in the CON group. The group showed an increase in knee flexion during swing phase ROM and peak knee flexion during swing, in the involved TKA knee post-intervention. A change in differences in knee flexion ROM during the swing phase of gait was also noted between pre and post-intervention. As demonstrated by McLeod and Blackburn, (1980), stationary cycling has been recommended and widely used successfully in rehabilitation after knee joint surgery. Stationary cycling allows TKA recipients to maintain a functional knee through low impact physical activity while protecting the knee from high impact forces thereby preserving the integrity of the prosthesis, as cycling limits the axial rotation occurring at the knee (Hamai et al., 2008). Ericson et al. (1988) also showed that the range of motion of the hip, knee and ankle joints utilized during cycling is approximately equal to, but more flexed compared to level walking. The nature of cycling allows the exercising patient to perform a greater number of repetitions at a low mechanical load, with greater knee flexion, in a shorter time when compared to walking. This would explain the significant increases in both knee flexion swing phase ROM and peak knee flexion during swing in the CON group post-intervention in our study.

Contrary to the study's hypothesis, the ECC rehabilitation intervention did not result in increased knee ROM during the swing phase of gait as predicted (Table 4.2). Codine et al. (2004) reported similar findings with no significant differences in knee flexion ROM in the experimental ECC group despite there being an improvement of 22.32° of knee ROM post-intervention. Their study however, focused on the recovery of knee extension ROM post-ECC contractions for the hamstring.

The inclusion criteria of our exploratory study included TKA patients with knee ROM greater than 110 degrees of full active flexion when measured in supine, which is more than sufficient to safely commence with a cycling intervention. Whereas the general consensus dictates at least 90 degrees of knee ROM, suggesting that the TKA participants in our study had a good baseline knee flexion ROM. The lack of significant improvement in knee flexion ROM post-ECC intervention could further be attributed to the increased tendon-muscular extensibility of the hamstring muscle as shown by Codine et al. (2004), where the ECC intervention achieved a significantly better knee extension ROM. However, they recorded knee ROM using a static measurement with a goniometer, whereas our study explored dynamic knee ROM during gait. Similarly, Marcus et al. (2011) recorded a significant increase in knee ROM following an ECC-based rehabilitation three weeks post-TKA. This however, is not comparable to our exploratory study, since the greatest improvements observed in TKA recipients are seen within the first three to six months post-TKA (Jones et al., 2003) and we investigated the end-phase of rehabilitation.

Furthermore, we need to take the duration of the ECC intervention as well as the duration of each rehabilitation session and the timing of the intervention of this study into consideration when compared to similar research studies. Previous studies yielded significant results in muscle strength and volume and on all mobility tests following a 12-week ECC intervention programme commenced 3 weeks post-surgery (Gerber et al., 2006; Gerber et al., 2007a; LaStayo et al., 2009). Our study intervention protocol, was designed using the limited literature on the effects of ECC rehabilitation post-TKA, where researchers aimed for a progressive increase in intensity to limit the possibility of delayed onset muscle soreness (DOMS), which is usually associated with ECC contractions, particularly noted in the older participant population (Armstrong, 1984, Brooks, 2008). The intervention implemented in our study possibly leaned towards the conservative side hence not yielding significant results.

5.2. THE EFFECT OF ECCENTRIC AND CONCENTRIC INTERVENTION ON MUSCLE ACTIVITY

The ECC intervention group showed the greatest changes in muscle activity post-intervention with a decrease in the muscle activity of the *biceps femoris* (lateral hamstring (LH)) during the load acceptance phase of gait (Table 4.3) which is consistent with a move towards a more typical asymptomatic gait pattern (Hubley-Kozey, et al., 2010). ECC muscle action, when performed exclusively, has shown to possess various physiological properties compared to CON muscle action, including inversed motor unit activation pattern (Nardone et al., 1989); faster neural adaptations secondary to resistance training (Hortobágyi et al., 1996); and reduced electromyography (EMG) amplitude at similar force levels (Tesch et al., 2018). Mechanically, better motor unit efficacy during ECC muscle activity results in an unusually high force production at an unusually low metabolic cost, leading to significant increases in strength and size as well as alterations in the spring properties of the muscle (Lindstedt et al., 2001).

Hubley-Kozey et al. (2010), reported decreased muscle activity during mid-stance for quadriceps and hamstrings in TKA recipients which was consistent with re-establishing soft tissue tension and passive joint stability, reducing the need for active muscle stiffness during single-leg stance. Also noted was a reduction in overall LH activity during prolonged mid-stance activity leaning towards a more balanced activation between the medial and lateral sites. This return to more typical neuromuscular responses may reflect the restoration of joint sensation and improved proprioception found following TKA surgery (Swanik et al. 2004). Neuromuscular changes observed in the presence of knee OA concluded that higher LH activity was observed during the stance phase of gait when compared to MH which supports the theory that the lateral muscles attempt to increase lateral forces to decrease medial joint loading (Andriacchi, 1994; Hubley-Kozey et al., 2006). As the ECC intervention group reported a decrease in LH activity during load acceptance phase of gait, it can be concluded that the ECC intervention can be implemented post-TKA in the restoration towards a typical asymptomatic gait pattern.

In addition to muscle activity, this exploratory study investigated the quadriceps:hamstring (Q:H) co-activation ratio and its correlation with joint stiffness, pre and post-intervention. Despite there not being any significant findings over the intervention with the Q:H co-activation ratio, significant correlations between the Q:H co-activation ratio and knee joint stiffness were observed in the CON intervention group pre-intervention (Figure 3.8A). The negative relationship between VM:BF co-activation ratio and knee joint stiffness in the pre-activation phase of gait (Figure 3.8B) suggests that as the Q:H ratio shifted towards a hamstring (BF) or antagonist dominant ratio, joint stiffness decreases. Increased hamstring activity prior to the stance phase has been noted in moderate OA to decelerate knee extension and prepares for initial loading (Ivanenko et al., 2004). Similarly, a negative relationship between VL:BF co-activation ratio and knee joint stiffness during the load acceptance phase of gait suggests as the Q:H ratio increased towards a quadriceps (VL) or agonist dominant ratio, joint stiffness decreases. Hubley-Kozey et al.,(2006) found lateral muscle sites produced higher forces to counteract the high medial joint loading often found in those with OA suggesting participants in this study still exhibited OA like tendencies post-TKA.

Despite there not being significant results post-intervention, a decrease in the strength of both these correlations were noted, suggesting a change in neuromuscular patterning. During pre-activation the CON group recorded decreased BF and VL activity with an increase in VM activity possibly suggesting a shift towards a more typical asymptomatic gait pattern (Hubley-Kozey, et al., 2010). Similar EMG activity was noted during load acceptance. Hubley-Kozey et al.,(2006) found the controls in their study exhibited lower VL and elevated VM activity than the experimental OA participants just prior to and during the loading phase of gait. An increase in VM recruitment amplitudes in the CON group could be attributed to a typical response to decreased medial joint loading, together with the reduction in VL and BF activity during these phases suggests a shift towards a more balanced activation between the medial and lateral sites (Hubley-Kozey et al., 2010). This return to more typical neuromuscular patterning may further emphasize the restoration of joint sensation and improved proprioception found following TKA surgery.

One has to question why this occurred in the CON group and not the ECC group pre-intervention. Various factors that should be considered include: the severity of knee OA exhibited in the CON group participants prior to surgery that could influence prognosis, an acute response to surgery and the participants response to phase I and II post-TKA rehabilitation, that could also affect prognosis. These findings requires further exploration to provide a better understanding of the relationship between the Q:H co-activation ratio and knee joint stiffness both prior to and post-intervention.

5.3 THE EFFECT OF ECCENTRIC AND CONCENTRIC INTERVENTION ON FUNCTIONAL OUTCOMES

The ECC rehabilitation intervention produced greater improvements in knee functional outcomes, as measured by The Knee injury and Osteoarthritis Outcome Score (KOOS), and the Tegner Activity Scale, despite both intervention groups improving in both outcome scores post-intervention while the CON intervention produced significant increases in the overall score of the of the SF-36 Health Survey post-intervention, with increases in three of the subscales

The Knee injury and Osteoarthritis Outcome Score (KOOS)

The KOOS was used to evaluate symptoms and function in participants and has been validated for various orthopaedic interventions including anterior cruciate ligament reconstruction, meniscectomy and TKA studies (Roos et al., 1998). The 5 subscales evaluated were; (1) Pain, (2) Other Symptoms, (3) Function in daily living (ADL), (4) Function in sport and recreational activities and (5) Quality of life (QOL). The last week was taken into consideration in the answering of the questions.

The ECC group had significantly better functional outcomes in the overall outcome score of KOOS post-intervention with a significant increase of 21% in function noted in the Sports and Recreation subscale. The KOOS was not used as an outcome measure in any of the ECC rehabilitation studies previously conducted, however Stevens-Lapsley et. al (2011) in their comparison of the KOOS and performance measures post-TKA demonstrated that by one month post-TKA, mean values for 4 of 5 self-reported subscales on the KOOS changed in the direction of improvement. Three of these changes improved in ADL, Pain, and QOL subscales. Interestingly, the mean score on the Sports and Recreation subscale remained virtually unchanged one month after TKA, as patients are generally limited to specific rehabilitation only, but by three and six months post-TKA, significant improvements were noted in all five subscales compared with pre-operative values.

The Tegner Activity Scale

The Tegner activity scale was used as a standardized method of grading activities of daily living, physical work and recreational and competitive sporting activities and was relevant as to the participants in this study who were at the end stage of rehabilitation.

Participants in the ECC intervention group reported being at a higher level of activity post-intervention than the CON intervention group confirming our hypothesis that the ECC rehabilitation intervention would produce greater improvements in knee functional outcomes. Gerber *et al.* (2007a) noted similar improvements in knee functional outcomes, where a significant group-by-time interaction was observed in the ECC group based on the Tegner Scale after completing 12 weeks of an ECC intervention post-ACL reconstruction. Hopper and Leach, (2008) reported only 63.6% of patients returned to sport post-TKA. This addresses a common concern of patients who, prior to surgery enquire about their ability to continue with sporting activities post-TKA. Perhaps with these new findings, an ECC intervention would change the level of activity and rate of return to sport/physical activity in patients post-TKA.

SF-36 Health Survey

The SF-36 short-form health survey gave us insight into the functional health and well-being scores as well as psychometrically based physical and mental health summary measures of the participants (Ware Jr., 1999) and has been widely used post-surgery in monitoring the heath related QOL and physical functioning of patients. The subscales measure the following health concepts: (1) physical functioning; (2) role limitations because of physical health problems; (3) role limitations because of emotional problems; (4) vitality (energy/fatigue); (5) emotional well-being;(6) social functioning; bodily pain; (7) and (8) general health perceptions.

The CON intervention produced significant increases in the overall score of the of the SF-36 Health Survey post-intervention, with increases in three of the subscales.

Participants reported bodily pains had improved, together with role of physical functioning and the role of emotional functioning. The CON group also showed improvement in the emotional health over the intervention. Despite these improvements seen over time, the CON group's role of physical functioning scores were still not comparable with those of health older adults: role of physical functioning (CON = 100.0 (25.0 - 100.0), Normative data =89.5 (31.5)) (Stevens-Lapsley et al., 2011).

Interestingly, the ECC group scored 100% in both the role of physical functioning and the role of emotional functioning post-intervention. This demonstrates that the ECC intervention did not negatively affect their role of physical functioning and emotional functioning but maintained it. In addition, the ECC group had higher baseline scores than the CON group in all the other subscales as well. Contrary to this study, Marcus et al. (2011) demonstrated an increase in the SF-36 Physical component summary in the ECC group by 59% post-intervention. Based on the changes in the direction of improvement seen over time in the ECC group and as discussed previously, further research with a longer duration intervention period may be required.

Six minute walk test

The 6MW test is a validated test for the assessment of functional capacity in clinical populations where a maximal distance is covered walking at a self- selected speed during 6 minutes (Parent & Moffet, 2002).

Both rehabilitation interventions produced similar improvements in the 6-minute walk test where a significant increase in the distance was covered post-intervention, thereby refuting our initial hypothesis that the ECC intervention group would produce greater improvements than the CON intervention group. However Marcus et al. (2011) and LaStayo et al. (2009) demonstrated in their respective ECC rehabilitation studies post-TKA, participants had better outcomes with an increased distance in 6MW test post-ECC intervention when compared with pre-intervention scores or the control group. Contrary to this study, Marcus et al. (2011) had longer duration intervention sessions (60 minutes) that commenced 4-weeks post-TKA, while LaStayo et al. (2009) and Gerber et al. (2007a) conducted a longer intervention period (12 weeks).

As discussed in Chapter 2, sarcopenia is the progressive loss of muscle mass with aging and is a fundamental contributor to disability and impaired function in the elderly population (Volpi et al., 2004), coupled with the loss of quadriceps strength post-TKA, limitations in the recovery of muscle function exist (Stevens-Lapsley et al., 2010). Perhaps increasing either the duration of each session in a shorter intervention period or increasing the entire intervention period, would allow for more muscle adaptation and better strength gains in this older population subsequently leading to better outcomes as demonstrated 11-12 weeks post-ECC intervention (LaStayo, et al., 2003; LaStayo et al., 2011). The timing of the intervention also needs further exploration as we know the greatest improvement is seen within the first three to six months after surgery, with more gradual improvements occurring up to two years after surgery (Jones et al. 2003).

The results of these functional outcomes once again pose many questions about the homogeneity between the groups and its effect on the results.

CHAPTER 6

SUMMARY AND CONCLUSION

6.1 OVERVIEW

It is reported that more than one-third of the TKA recipients experience sub-optimal physical function following TKA surgery (Brander et al., 2003; Dickstein et al., 1998; Franklin et al., 2008; C A Jones et al., 2000). In addition, almost all TKA recipients report levels of physical function that are below age-matched normative levels (Singh & Sloan, 2008) with their performance based physical function scores rarely matching those levels of healthy controls (Yoshida et al., 2008). The effectiveness of physiotherapy rehabilitation post-TKA has shown the short-term benefits of a structured TKA rehabilitation programme, while no long-term benefits were recorded (Minns Lowe et al., 2007).

The purpose of this exploratory study was to investigate and compare the effects of an eight-week eccentric versus concentric cycling rehabilitation intervention in TKA recipients focusing on changes in joint kinematics, kinetics and muscle activity during the phases of walking gait. This study also assessed changes in knee function and health-related quality of life as measured by validated functional outcomes and other functional assessments.

Changes in the kinematics of the involved TKA knee was seen in the CON group with an increase in knee flexion ROM and in peak knee angle during the swing phase of gait. This could be attributed to the nature of cycling rehabilitation allowing the patient to perform a greater number of repetitions at a low mechanical load, with greater knee flexion while protecting the knee from high impact forces thereby preserving the integrity of the prosthesis (Hamai et al., 2008). No kinetic changes, changes in knee stiffness or vertical ground reaction force of the involved TKA knee were noted in either intervention group during walking gait.

The ECC intervention group showed neuromuscular changes with the decrease in the muscle activity of the *biceps femoris* muscle during load acceptance phase of gait, which is consistent with a move towards a typical asymptomatic gait pattern (Hubley-

Kozey, et al., 2010). Significant correlations between the Q:H co-activation ratio and knee joint stiffness were observed in the CON intervention group pre-intervention. The negative relationship between VM:BF co-activation ratio and knee joint stiffness in the pre-activation phase of gait suggests an increased hamstring activity prior to the stance phase has been noted in moderate OA to decelerate knee extension and prepares for initial loading (Ivanenko et al., 2004). Similarly, a negative relationship between VL:BF co-activation ratio and knee joint stiffness during the load acceptance phase of gait suggest higher forces of the lateral muscle sites are produced to counteract the high medial joint loading which is often found in those with OA. (Hubley-Kozey, et al., 2010). A decrease in the strength of both these correlations were noted post-intervention, suggesting a change in neuromuscular patterning, suggesting a shift towards a more typical asymptomatic gait pattern (Hubley-Kozey, et al., 2010).

According to the knee functional outcomes measures the ECC group reported an overall significant outcome on Knee injury and Osteoarthritis Outcome Score and the Sport and Recreation subscale. There was also a significant increase in the level of activity on the Tegner Activity Scale. Both intervention groups had significant improvements on the distance covered in 6-minute walk test post-intervention. The CON group reported greater improvements in health-related quality of life and overall well-being as measured by the SF-36 Health Survey having had improvements on three subscales: bodily pains, role of emotional and physical functioning. Despite these improvements seen over time, the role of physical functioning subscale scores were still not comparable with those of health older adults (Stevens-Lapsley et. al, 2011). Interestingly, the ECC group had higher baseline scores and showed improvement over time that was not significant.

6.2 CLINICAL APPLICATIONS

The overall aim of this exploratory study was to investigate the effects of an eccentric cycling intervention as a potential method of rehabilitation in the restoration of function in patients post-TKA.

Results show that both the CON and ECC interventions were beneficial to the participants post-TKA. The CON group showed increased knee ROM during walking with changes in neuromuscular patterning and an overall improvement in health-related QOL markers. However, the ECC group showed neuromuscular changes leaning towards a more typical asymptomatic gait pattern and had greater functional improvements with knee functional assessments. The benefits of both these cycling interventions was seen in the similar significant increase in the distance covered during 6MW test post-intervention.

As discussed in Chapter 2, the standard rehabilitation generally implemented post-TKA comprises a three-phase progressive exercise programme: the acute, sub-acute and end-stage rehabilitation phases. Some of the key rehabilitation goals focus on improvements in knee ROM and muscle strength, a decrease in pain level and improvements in independence with activities of daily living. All these goals but one, muscle strength, have been fulfilled by either the CON and ECC interventions. The benefits of stationery CON ergometry in TKA rehabilitation is well documented, with its low impact and decreased risk of dislocation and periprosthetic fracture and has is widely used in rehabilitation. Presently, the introduction of ECC ergometry is lacking in the standard rehabilitation as demonstrated by the only three eccentric studies involving TKA.

Despite the fact that the ECC intervention did not yield the expected results and consequently impact on post-TKA rehabilitation guidelines, the secondary benefits of eccentric training in the prevention of falls in a typically older population must be considered.

Both CON and ECC interventions have proved to be safe and beneficial, yielding physical and functional advantages and can be implemented as part of the rehabilitation regime in the restoration of functional ability as early as three months post-TKA.

6.3 CONSIDERATIONS AND FUTURE DIRECTIONS

The strength of this exploratory clinical trial was the functional component that appealed to participants where they were able to track changes in gait, ADLs and general well-being which could be have contributed to the compliance exhibited over the 8 week intervention. Based on our findings, there is much scope and potential for an eccentrically-based intervention in the restoration of function post-TKA. The current limited research base further dictates the need to explore this novel training method in this older patient population.

One of the limitations in this study was the large age range of participants. Participants between the ages of 30 to 80 years old were recruited and presented with varied range of functional abilities, that lead to higher than expected standard deviations. This together with the small sample size (18 participants) may have influenced the statistical analysis leading to fewer significant findings in the study. The inclusion criteria in the study did not consider the varying ages and subsequent functional ability of participants and needs to be more stringent in future research to include only those participants representative of the homogenous TKA population. Further analysis of the data by gender and age groups is also recommended.

Another limitation in this study was the shorter intervention time period of eight weeks. A 12-week intervention period would be recommended as conducted in previous eccentrically-based interventions allowing for a longer duration of muscle adaptations in this compromised population subsequently affecting gait and function.

The timing of the intervention also needs to be considered as a limitation and contributing factor. Participants who had undergone TKA surgery in the preceding three to nine months prior to recruitment were enrolled in this study. This meant participants presented at the cusp of Phase II and Phase III rehabilitation (three months post-TKA) or at the end of Phase III or final stage rehabilitation (six to nine months post-TKA). Due to this heterogeneity, participants presented with varying functional abilities that could have affected performance in the intervention. The inclusion criteria in the study did not consider the stage of rehabilitation the participants were at during the recruitment procedure.

With no pre-TKA surgery data collected, no comparisons in gait changes, neuromuscular adaptations and functional ability could be tracked post-TKA and then compared with post-intervention. This would be a strong recommendation for future studies.

6.4 CONCLUSION

The results of this exploratory study did not find the eccentric cycling rehabilitation intervention exclusively more effective than the concentric cycling intervention in the restoration of functional ability in patients post-TKA. The eccentric intervention did result in neuromuscular adaptations consistent with a move towards a more typical asymptomatic gait pattern and participants reported greater functional improvements on validated knee functional assessments and levels of activity scores. The concentric intervention yielded kinematic changes and participants reported improvements in their emotional and physical health post-intervention.

Eccentric training and its role in early stage post-operative rehabilitation is limited. Based on the findings from this exploratory study, the benefit of eccentric training as an adjunct to rehabilitation and its role in contributing to greater improvements in the restoration of functional ability post-TKA needs to be further explored.

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APPENDICES

APPENDIX A: INFORMED CONSENT FORM

Department of Human Biology
UCT/MRC RESEARCH UNIT FOR EXERCISE SCIENCE & SPORTS MEDICINE
Faculty of Health Sciences, University of Cape Town
Private Bag, Rondebosch 7700, South Africa
Tel: + 27 21 650 4561
Fax: + 27 21 686 7530

TOTAL KNEE ARTHROPLASTY: COMPARISON OF TWO TREATMENT MODALITIES USED IN END-STAGE REHABILITATION AFTER TOTAL KNEE ARTHROPLASTY (TKA)

INFORMED CONSENT FORM

I, the undersigned, have been fully informed about the UCT/MRC Research Unit for Exercise Science and Sports Medicine within the Department of Human Biology of the University of Cape Town and the Sports Science Orthopaedic Clinic's study on the comparison of two treatment modalities for end-stage rehabilitation after total knee arthroplasty.

I have undergone total knee replacement surgery and agree to participate in one of two treatment modalities. I understand that if I am deemed fit to participate in an exercise program, I will be given an exercise program to follow for 8 weeks and I will be expected to attend three 20 minute exercise sessions for each of the 8 weeks. To avoid bias in the study, I understand that none of the investigators will discuss how the specific exercise program I have been allocated to differ from the other exercise protocol. I understand that this process will be random (drawing out of a hat). I understand that the exercise treatment I receive may result in discomfort and pain as a result of muscle damage.

I agree to perform all the baseline measurements and assessments prior to starting the exercise protocol and after completing the 8-week exercise protocol. It has been explained to me that I will attend a 30 minute familiarization visit, followed by a 3 hour visit in which I will complete a 6-minute walk test, an isokinetic strength assessment, a gait analysis assessment and other questionnaires about my knee. I will again attend an identical 3-hour visit after I have completed the 8-week exercise protocol.

I understand that all the information that is collected during the study will be treated with the strictest confidentiality and will only be used for scientific research purposes. I have been informed that participation the rehabilitation provided in this study, as well as all the assessments will be provided free of charge. I will not be paid for participating in this trial.

I understand that all the information that is collected during the study will be treated with the strictest confidentiality and will only be used for scientific research purposes. I have been informed that participation the rehabilitation provided in this study, as well as all the assessments will be provided free of charge. I will not be paid for participating in this trial.

The University of Cape Town (UCT) undertakes that in the event of you suffering any significant deterioration in health or well-being, or from any unexpected sensitivity or toxicity, that is caused by your participation in the study, it will provide immediate medical care. UCT has appropriate insurance cover to provide prompt payment of compensation for any trial-related injury according to the guidelines outlined by the Association of the British Pharmaceutical Industry, ABPI 1991. Broadly-speaking, the ABPI guidelines recommend that the insured company (UCT), without legal commitment, should compensate you without you having to prove that UCT is at fault. An injury is considered trial-related if, and to the extent that, it is caused by study activities. You must notify the study doctor immediately of any side effects and/or injuries during the trial, whether they are research-related or other related complications.

The University of Cape Town (UCT) has an appropriate insurance policy to cover payment for any trial-related injury. You may therefore receive compensation in the event of you sustaining any injury and or a significant deterioration in health Your right in law to claim compensation for injury where you prove negligence is not affected. Copies of these guidelines are available on request.

I agree to participate in the study and I have been informed that I will be free to withdraw from the study at any time if I so wish. I understand that I will receive the overall results of the study. I have read (or where appropriate, have had read to me) and understand the information about this study, and any questions I have asked have been answered to my satisfaction. I agree that research data provided by me or with my permission during the project may be presented at conferences and published in journals on the condition that neither my name nor any other identifying information is used.

This study was granted Ethics approval from the Faculty of Health Sciences (FHS) Human Research Ethics Committee (REC) at the University of Cape Town. If you have any complaints or queries that the investigator has not been able to answer to your satisfaction, you may contact the **Prof Marc Blockman** from the FHS REC on telephone number **021 406 6452**.

FULL NAME OF SUBJECT:	______________________________
SUBJECT'S SIGNATURE:	______________________________
DATE:	______________________________
INVESTIGATOR:	______________________________
INVESTIGATOR'S SIGNATURE:	______________________________

Department of Human Biology
UCT/MRC RESEARCH UNIT FOR EXERCISE SCIENCE & SPORTS MEDICINE
Faculty of Health Sciences, University of Cape Town
Private Bag, Rondebosch 7700, South Africa
Tel: + 27 21 650 4561
Fax: + 27 21 686 7530

COMPARISON OF TWO TREATMENT MODALITIES FOR END-STAGE REHABILITATION AFTER TOTAL KNEE ARTHROPLASTY

PARTICIPANT INFORMATION

The UCT/MRC Research Unit for Exercise Science and Sports Medicine will be conducting a study to investigate the effects of two exercise interventions in rehabilitation after total knee replacement surgery. There are multiple researchers involved in this study and the study will contribute towards an MPhil degree in Sports Physiotherapy and an MPhil in Biokinetics

Introduction and Purpose of the study

Total knee replacement surgery or a total knee arthroplasty is a universally performed surgical procedure in which the weight-bearing surfaces of the knee joint are replaced in an attempt to relieve or alleviate joint pain and disability. Whilst some patients experience successful reductions in their levels of pain and improvements in overall knee function, more than one-third of the patients experience suboptimal physical function following total knee replacement surgery. The predominant impairment to function following a total knee replacement is a distinctive reduction in quadriceps strength that has been associated with a limitation of postoperative physical activity. A strengthening programme focused on improving quadriceps weakness is required to regain full function of the knee and return to physical activity. In this study we are planning to investigate two different strengthening programmes during the end-stage rehabilitation period after total knee replacement surgery. The strengthening programme will be performed on specially designed stationary bike known as the Grucox Rehabilitation Cycle, Studies have shown that both types of exercise programmes lead to improvements in knee function and strength. However, the specific aim of this study is to investigate if any of the exercise programs yield greater improvements in knee function and strength than the other.

Study Design

There will be twenty four patients, who had undergone total knee replacement surgery within the last 3 to 9 months, who will be recruited for this study Only once you have met the pre-determined inclusion criteria will you be selected to participate in this study. You will be required to sign an informed consent form. Once enrolled, you will be randomised into one of the two treatment groups, an eccentric group or a concentric group. Each of the treatment groups will undergo 8 weeks of exercise intervention). Baseline and post-exercise intervention tests and assessments will be conducted to evaluate which of the exercise interventions lead to greater improvements in knee function and strength.

The Pre and Post-intervention Assessments and Tests

You will be required to complete 2 sets of assessments and testing: a pre-intervention assessment within a week of commencing the exercise therapy and a post-intervention assessment, within a week of completing the exercise therapy. Each testing session will be 3 hours each. You will therefore have to attend a protocol and equipment familiarization visit (1 hour) 2 to 4 days before testing. All the testing will occur at the Sports Science Institute in Newlands. You will be required to complete a questionnaire of demographics, medical and knee injury history. The baseline and post-intervention assessments (Outcome variables) include validated measures of physical activity (The Tegner Activity Level Scale), global health (The SF-36 Health Survey) and functional capacity (The Knee Injury and osteoarthritis Outcome score [KOOS] and 6-minute walk test.) assessments. The Tegner Activity Level Scale, The SF-36 Health Survey) and The Knee Injury and osteoarthritis Outcome score are questionnaires. In the 6-minute walk test you will be instructed to walk as fast as you can in 6 minutes on a 70m indoor track. In addition, you will be required to complete 3 other physical assessments. A walking test (gait analysis) will evaluate your walking patterns. During the muscle strength test (isokinetic strength assessment) you will be required to apply a force against the machine, which will take a measurement. The muscle volume test is an assessment of muscle volume and cross-sectional area. In addition, muscle activity patterns (Electromyography [EMG]) will also be recorded during all the physical assessments. This will entail having electrodes being placed on various joints on your leg.

The Exercise Intervention

The cycle ergometer to be used in this study is known as the Grucox Rehabilitation Cycle and is driven by a small industrial automation system. The speed and torque of the cycle are set using a user - friendly touch screen. The screen dynamically displays real time progress of effort (measured in watts), with the speed and torque against set points. Pedals are driven in either a forward or reverse direction while the speed and torque are selected in accordance with the exercise protocol. All exercise sessions will be conducted at the Sports Science Institute.

You will be required to attend 3 exercise sessions per week over a period of 8 weeks. During each exercise session, you will perform a 20-minute exercise protocol focusing on either eccentric work (when a muscle lengthens during a contraction) or concentric work (when a muscle shortens during a contraction). Work will be performed in both the forwards and reverse directions. Either a physiotherapist or biokineticist will supervise you at all times during the session recording various readings including your heart rate, Rate of Perceived Exertion (effort) and a rating on pain if any felt in the affected knee.

Costs of participating:

The exercise therapy will be provided free of any cost to you. Additional medical consultations, assessing the knee, will also bear no cost to you. You will also not receive any payment for participating in this trial.

Benefit to the participants:

Strengthening exercises, regardless of the nature (concentric or eccentric) is beneficial to the participant's health and knee function.

Risks to participants:

Assessment and testing procedure:

<u>Electromyography (EMG):</u>

You may have an allergic reaction to electrodes or the gel used, or may be sensitive to shaving or the use of alcohol on exposed skin. These will be minimised by the use of sterile equipment and availability of soothing lotions after completion of the testing session.

Isokinetic (muscle) testing:

There is a possible risk of acute muscle strain injury during the testing procedure.
Injury as a result of the muscle testing has been reduced by the following steps:
(1) Conducting only concentric isokinetic tests
(2) The testing will be performed at a moderate speed; which reduces any injury of risk,
(3) You will be screened to ensure they are functionally fit to undergo testing and training, and
(4) You will be required to exert the desired force and not the machine, therefore the machine will not be able to induce any uncontrolled muscle or joint damage.
In addition, you may experience delayed onset muscle soreness (DOMS), thought to be the result of microscopic tearing of the muscle fibres following unaccustomed physical activity. These however will be minimised by correct and sufficient warm up prior to testing and familiarization with the procedure (2 to 4 days prior to baseline testing), which decreases the possibility of injury and DOMS. You will also be given an emergency button to use during the procedure should you feel unsafe. Medical personnel will also be available in the event of a medical emergency.

Exercise/Training Intervention:

You may feel discomfort during the exercise protocol. Swelling and pain may results from the exercise protocol. Although the protocol is developed to slowly get you used to the training intensity, with a gradual increase in intensity, delayed on muscle soreness (DOMS) may still occur, specifically in the eccentric training protocol group. This is however normal for an eccentric exercise (when a muscle lengthens during a contraction) protocol. This will be minimised by correct and sufficient warm up prior to testing and familiarization with the protocol and bike, which decreases the possibility of injury and DOMS. A trained physiotherapist or biokineticist will also be supervising each exercise session where your Rate of Perceived Exertion (effort) will be monitored. Hence, the intensity of the workload can be accordingly adjusted to ensure the desired level of comfort

Insurance Policy:

The University of Cape Town (UCT) has an appropriate insurance policy to cover payment for any trial-related injury. You may therefore receive compensation in the event of you sustaining any injury and or a significant deterioration in health.

Ethics

This study was granted Ethics approval from the Faculty of Health Sciences (FHS) Human Research Ethics Committee (REC) at the University of Cape Town. If you have any complaints or queries that the investigator has not been able to answer to your satisfaction, you may contact Prof Marc Blockman from the FHS REC on telephone number 021 406 6452.

We will keep you informed about the outcomes of your assessment and the overall findings of the study. All assessment and study results will be summarized and posted/emailed to the participant. Thank you for your time and we look forward to working with you. If you have any questions about this study, please feel free to contact us at: -

Dr. Mike Posthumus, PhD
The University of Cape Town
(021) 650 4572
mposthumus@uct.ac.za

Dr. Willem Van Der Merwe, MD
The Sports Science Orthopaedic Clinic
(021) 686 1196
willem@grucox.com

Ms Sandhya Silal
The University of Cape Town
(021) 659 5684
sandhya.silal@uct.ac.za

Ms Amanda Bakkum
The University of Cape Town
(021) 659 5684
amanda.bakkum@uct.ac.za

APPENDIX B: PATIENT HISTORY FORM

PATIENT HISTORY

A. PATIENT DEMOGRAPHIC

1. Age at Time of Surgery: ______ Years

2. Gender: ☐ Male ☐ Female

3. Weight: ____________ Kilograms

4. Height: ____________ Centimeters

B. MEDICAL HISTORY

1. Have you been diagnosed with one or more Chronic Diseases? ☐ Yes ☐ No

If yes, Please elaborate:

____

____

2. Are you currently on any prescription or non-prescription medication? ☐Yes ☐No

If yes, Please elaborate:

____

____

C. KNEE HISTORY *(*Involved Knee refers to the operative knee.)*

1. Involved Knee: ☐ Right ☐ Left

3. Pre-operative Duration of Symptoms: _________ Months ☐ Unknown

4. Activity at Onset of Symptoms/Injury: ☐Sports ☐ ADL ☐ Work ☐ Motor Accident

OTHER: (specify) ____________________________ ☐ Unknown

5. Mechanism of Injury:

☐ Non-traumatic gradual onset ☐ Traumatic non-contact onset

☐ Non-traumatic sudden onset ☐ Traumatic contact onset

D. SURGICAL HISTORY:

1. Record any significant surgical procedures of the past ***other than in the involved knee***:

____

____

2. Previous Cartilage Procedure in the Involved Knee: ☐ **No Prior Cartilage Procedure**

☐ 0–6 Months ☐ 6–12 Months ☐ >12 Months ☐ >2 Years ☐ >3 Years

3. Comments on Surgical History:

____

____

4. Surgical History. *Please indicate the* ***number*** *of previous procedures in the* ***involved knee*** *(excluding the current total knee replacement):*

Medial Compartment Surgical History: ☐ **No Prior Procedure**

Medial Femoral Condyle
Debridement ______
Microfracture ______
Abrasion Arthroplasty/Chondroplasty/Drilling ______
Thermal Tissue Ablation ______
Osteochondral Autograft ______
Osteochondral Allograft ______
Cell Based Cartilage Procedures ______
Focal HemiCAP Resurfacing (15/20mm) ______
OTHER:
____

Medial Tibial Plateau
Debridement ______
Microfracture ______
Abrasion Arthroplasty/Chondroplasty/Drilling ______
Thermal Tissue Ablation ______
OTHER:
____

Medial Meniscus
Partial Meniscectomy ______
Meniscal Repair ______
Meniscal Allograft ______
OTHER:
____

Lateral Compartment Surgical History: ☐**No Prior Procedure**

Lateral Femoral Condyle
Debridement ______
Microfracture ______
Abrasion Arthroplasty/Chondroplasty/Drilling ______
Thermal Tissue Ablation ______
Osteochondral Autograft ______
Osteochondral Allograft ______
Cell Based Cartilage Procedures ______
Focal HemiCAP Resurfacing (15/20mm) ______
OTHER:
____

Lateral Tibial Plateau
Debridement ______
Microfracture ______
Abrasion Arthroplasty/Chondroplasty/Drilling ______
Thermal Tissue Ablation ______
OTHER:
____

Lateral Meniscus
Partial Meniscectomy ______
Meniscal Repair ______
Meniscal Allograft ______
OTHER:
____

Patellofemoral Joint Surgical History: ☐ **No Prior Procedure**

Patella
Debridement ______
Microfracture ______
Abrasion Arthroplasty/Chondroplasty/Drilling ______
Thermal Tissue Ablation ______
Osteochondral Autograft ______
Osteochondral Allograft ______
Cell Based Cartilage Procedures ______
OTHER:
____

Trochlea
Debridement ______
Microfracture ______
Abrasion Arthroplasty/Chondroplasty/Drilling ______
Thermal Tissue Ablation ______
Osteochondral Autograft ______
Osteochondral Allograft ______
Cell Based Cartilage Procedures ______
OTHER:
____

Ligament, Tendon, Capsular, Realignment Procedures, etc.: ☐ **No Prior Procedure**

ACL Reconstruction ______
PCL Reconstruction ______
MCL Reconstruction ______
LCL Reconstruction ______
Posterolateral Reconstruction ______
OTHER:
____

Patella Tendon Repair ______
Quadriceps Tendon Repair ______
PF Medial Imbrication ______
PF Lateral Release ______
PF Tibial Tubercle Transfer ______
Trochleoplasty ______
Patellectomy ______
High Tibial Osteotomy ______

5. Surgical History. *Please indicate the **number** of previous procedures in the **uninvolved knee:***

Medial Compartment Surgical History:		☐ **No Prior Procedure**	
Medial Femoral Condyle		**Medial Tibial Plateau**	
Debridement	_____	Debridement	_____
Microfracture	_____	Microfracture	_____
Abrasion Arthroplasty/Chondroplasty/Drilling	_____	Abrasion Arthroplasty/Chondroplasty/Drilling	_____
Thermal Tissue Ablation	_____	Thermal Tissue Ablation	_____
Osteochondral Autograft	_____	OTHER: ______________________________	
Osteochondral Allograft	_____		
Cell Based Cartilage Procedures	_____	**Medial Meniscus**	
Focal HemiCAP Resurfacing (15/20mm)	_____	Partial Meniscectomy	_____
OTHER: ______________________________		Meniscal Repair	_____
		Meniscal Allograft	_____
		OTHER: ______________________________	

Lateral Compartment Surgical History:		☐ **No Prior Procedure**	
Lateral Femoral Condyle		**Lateral Tibial Plateau**	
Debridement	_____	Debridement	_____
Microfracture	_____	Microfracture	_____
Abrasion Arthroplasty/Chondroplasty/Drilling	_____	Abrasion Arthroplasty/Chondroplasty/Drilling	_____
Thermal Tissue Ablation	_____	Thermal Tissue Ablation	_____
Osteochondral Autograft	_____	OTHER: ______________________________	
Osteochondral Allograft	_____		
Cell Based Cartilage Procedures	_____	**Lateral Meniscus**	
Focal HemiCAP Resurfacing (15/20mm)	_____	Partial Meniscectomy	_____
OTHER: ______________________________		Meniscal Repair	_____
		Meniscal Allograft	_____
		OTHER: ______________________________	

Patellofemoral Joint Surgical History:		☐ **No Prior Procedure**	
Patella		**Trochlea**	
Debridement	_____	Debridement	_____
Microfracture	_____	Microfracture	_____
Abrasion Arthroplasty/Chondroplasty/Drilling	_____	Abrasion Arthroplasty/Chondroplasty/Drilling	_____
Thermal Tissue Ablation	_____	Thermal Tissue Ablation	_____
Osteochondral Autograft	_____	Osteochondral Autograft	_____
Osteochondral Allograft	_____	Osteochondral Allograft	_____
Cell Based Cartilage Procedures	_____	Cell Based Cartilage Procedures	_____
OTHER: ______________________________		OTHER: ______________________________	

Ligament, Tendon, Capsular, Realignment Procedures, etc.:		☐ **No Prior Procedure**	
ACL Reconstruction	_____	Patella Tendon Repair	_____
PCL Reconstruction	_____	Quadriceps Tendon Repair	_____
MCL Reconstruction	_____	PF Medial Imbrication	_____
LCL Reconstruction	_____	PF Lateral Release	_____
Posterolateral Reconstruction	_____	PF Tibial Tubercle Transfer	_____
OTHER: ______________________________		Trochleoplasty	_____
		Patellectomy	_____
		High Tibial Osteotomy	_____

A. FOLLOW-UP KNEE EXAMINATION

1. Symptoms of the Involved Knee *("Involved Knee" refers to the operative knee)*

Pain:	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
Swelling:	☐ Yes	☐ No			
Locking:	☐Yes	☐ No			
Giving-way:	☐ Yes	☐ No			

B. POSTOPERATIVE MILESTONES

1. Length of Hospitalization (admission to discharge): ________ **Hours**

2. Time to Ambulation with Support (Crutches etc): ________ **Hours**

3. Time to Ambulation without Support (Crutches etc.): ________ **Days**

3. Time to reach full range of motion (ROM): ________ **Days**

4. Length of Postoperative Rehabilitation ________ **Weeks**

Please explain what this rehabilitation entailed and its duration (Physiotherapy, Biokinetics etc.):____
____
____

5. Time to Return to Work ________ **Weeks**
   ☐ NA - Patient not working prior to surgery

6. Time to Return to Sports ________ **Months**
   ☐ NA - Patient was not seeking to return to sport

G. ADDITIONAL COMMENTS

____
____
____

Patient Signature: ________________________ **Date: ____________________**

Investigator Signature: ____________________ **Date: ____________________**

Thank you for completing all the questions in this questionnaire.

APPENDIX C: PHYSICAL ACTIVITY READINESS QUESTIONNAIRE

University of Cape Town
Sport Science Orthopaedic Centre

Physical Activity Readiness Questionnaire (PAR-Q)

Name			Date
DOB:	Age:	Home Phone:	Work Phone:

Regular exercise is associated with many health benefits, yet any change of activity may increase the risk of injury. This questionnaire identifies whether you are at risk.

Please read each question carefully and answer every question honestly:

Yes	No	1) Has a physician ever said you have a heart condition and you should only do physical activity recommended by a physician?
Yes	No	2) When you do physical activity, do you feel pain in your chest?
Yes	No	3) When you were not doing physical activity, have you had chest pain in the past month?
Yes	No	4) Do you ever lose consciousness or do you lose your balance because of dizziness?
Yes	No	5) Do you have a joint or bone problem that may be made worse by a change in your physical activity?
Yes	No	6) Is a physician currently prescribing medications for your blood pressure or heart condition?
Yes	No	7) Are you pregnant?
Yes	No	8) Do you have insulin dependent diabetes?
Yes	No	9) Are you 69 years of age or older?
Yes	No	10) Do you know of any other reason you should not exercise or increase your physical activity?

If you answered **yes** to any of the above questions, you need to consult your doctor BEFORE you can participate in this experiment. If you honestly answered **no** to all questions, you can be reasonably positive that you are not at an increased risk by participating in this study. If your health changes so you then answer **yes** to any of the above questions, seek guidance from a physician.

Participant Signature	Date

Thank you for completing all the questions in this questionnaire

APPENDIX D: KNEE INJURY AND OSTEOARTHRITIS OUTCOME SCORE

University of Cape Town
Sport Science Orthopaedic Centre

KNEE INJURY AND OSTEOARTHRITIS OUTCOME SCORE (KOOS)

iNSTRUCTIONS:

This survey asks for your view about your knee. This information will help us keep track of how you feel about your knee and how well you are able to do your usual activities. Answer every question by ticking the appropriate box, only one box for each question. If you are unsure about how to answer a question, please give the best answer you can.

SYMPTOMS:

These questions should be answered thinking of your knee symptoms during the **last week**.

S1. Do you have swelling in your knee?

Never	Rarely	Sometime	Often	Always
☐	☐	☐	☐	☐

S2. Do you feel grinding; hear clicking or any other type of noise when your knee moves?

Never	Rarely	Sometime	Often	Always
☐	☐	☐	☐	☐

S3. Does your knee catch or hang up when moving?

Never	Rarely	Sometime	Often	Always
☐	☐	☐	☐	☐

S4. Can you straighten your knee fully?

Always	Often	Sometime	Rarely	Never
☐	☐	☐	☐	☐

S5. Can you bend your knee fully?

Always	Often	Sometime	Rarely	Never
☐	☐	☐	☐	☐

STIFFNESS:

The following questions concern the amount of joint stiffness you have experienced during the **last week** in your knee. Stiffness is a sensation of restriction or slowness in the ease with which you move your knee joint.

S6. How severe is your knee joint stiffness after first wakening in the morning?

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

S7. How severe is your knee stiffness after sitting, lying or resting **later in the day**?

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

PAIN:

P1. How often do you experience knee pain?

Never	Monthly	Weekly	Daily	Always
☐	☐	☐	☐	☐

What amount of knee pain have you experienced the **last week** during the following activities?

P2. Twisting/pivoting on your knee

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P3. Straightening knee fully

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P4. Bending knee fully

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P5. Walking on flat surface

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P6. Going up or down stairs

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P7. At night while in bed

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P8. Sitting or lying

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P9. Standing upright

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

FUNCTION, DAILY LIVING:
The following questions concern your physical function. By this we mean your ability to move around and to look after yourself. For each of the following activities please indicate the degree of difficulty you have experienced in the **last week** due to your knee.

A1. Descending stairs

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A2. Ascending stairs

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

For each of the following activities please indicate the degree of difficulty you have experienced in the **last week** due to your knee.

A3. Rising from sitting

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A4. Standing

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A5. Bending to floor/pick up an object

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A6. Walking on flat surface

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A7. Getting in/out of car

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A8. Going shopping

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A9. Putting on socks/stockings

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A10. Rising from bed

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A11. Taking off socks/stockings

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A12. Lying in bed (turning over, maintaining knee position)

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A13. Getting in/out of bath

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A14. Sitting

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A15. Getting on/off toilet

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

For each of the following activities please indicate the degree of difficulty you have experienced in the **last week** due to your knee.

A16. Heavy domestic duties: moving heavy boxes, scrubbing floors, etc.

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A17. Light domestic duties (cooking, dusting, etc.)

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

FUNCTION, SPORTS AND RECREATIONAL ACTIVITIES:
The following questions concern your physical function when being active on a higher level. The questions should be answered thinking of what degree of difficulty you have experienced during the **last week** due to your knee.

SP1. Squatting

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP2. Running

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP3. Jumping

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP4. Twisting/pivoting on your injured knee

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP5. Kneeling

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

QUALITY OF LIFE:

Q1. How often are you aware of your knee problem?

Never	Monthly	Weekly	Daily	Constantly
☐	☐	☐	☐	☐

Q2. Have you modified your life style to avoid potentially damaging activities to your knee?

Not at all	Mildly	Moderately	Severely	Totally
☐	☐	☐	☐	☐

Q3. How much are you troubled with lack of confidence in your knee?

Not at all	Mildly	Moderately	Severely	Extremely
☐	☐	☐	☐	☐

Q4. In general, how much difficulty do you have with your knee?

Not at all	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Thank you for completing all the questions in this questionnaire

APPENDIX E: SF-36 HEALTH SURVEY

University of Cape Town
Sport Science Orthopaedic Centre

SF-36 HEALTH SURVEY

This survey asks for your views about your health. Answer every question by ticking the appropriate box, only one box for each question. If you are unsure about how to answer a question, please give the best answer you can.

1. In general, would you say your health is:

Excellent	Very Good	Good	Fair	Poor
☐	☐	☐	☐	☐

2. Compared to one *year ago*, how would you rate your health in general *now*?

Much Better Now	Somewhat Better Now	About the Same	Somewhat Worse	Much Worse
☐	☐	☐	☐	☐

3. The following questions are about activities you might do during a typical day. Does your health now limit you in these activities? If so, how much?

	Yes. Limited a Lot	Yes. Limited a little	No. Not limited at all
Vigorous Activities: running, lifting heavy objects, participating in strenuous sports…………………………………………………	☐	☐	☐
Moderate Activities: moving a table, pushing a vacuum cleaner, bowling or playing golf ………………………………………………	☐	☐	☐
Lifting or carrying groceries……………………………………...	☐	☐	☐
Climbing several flights of stairs………………………………..	☐	☐	☐
Climbing one flight of stairs……………………………………..	☐	☐	☐
Bending, kneeling or stooping………………………………….	☐	☐	☐
Walking more than one kilometre……………………………….	☐	☐	☐
Walking several hundred metres……………………………….	☐	☐	☐
Walking one hundred metres…………………………………...	☐	☐	☐
Bathing or dressing yourself………………………………………	☐	☐	☐

4. During the <u>past 4 weeks</u>, how much of the time have you had any of the following problems with your work or other regular daily activities <u>as a result of your physical health</u>?

	All of the time	Most of the time	Some of the time	A little of the time	None of the time
Cut down on the <u>amount of time</u> you spent on work or other activities……..	☐	☐	☐	☐	☐
<u>Accomplished less</u> than you would like…….	☐	☐	☐	☐	☐
Were limited in the <u>kind</u> of work or other activities………………………	☐	☐	☐	☐	☐
Had <u>difficulty</u> performing the work or other activities (for example, it took extra effort)...	☐	☐	☐	☐	☐

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5. During the <u>past 4 years</u>, how much of the time have you had any of the following problems with your work or other regular daily activities <u>as a result of any emotional problems</u> (such as feeling depressed or anxious)?

	All of the time	Most of the time	Some of the time	A little of the time	None of the time
Cut down on the <u>amount of time</u> you spent on work or other activities……….	☐	☐	☐	☐	☐
<u>Accomplished less</u> than you would like……	☐	☐	☐	☐	☐

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6. During the <u>past 4 weeks</u>, to what extent has your physical health or emotional problems interfered with your normal social activities with family, friends, neighbours or groups?

Not at all	Slightly	Moderately	Quite a bit	Extremely
☐	☐	☐	☐	☐

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7. How much bodily pain have you had during the <u>past 4 weeks?</u>

None	Very Mild	Mild	Moderate	Severe	Very Severe
☐	☐	☐	☐	☐	☐

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8. During the <u>past 4 weeks</u>, how much did <u>pain</u> interfere with your normal work (including both work outside and home and housework)?

Not at all	Slightly	Moderately	Quite a bit	Extremely
☐	☐	☐	☐	☐

9. These questions are about how you feel and how things have been with you <u>during the past 4 weeks</u>. For each question, please give the one answer that comes closest to the way you have been feeling. How much of the time during the <u>past 4 weeks</u>…

	All of the time	Most of the time	Some of the time	A little of the time	None of the time
Did you feel full of life?.........................	☐	☐	☐	☐	☐
Have you been very nervous?	☐	☐	☐	☐	☐
Have you felt so down in the dumps that nothing could cheer you up? …	☐	☐	☐	☐	☐
Have you felt calm and peaceful? …	☐	☐	☐	☐	☐
Do you have a lot of energy? ………	☐	☐	☐	☐	☐
Have you felt downhearted and depressed? …………………………	☐	☐	☐	☐	☐
Did you feel worn out? ………………	☐	☐	☐	☐	☐
Have you been happy? ……………	☐	☐	☐	☐	☐
Did you feel tired? ……………………	☐	☐	☐	☐	☐

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10. During the <u>past 4 weeks</u>, how much of the time has your <u>physical health or emotional problems</u> interfered with your social activities (like visiting with friends, relatives, etc.)?

All of the time	Most of the time	Some of the time	A little of the time	None of the time
☐	☐	☐	☐	☐

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11. How TRUE or FALSE is <u>each</u> of the following statements for you?

	Definitely true	Mostly true	Don't know	Mostly false	Definitely false
I seem to get sick a little easier than other people……………………..……	☐	☐	☐	☐	☐
I am as healthy as anybody I know…	☐	☐	☐	☐	☐
I expect my health to get worse……	☐	☐	☐	☐	☐
My health is excellent……………..	☐	☐	☐	☐	☐

Thank you for completing all the questions in this questionnaire.

APPENDIX F: TEGNER ACTIVITY LEVEL SCALE

University of Cape Town
Sport Science Orthopaedic Centre

TEGNER ACTIVITY LEVEL SCALE

Current Level: ___________

LEVEL 10	Competitive Sports: Soccer- National And International Elite
LEVEL 9	Competitive Sports: Soccer (Lower Divisions), Ice Hockey, Wrestling, Gymnastics
LEVEL 8	Competitive Sports: Squash, Badminton, Athletics (Jumping, Etc.), Downhill Skiing
LEVEL 7	Competitive Sports: Tennis, Athletics (Running, Etc.), Motocross, Speedway, Handball, Basketball Recreational Sports: Soccer, Bandy And Ice Hockey, Squash, Athletics (Jumping, Etc.), Cross-Country Track Findings Both Recreational and Competitive
LEVEL 6	Recreational Sports: Tennis and Badminton, Handball, Basketball, Downhill Skiing, Jogging at Least 5 Days a Week
LEVEL 5	Work: Heavy Labour (E.G. Building Or Forestry) Competitive Sports: Cycling, Cross- Country Skiing Recreation Sports: Jogging on Uneven Ground at Least Twice a Week
LEVEL 4	Work: Moderately Heavy Labour (E.G. Truck Driving, Heavy Domestic Work) Recreational Sports: Cycling, Cross- Country Skiing, Jogging, on Even Ground at Least Twice Weekly
LEVEL 3	Work: Light Labour (E.G. Nursing) Competitive and Recreational Sports: Swimming, Walking in Forest is Possible
LEVEL 2	Work: Light Labour, Walking on Uneven Ground is Possible, But Impossible to Walk in Forest
LEVEL 1	Work: Sedentary Work, Walking on Even Ground is Possible
LEVEL 0	Sick Leave or Disability Pension Because of Knee Problems

Patient Signature: ___________________________ **Date: ________________**

Investigator Signature: ______________________ **Date: _________________**

APPENDIX G: INTERVENTION TESTING SHEET

University of Cape Town
Sport Science Orthopaedic Centre

INTERVENTION TESTING SHEET

Name: ______________________________ **Date:** ____________________

Session: ____________________________

Bike Setup:

Weight: _____________________

Speed: ______________________

Torque:______________________

Seat Height: __________________

Time: Minutes	VAS: Visual analogue scale	HR: Heart rate	RPE: Rating of Perceived Exertion
0			
2			
5			
9			
10			
14			
18			

Watts	Concentric		Eccentric	
Left	Ave:__________	Max:________	Ave:__________	Max:_________
Right	Ave:__________	Max:_________	Ave:__________	Max:_________