UNIVERSITY OF THE WITWATERSRAND

CENTRE FOR EXERCISE SCIENCE AND SPORTS MEDICINE

RESEARCH REPORT

Functional Isokinetic Hamstring to Quadriceps Ratio Profile of Rugby Union Players: A Comparison between Forward & Backline Players

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CENTRE FOR EXERCISE SCIENCE AND SPORTS MEDICINE

In partial Fulfilment of Masters of Science (Med) in Biokinetics

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ABSTRACT

Background: Balanced muscle strength of the hamstrings and quadriceps muscle groups, are crucial for knee joint stability, movement efficiency and injury prevention. The occurrence of injury to the knee joint and the hamstring muscles in particular is high in rugby players. The dynamic control ratio (DCR) is important to assess as it gives an indication of the hamstring muscle's functional capacity relative to the quadriceps muscles and is an important factor in injury prevention.

Aim: The aim of this study was to evaluate and compare the bilateral functional dynamic control hamstring to quadriceps ratios between forward and backline rugby union players.

Design: **A cross-sectional study design was utilized in this study.**

Methods: **Thirty one** rugby players from the WITS, UJ and NWU rugby club's first, second and third teams, willing to participate, were included in this study. Isokinetic dynamometry was used to evaluate bilateral eccentric and concentric peak torque of the hamstring and quadriceps muscles at 60˚/sec the following ratios were then calculated: DCR, reciprocal ratio, bilateral deficits and peak torque to body weight ratio. Statistical significance was set at $p < 0.05$.

Results: Thirty one subjects, 16 forward and 15 backline players from WITS, UJ and NWU were assessed. The forwards were significantly taller ($p = 0.001$)(187.5 ± 8.5cm) and heavier ($p = 0.000002$)(106.2 ± 12.9kg) than the backline players (Height: 178.6 ± 3.8cm; Weight: 83.7 ± 7.0kg). The forwards produced significantly ($p<0.05$) greater eccentric (F: 227.9 ± 41.9Nm; B: 199.6 ± 24.6Nm; $p = 0.015$)(F: 222.5 ± 41.5Nm; B: 191.2 ± 22.8Nm; $p = 0.01$) and concentric peak torque (F: 314.5 ± 36.1Nm; B: 282.2 ± 45.9Nm; $p = 0.02$)(F: 307.3 ± 44.7Nm; B: 271.9 ± 38.4Nm; $p = 0.013$) in the dominant and non-dominant limbs during extension and flexion compared to backs. There was no significant difference ($p>0.05$) in the DCR between forward and backline players on the dominant (F: 0.72 ± 0.1; B: 0.71 ± 0.07; $p = 0.38$) or non-dominant (F: 0.73 ± 0.09; B: 0.71 ± 0.08; $p = 0.30$) limbs.

Conclusion: The findings from the present study found no significant difference between the DCR of forward compared to backline rugby union players. Further research should investigate, on a bigger sample group, if there is a difference in the DCR between the tight five, loose forwards, inside- and outside backline players.

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TABLE OF CONTENTS

		Page
	Declaration……………………………………………………………………………….	i
	Abstract………………………………………………………………………………..	ii
	Acknowledgements………………………………………………………………………	iv
	Table of Contents………………………………………………………………………..	v
	List of Tables………………………………………………………………………...	viii
	Definition of Terms……………………………………………………………………..	ix
	List of Abbreviations……………………………………………………………………..	xi
1.	**Chapter 1: Introduction**………………………………………………………………….	1
1.1	Motivation for Study………………………………………………………………………	2
1.2	Aim of Study………………………………………………………………………………	2
1.3	Objectives…………………………………………………………………………………	2
1.4	Hypothesis…………………………………………………………………………………	2
2.	**Chapter 2: Literature Review**………………………………………………………..	3
2.1	Physical Demands of Rugby……………………………………………………………	3
2.2	Patellofemoral and Tibiofemoral Joint Anatomy and Biomechanics……………………	9
2.2.1	Anterior Compartment……………………………………………………………………	11
2.2.2	Posterior Compartment……………………………………………………………..	11
2.2.3	Lateral Compartment…………………….……………………………………………...	12
2.2.4	Medial Compartment…………………………………………………………………...	12
2.3	Muscular Strength Testing…………………………………………………………….	13
2.4	Isokinetics…………………………………………………………………………………	15
2.4.1	Advantages and Disadvantages of Isokinetic devices……………………………….	16
2.4.2	Position Specific Isokinetics……………………………………………………………..	19
2.4.3	Peak Torque and DCR in rugby………………………………………………………	20
2.4.4	Effect of Injury on Muscle Balance around the Knee Joint…………………………..	22
3.	**Chapter 3: Research Design and Methodology**……………………………………..	24
3.1	Research Design………………………………………………………………………....	24
3.2	Site of Study…………………………………………………………………………….	24
3.3	Study Population………………………………………………………………………..	24
3.3.1	Sampling……………………………………………………………………………………	24
3.3.2	Recruitment of Subjects…………………………………………………………………	24

3.3.3	Inclusion and Exclusion Criteria……………………………………………………….	24
3.4	Ethical Considerations…………………………………………………………………...	25
3.5	Testing Procedures, Measuring Tools and Instruments………………………………..	25
3.5.1	Anthropometry……………………………………………………………………….	25
3.5.2	Injury History………………………………………………………………………..	25
3.5.3	Isokinetic Testing……………………………………………………………………..	25
3.5.4	Positioning and Stabilisation of Participants……………………………………………	26
3.5.5	Gravity Correction………………………………………………………………………	26
3.5.6	Testing Procedure…………………………………………………………………….	26
3.5.7	Risks and Benefits…………………………………………………………………….	27
3.6	Data Analysis……………………………………………………………………………	27
4.	**Chapter 4: Results**……………………………………………………………….	28
4.1	Participant Characteristics………………………………………………………………	28
4.2	Dynamic Control Ratio……………………………………………………………….	28
4.3	Peak Torque…………………………………………………………………………...	29
4.4	Knee Peak Torque to Body Weight……………………………………………………	29
4.5	Reciprocal Ratio (H/Q Ratio)…………………………………………………………..	31
4.6	Bilateral Deficit……………………………………………………………………….	32
5.	**Chapter 5: Discussion**………………………………………………………………..	33
5.1	Participant Characteristics………………………………………………………………	33
5.2.	Dynamic Control Ration (DCR)………………………………………………………..	33
5.2.1	Group DCR……………………………………………………………………………...	33
5.2.2	DCR Forwards vs. Backline Players…………………………………………………..	34
5.3	Peak Torque……………………………………………………………………………...	34
5.3.1	Peak Torque Group……………………………………………………………………...	34
5.3.2	Peak Torque Forwards vs. Backline Players……………………………………………	35
5.4	Peak Torque Relative to Body Weight (PT/BW)………………………………………	37
5.4.1	PT/BW Group…………………………………………………………………………	37
5.4.2	PT/BW Forwards vs. Backline Players………………………………………………….	38
5.5	Bilateral Deficit…………………………………………………………………………	39
5.5.1	Bilateral Deficit Group………………………………………………………………….	40
5.5.2	Bilateral Deficit Forwards vs. Backline Players………………………………………	40
6.	**Chapter 6: Conclusion, Recommendations and Limitations**……………………….	41

6.1 Conclusion………………………………………………………………………………. 41
6.2 Recommendations and Limitations…………………………………………………….. 41

7. **References**………………………………………………………………………………. 43

Appendix A: Information letter…………………………………………………………. 50
Appendix B: Letter to players…………………………………………………………….. 52
Appendix C: Informed consent…………………………………………………………… 54
Appendix D: Ethical clearance…………………………………………………………… 55
Appendix E: Anthropometric data sheet………………………………………………. 56
Appendix F: Injury history form………………………………………………………. 58
Appendix G: Test recording sheet……………………………………………………… 59
Appendix H: Plagiarism declaration……………………………………………………. 60

LIST OF TABLES

		Page
Table 4.1:	Demographic information for Forward and Backline Rugby players (n=31)……….	28
Table 4.2:	Mean dynamic control ratio at 60º/sec for Forward (n=16) and Backline (n=15) rugby players…………………………………………………………………………….	28
Table 4.3:	Mean concentric and eccentric quadriceps and hamstring peak torque (Nm) at 60º/sec for Forward (n=16) and Backline (n=15) rugby players……………………	29
Table 4.4:	Peak torque relative to body weight (Nm/kg) of Forward (n=16) and Backline (n=15) rugby players at 60˚/sec……………………………………………………	31
Table 4.5:	Mean reciprocal ratio at 60˚/sec for Forward (n=16) and Backline (n=15) rugby players…………………………………………………………………………………	32
Table 4.6:	Bilateral deficit at 60˚/sec for Forward (n=16) and Backline (n=15) rugby players….	32

DEFINITION OF TERMS

Concentric muscle action: Concentric muscle contraction is defined as a shortening contraction in which a muscle's origin and insertion are drawn toward one another as the muscle contracts and overcomes an external resistance.[3]

Eccentric muscle action: An eccentric contraction is defined as a contraction whilst there is a lengthening action in which a muscle's origin and insertion are drawn away from one another by an external resistance.[3]

Isometric muscle action: In an isometric muscle contraction there is force development at a constant length and therefore no movement of the involved body part.[41]

Delayed-onset muscle soreness (DOMS): Muscle soreness that increases in intensity for the first 24 hours after activity, peaks from 24 to 48 hours, and then declines during the next 5 to 7 days.[44]

Knock-on: A knock-on occurs when a player loses possession of the ball and it goes forward, or when a player hits the ball forward with the hand or arm, or when the ball hits the hand or arm and goes forward, and the ball touches the ground or another player before the original player can catch it. Forward means towards the opposing team's dead ball line.[20]

Lineout: A lineout is formed where the ball goes outside the area of play in other words crosses the touchline. The hooker throws the ball from the touchline down the center of the two lines of forwards.[20]

Maul: When the ball carrier is held by one or more opponents, and one or more of the ball carrier's teammates bind onto him a maul is formed .[20]

Penalty: The non-offending team is awarded a penalty- or free kick for infringements by their opponents.[20]

Ruck: When at least one player from each side bind together with the ball on the ground between them a ruck is formed.[20]

Scrum: The scrum is used to restart play after a minor infringement. Eight players of both sides bind together and interlock with the opposing team's forwards. The ball is then fed into the scum and competed for by both forward packs.[20]

Forward pass: A throw forward occurs when a player throws or passes the ball forward. Forward means toward the opposing team's dead ball line.[20]

LIST OF ABBREVIATIONS

ACL	-Anterior Cruciate Ligament
CON	-Concentric
CV	-Coefficient of Variance
DOMS	-Delayed-Onset Muscle Soreness
D	-Dominant
DCR or H_{ecc}/Q_{con} ratio	-Dynamic Control Ratio or Hamstring Eccentric to Quadriceps Concentric ratio
ECC	-Eccentric
G	-Gravitational Force/Gravity
GET	-Gravity Effect of Torque
GPS	-Global Positioning System
HR	-Heart Rate
IRB	-International Rugby Board
ND	-Non-Dominant
Nm	-Newton meters
NWU	-North West University
PFJ	-Patellofemoral Joint
PT	-Peak Torque
PT/BW	-Peak Torque to Body Weight
RM	-Repetition Maximum
ROM	-Range of Motion
RR	-Reciprocal Ratio
RWC	-Rugby World Cup
UJ	-University of Johannesburg
WITS	-University of the Witwatersrand

CHAPTER 1: INTRODUCTION

Balanced strength and coactivation of antagonistic muscles around a joint are necessary for joint stabilisation, movement efficiency, injury prevention and rehabilitation.[1, 2] Antagonistic muscles have opposite functions to one another, for example the knee flexor and extensor muscles work antagonistically. To bring about extension the distal portion of a joint is brought in line with the long axis of the proximal portion.[3] Bending a joint to approximate the parts it connects is known as flexion.

It has been proposed that imbalances between the hamstring and quadriceps muscle groups predispose athletes to lower extremity injury.[1, 4] If the quadriceps muscles are significantly stronger than the hamstring muscles it may lead to a muscle strain when the hamstring is required to contract eccentrically during knee extension to decelerate the lower limb.[5] The same mechanism will place the anterior cruciate ligament at increased risk for injury by compromising dynamic joint stabilisation through decreased muscular strength. Hamstring injury rates amongst rugby union players were found to be high at 0.27 per 1000 player training hours and 5.6 per 1000 player match hours.[6]

Injury to the knee joint accounted for the highest number of days absent due to injury in English professional rugby union players.[7] The highest percentage of these was damage to the anterior cruciate ligament followed by the medial collateral ligament. Strains to the thigh and hamstring muscles were the most frequently injured and not the knee joint.

Research on the subject can be conflicting but it has been reported that after injury the agonist-antagonist muscle balance of the knee could be disturbed.[8, 9, 10, 11, 12, 13, 14] What is clear is that when investigating the muscle balance around the knee joint, eccentric muscle contractions should receive the same amount of consideration as concentric contractions. By utilising the dynamic control ratio (DCR) the eccentric muscle action around the knee was considered in combination with the concentric action in a functional manner. In this study the DCR is used for this purpose. Early identification of these imbalances could therefore play an important role in the prevention of injury and also in the rehabilitation process following injury.[1, 4]

The DCR has been used to identify previous injury and predict new muscle injury.[12, 13, 14] It has been used to identify previous hamstring injuries in actively participating football players with high accuracy.[12] Similarly, previously injured athletes actively participating in their sports presented with a significantly reduced DCR on the injured limb compared to the uninjured limb.[13] Individualised correction of the imbalances decreased persistent symptoms. Correction of the DCR also reduced injury frequency in a group of football players.[14] There exists a lack of research on the DCR in the rugby union population.

1.1 MOTIVATION FOR STUDY

Position-specific training, conditioning and rehabilitation are becoming the norm for athletes.[15, 16] The DCR with regards to rugby union players has not been thoroughly researched; therefore this study specifically addresses the DCR in rugby union players. This study may contribute to our understanding of the prevention and rehabilitation of a frequently injured area, namely the patellofemoral joint (PFJ).

1.2 AIM OF STUDY

The aim of this study was to evaluate and compare the bilateral functional dynamic control hamstrings to quadriceps ratios between forward and backline rugby union players.

1.3 OBJECTIVES

Three objectives were chosen for this study:

- To determine the concentric quadriceps and eccentric hamstring muscle strength in rugby union players

- To determine the dynamic control ratio and compare this between the forward and backline rugby union players.

- To determine the reciprocal ratio, bilateral deficit and peak torque to body weight ratio in rugby union players.

1.4 HYPOTHESIS

The dynamic control ratio will be higher for forwards compared to backline players.

Chapter 2: REVIEW OF LITERATURE

This study investigated the functional relationship between the knee extensor and flexor muscles in a group of rugby union players and compares the differences and/or similarities if any between the different positional groupings amongst them, i.e. forwards versus backline players. As an introduction the relevant concepts, definitions and equipment are discussed. These include a basic summary of the physical demands of rugby, work to rest ratios, anthropometrics, knee joint anatomy and biomechanics, muscular strength and endurance testing and isokinetics.

2.1 PHYSICAL DEMANDS OF RUGBY

Technical, tactical, physical and psychological skills and knowledge are components that influence the way rugby is played.[17] The above mentioned components resulted in rugby union evolving into a game of high energy, power and intricate skills performed in rhythm.[15] A rugby match is played in 80 minutes with alternate bouts of high intensity work such as sprinting, rucking and mauling, tackling and with low intensity activities such as jogging, walking and standing.

A team is made up of fifteen players in each side and sub-divided into two main groups, namely forwards and backline players. There are a total of 8 forward and 7 backline players. Different physical and skill demands are placed on the players with respect to playing position, the major difference being that the forwards participate in the set pieces, such as the scrum and lineout, whereas, backline players do not.[17, 18] Forwards include numbers one to eight and can be further sub-divided into the front row (players number 1-3), second row (players number 4 and 5) and loose forwards (players number 6-8). Collectively the front row and second row are known as the tight five. Forwards have to gain and retain possession of the ball and participate in scrummaging and lineouts. Backline players utilise the gained possession to score points. They run or kick the ball to achieve this.[17, 18]

After a minor infringement the scrum is used to restart play.[19] Eight players of both sides bind together and interlock with the opposing team's forwards.[20] The ball is then fed into the scrum and competed for by both forward packs. Collapsing the scrum or incorrectly placing the ball into the scrum correctly could result in a penalty. A scrum is could be awarded for one of three reasons; knocking the ball forward, passing it forward, or trapping the ball in a ruck or maul. When at least one player from each side bind together with the ball on the ground between them a ruck is formed.[19] When the ball carrier is held by one or more opponents, and one or more of the ball carrier's teammates bind onto him a maul is formed.[20]

A lineout is formed when the ball goes outside the area of play, in other words crosses the touchline.[19] The opposing forwards line up next to each other a meter apart and perpendicular to the touchline. The hooker throws the ball from the touchline down the center of the two lines of forwards. Usually the locks from both sides then compete for the ball by jumping to catch it while being supported by their teammates.

The role of the props (players number 1 and 3) are to provide quality balls for the team and deny it for the opposition.[17] They provide a critical role in the scrums and lineout and a high work rate is expected from them during rucks, mauls and tackles.[19] Props are required to provide a solid foundation for quality ball in the scrum and must aim to physically dominate their opponent. They must lift and support the jumpers in the air during lineouts and kick-offs. The hooker (player number 2) has a similar job description to the props with some variation at the scrum and lineout. The hooker is required to organise the scrum, act as a thrower in the lineout and to support jumpers at kick-off.[19] Modern hookers are also required to be more involved during open play as ball carriers.[17] Locks (players number 4 and 5) have to win balls in the lineouts and provide drive and forward motion in the scrums and act as catchers at the kick-off.

The loose forwards unit comprises the blind side (player number 6), open side (player number 7) and the eighthman (player number 8), together forming the loose trio.[17] They are responsible for pushing in the scrum and can be utilised as additional lineout jumpers or options. Their main function is to secure possession through turn-overs.[19] The eighthman has to coordinate the back of the scrum and is the link between the scrum-half and the backline.

The backline players use possession gained by the forwards to score points by either running or kicking the ball. The scrum-half (player number 9) is the link between the forwards and backline players.[17] This player is responsible for putting the ball into the scrum and also to retrieve it from the back of the scrum. This position requires tactical awareness and good ball handling skills.[19] The fly-half (player number 10) needs to be a good decision-maker, communicator and be able to direct the backline and is usually the kicker of the team.[17, 19] Centers (player's number 12 and 13) should possess a strong all-round game and be able to carry attack moves and provide defense in the midfield.[17, 19] They help to put the back three (players 11, 14 and 15) into space to give them the opportunity to score. They chase kick and fall back in defense to assist the back three when needed.

Left and right wingers (players number 11 and 14) are almost always the quickest members of the team and thrive in open space usually created by the centers.[17, 19] They are the finishers who will ideally conclude a tactical movement by scoring. They put pressure on opposition players receiving a kick and are often the last line of defense. The fullback (player number 15) is also a finisher and like the center a space creator.[17] Quite often he is also the last line of defense and has to defend on high kicks.[19] In the modern game the wingers and fullbacks are often interchangeable.

Objectively quantifying the physiological requirements of an activity can be determined through work-to-rest ratios (W:R ratio).[18] It is a method in which the frequency mean duration and total time spent in activities are calculated through the use of time motion analysis.[21] Research on the work-to-rest ratio has shown that there are positional differences in the quantity and time spent in rugby-specific demands.[22] In a movement analysis study these demands were divided into high intensity (HI), low intensity (LI) or recovery. HI tasks included sprinting ($>7ms^{-1}$), high speed runs ($>5.5ms^{-1}$), runs ($>4ms^{-1}$), scrums, rucks and mauls, tackling (tackler or tackled) and lineouts (jumper or lifter). Jogging ($>2ms^{-1}$), walking ($>0.5ms^{-1}$) and standing ($<0.5ms^{-1}$) were classified as LI. The researchers found a clear difference in the quantity and time spent in rugby specific demands for the different positions. For example the forwards were involved in more HI activities for a longer duration than the backline players. On average the forwards spent 10.2 ± 4.2min engaged in all HI activities, compared to the backline players that spent 6.62 ± 1.10min.

Analysis of the physical demands of elite English rugby union players confirms the differing physical demands between forwards and backline players.[23] In this study movements based on speeds were categorised into low-intensity activities namely, standing, walking, jogging and medium intensity running, and high-intensity running, sprinting, and static exertion (scrummaging, rucking, mauling, and tackling) activities. Backline players travelled longer total distance than forwards (6127m, $s = 724$ vs. 5581m, $s = 692$; $p < 0.05$) and greater distances in walking (2351m, $s = 287$ vs. 1928m, $s = 2342$; $p < 0.001$) and high intensity running (448m, $s = 149$ vs. 298m, $s = 107$; $p < 0.05$). The average distance covered by positional group was: front row forwards (5408m), back row forwards (5812m), inside backline players (6055m) and outside backline players (6190m). Forwards again performed more high-intensity activity than backline players (9:09min:s = 1:39 vs. 3:04min:s = 1:01; $p < 0.001$), which was attributed to more time performing static exertions (7:56min:s, $s = 1:56$ vs. 1:18min:s, $s = 0:30$; $p < 0.001$).

Match running performance analysis in Spanish elite rugby had similar results.[24] With backline players covering more distance than forwards and performing more sprints. Backline players had to accelerate more times during the match and the authors speculated that this could be a result of the type of role they have to fulfil.

Researchers utilising the W:R ratio technique analysed the 2001 and 2002 Super Twelve rugby seasons and found that forwards performed more work activities than backline players and that backline players performed more sprints than forwards.[21] The average distance covered by positional group was: front row forwards (4400m), back row forwards (4080m), inside backline players (5530m) and outside backline players (5750m). Forwards worked an average of 7 minutes 31 seconds more than the backline players in a game and spent an average of 7 minutes 47 seconds more time in static exertion than the backline players. Backline players sprinted an average of 0.7 seconds faster than forwards and spent 52 seconds more sprinting than forwards. High intensity work duration per involvement averaged 4 seconds with an average of 20 seconds recovery and 1 minute 40 seconds recovery for the forwards and the backline players respectively. By dividing the duration of each high-intensity work interval by the duration of the following rest interval a work to rest ratio is produced. Work periods included high intensity activities such as forwards striding and sprinting, tackling, static holds and scrummaging. Periods of rest included low intensity activities such as standing, walking, lateral movement and jogging. Work-to-rest ratios of 1:7, 1:6, 1:15 and 1:21 for the front row, back row, inside- and outside backline players were reported, respectively. Comparable values of 1:7, 1:8, 1:21 and 1:23 were reported by Deutsch et al. (2007)[25], in their analysis of Super 12 rugby. High intensity duration efforts for the forwards mainly involved static exertions and sprinting for the backline. They attributed the greater work by the forwards to longer static exertion efforts. It was therefore recommended that positional demands be taken into account when prescribing training programs and testing players.[21]

A study utilising the same positional groupings used by Duthie et al. (2005)[21] analysed the movements of 20 players from the Queensland rugby union team during the 2008 and 2009 seasons. The authors found that players spent less time standing and jogging, and greater relative time in high-intensity activities than the Super 12 players studied in the 2000 and 2001 season.[26] The maximum distance covered by positional group was: front row forwards (5139m), back row forwards (5422m), inside backline players (6389m) and outside backline players (5489m). Back row forwards spent the greatest amount of time in high-intensity exercise (1190s) followed by the front row forwards (1015s), the inside backline players (876s) and the outside backline players (570s). W:R ratios of 1:4, 1:4, 1:5 and 1:6 were reported for the front row, back row, inside and outside backline players respectively. When these ratios are compared to the previous W:R ratio work done by Duthie et al. (2003)[1] and Deutch et al. (2007)[2] it becomes clear that the intensity with which rugby union is played has increased over the years. Average distances covered in individual sprint efforts were: front row forwards (16m), back row forwards (14m), inside backline players (17m) and outside backline players (18m).

Research at under-19 elite level utilised global positioning system (GPS) tracking devices to assess movement demands and impacts on players.[27] The average distance covered over the five matches for each positional group was: front row forwards (4672 ± 215m), back row forwards (4302.1 ± 529.8m), inside backline players (4307.8 ± 214m) and outside backline players (4597.9 ± 210.2m). Maximum speeds reached did not differ significantly between positional groups. Props and locks spent more time jogging (26.11 ± 3.77%), compared to outside backline players (15.6 ± 2.3%). The outside backline players spent more time sprinting (1.11 ± 1.18%) than inside backline players (0.72 ± 0.30%) or the front and back row forwards (0.48 ± 0.23% and 48 ± 0.13%) respectively. Analysis of impact, measured in G-force (g), showed that the back row forwards had the highest total amounts of impacts during the games and that the inside backline players experienced the highest amount of severe impacts (>10g)(12.6±3.18) per match. Unfortunately the technology used in this study registered activities like the scrum as low impact collisions where it could be seen as high static exertion activities. The authors acknowledge this and state that combining the GPS devices with time-motion analysis could resolve this issue. This study again highlights the intermittent nature of rugby union and the different demands on positional groups.

Another study at under-19 elite level found different results with regards to distance traveled.[28] In this study outside backline players (5750 ± 405m) traveled further than front row forwards (4400 ± 398m). Inside backline players and back row forwards traveled 5530 ± 337m and 4080 ± 363m respectively. This study does however agree with previous findings that rugby union forwards spend significantly more time in static high exertion than backline players. Heart rate (HR) data indicated that props and locks (58.4%) and back row forwards (56.2%) spent significantly more time in high exertion (85-95% HR_{max}) than inside- (40.5%) and outside backline players (33.9%)($p < 0.001$). Inside- and outside backline players like in previous studies spent more time sprinting than front row and back row forwards.[28]

Inconsistency in distance traveled between positional groups across studies could be due to such factors as different playing style, level of play, weather conditions or analysis method i.e. time motion analysis as opposed to GPS tracking. Except for this observation it is clear that rugby union is a high intensity intermittent type game. Forwards spend more time in high intensity type activities than backline players mainly due to their participation in more static activities like the scrum, lineout, rucks and mauls. Recovery time after exertion has gone down as the game has evolved over the years and consequently increased the physical demands on players. It could also be argued that certain rule changes aimed at making the game more attractive for the viewing public contributed to this. Since the sport turned professional in 1995 monetary incentives has increased for all parties involved.[29] Players needed to be better conditioned for a game that required far more from them.

Further evidence for the argument of increasing physical demand and game intensity comes from a statistical analysis done by the IRB (International Rugby Board)[30] after the 2011 Rugby World Cup (RWC). They compared the 1995 RWC, when the sport turned professional, to the 2011 RWC and found significant differences in several game parameters. The time the ball was in play increased by 33%, passes from 179 per game to 263 (an increase of almost 50%) and rucks/mauls 69 to 162. Kicks have gone down from 75 to 41 per game, scrums 27 to 17 and lineouts 37 to 24.

A similar analysis by the IRB in 2003 comparing an international match played in the 1970's with one played in 2000 further eludes to the evolution of the game. The time the ball was in play increased from 24 min 34 sec (31%) to 34 minutes 17 seconds (43%) and cycles over 30 sec from 3 (7%) to 27 (40%). Stoppages decreased from 151 to 68, lineouts from 71 to 18 and scrums from 39 to 14.[31]

An analysis of the Bledisloe Cup matches from 1995 to 2004 between Australia and New Zealand found similar results to the two analyses done by the IRB.[29] Number of scrums, lineouts and kicks went down from 33 ± 7 to 26 ± 7, 39 ± 6 to 28 ± 10 and 66 ± 8 to 46 ± 13 respectively. Rucks, mauls, passes and tackles all went up from 72 ± 18 to 178 ± 27, 33 ± 8 to 22 ± 9, 204 ± 30 to 247 ± 32 and 160 ± 32 to 270 ± 25, respectively. This illustrates the change in the game.

A 2006 survey of the 6 Nations tournament covered 8 games.[17] The average ball in play time was 39% of the total game time. Of this 39% an average of 18 scrums, 34 lineouts, 157 tackles/rucks (rucks where 89% of the tackles were made) took place. Twenty percent of ball possession was kicked.

The game has therefore evolved, for example the loose forwards have become more mobile and the halves more skilled in play in their position and responsible for decision-making.[32] As the tasks of the positional groups changed so did their anthropometric, physical and motor characteristics. Based on ergogenesis and work to rest ratio research physical and anthropometric differences between positions as a function of exercise prescription and the task specific requirements of a position could develop.

2.2 PATELLOFEMORAL AND TIBIOFEMORAL JOINT ANATOMY AND BIOMECHANICS

Stability to the patellofemoral joint (PFJ) is provided mainly by an extensive ligamentous capsule and large muscles crossing the joint.[33] The muscles can be categorised into anterior thigh muscles collectively known as the quadriceps femoris muscles (rectus femoris, vastus lateralis, vastus intermedius, vastus medialis) and the posterior thigh muscles collectively known as the hamstring muscles (semimembranosus, semitendinosus, biceps femoris). Research aimed at investigating relationships between antagonistic muscle groups have been done, with the PFJ receiving specific attention in the past.[34, 35] Through various types of muscular contraction (isometric, concentric, eccentric) the quadriceps and hamstring groups are responsible for multiple functions at the knee.[33] Concentric muscle contraction is defined as a shortening contraction in which a muscle's attachments are drawn toward one another as the muscle contracts and overcomes an external resistance.[3] An eccentric contraction is defined as contraction whilst there is a lengthening action drawing muscle attachments away from one another through an external resistance. Concentric contraction of the quadriceps musculature causes knee extension and eccentric contraction controls knee flexion. Whilst concentric contraction of the hamstrings musculature causes knee flexion and eccentric contraction controls knee extension.

Technically the patellofemoral, tibiofemoral and tibiofibular joints combine to form the knee joint. The tibiofemoral joint functions as a hinge and is therefore classified as a ginglymus joint.[36] It allows for flexion and extension movement, without abduction or adduction while internal and external rotation during flexion is possible. It is associated with the collateral ligaments, cruciate ligaments and the menisci.[37] The medial (MCL) and lateral (LCL) collateral ligaments prevent valgus (medial opening) and varus (lateral opening) of the tibiofemoral joint respectively.[37] These ligaments are referred to as static stabilisers of the knee joint.[38] The anterior cruciate ligament (ACL) extends from the anterior intercondylar area of the tibia to the posterior part of the medial surface of the lateral condyle of the femur.[3] It prevents forward movement of the tibia on the femur. The posterior cruciate ligament (PCL) is a strong fibrous cord that extends from the posterior intercondylar area of the tibia to the anterior part of the lateral surface of the medial condyle of the femur.[3] The PCL prevents anterior movement of the femur on the tibia. The meniscus of the knee is a crescent-shaped fibro-cartilaginous structure responsible for buffering forces placed through the knee joint.[3, 37] It also increases the concavity of the tibia thereby assisting in stabilising the joint.

Due to the gliding of the patella on the femoral condyles the patellofemoral joint is classified as an arthrodial joint. The patella augments the torque potential of the quadriceps by displacing the quadriceps tendon anteriorly, thereby increasing the internal motion arm of the knee extensor mechanism.[33] Medial and lateral retinacula and the extensor mechanism tendons (quadriceps and patellar tendons) assist the joint with stability.[37] The tibiofibular joint is a non-weight- bearing bone that splints the lateral side of the tibia and assists with maintaining the alignment of the knee.[33]

Dynamic stabilisation of the knee joint is provided by the muscles crossing the joint. These muscles can be divided into anterior, posterior, lateral and medial compartments.

2.2.1 Anterior Compartment

The quadriceps group forms a major part of the anterior compartment and includes the rectus femoris, vastus medialis, vastus lateralis and vastus intermedialis.[38] The rectus femoris originates on the anterior inferior iliac spine of the ilium and superior margin of the acetabulum and inserts on the superior aspect of the patella and the patellar tendon to the tibial tuberosity.[36]

The vastus lateralis originates on the intertrochanteric line, anterior and inferior borders of the greater trochanter, gluteal tuberosity, and upper half of the linea aspera and the entire lateral intermuscular septum.[36] It inserts on the lateral border of the patella and patellar tendon to the tibial tuberosity. Vastus intermedius originates on the upper two-thirds of the anterior surface of the femur and inserts on the upper border of the patella and the patellar tendon to the tibial tuberosity.[36] Vastus medialis originates on the whole length of the linea aspera and the medial condyloid ridge and inserts on the medial half of the upper border of the patella and patellar tendon to the tibial tuberosity.[36]

The three vastus muscles together with rectus femoris serve to extend the knee joint.[33] Additionally the rectus femoris also flexes the hip joint.[36]

The quadriceps group plays an important role in sporting activity. Jumping ability is correlated with strong quadriceps. The group also has a function as an eccentric decelerator for example, when it is necessary to reduce speed when changing direction or when landing from a jump.[36]

2.2.2 Posterior Compartment

The posterior compartment or hamstring group include the biceps femoris, semimembranosus, and semitendinosis. Hamstring muscles originate on the ischial tuberosity.[36] Semitendinosus and semimembranosus insert on the anteromedial and posteromedial side of the tibia, respectively. The long head of the biceps femoris inserts on the lateral tibial condyle and head of the fibula. The short head inserts on the linea aspera of the femur.[33]

The hamstring muscle group performs knee flexion. Hip extension is also performed by the hamstring muscle group with the exception of the short head of the biceps femoris.[36] Additionally semimembranosus and semitendinosis also internally rotate the knee joint.[33] Biceps femoris on the other hand externally rotates the knee joint.[36]

The hamstrings group has an important role as accelerator during running through its function as a hip extensor. Because of this role it is susceptible to strain especially if the gluteus maximus, another powerful hip extensor, is not contributing effectively.[36]

The gastrocnemius is usually seen as a plantar flexor of the ankle joint but the muscle can also contribute to knee flexion.[33] The muscle's medial head originates on the posterior surface of the medial femoral condyle and the lateral head on the posterior surface of the lateral femoral condyle.[36] The two heads share a common insertion point on the calcaneus via the achilles tendon.[33]

2.2.3 Lateral Compartment

The lateral compartment contains the tensor fasciae latae and gluteus medius.[38] The gluteus medius originates on the lateral surface of the ilium just below the crest and inserts on the posterior and medial surfaces of the greater trochanter of the femur.[36] The gluteus medius abducts the hip and its posterior fibers externally rotate the hip as the hip abducts while the anterior fibers internally rotates the hip.[33]

The tensor fascia latae originates on the anterior crest and surface of the ilium just below the crest and inserts one-fourth of the way down the thigh into the iliotibial tract, which in turn inserts onto Gerdy's tubercle of the anterolateral tibial condyle.[36] It abducts and flexes the hip and has a tendency to internally rotate the hip during flexion.[33]

2.2.4 Medial Compartment

The medial compartment contains the hip adductors (adductor brevis, longus and magnus).[38] The adductor brevis originates on the inferior pubic ramus just below the origin of the longus and inserts on the lower two-thirds of the pectineal line of the femur and the upper half of the medial lip of the linea aspera.[36] It is responsible for hip adduction and external rotation (during adduction).[33]

Adductor longus originates on the anterior pubis just below its crest and inserts on the middle third of the linea aspera.[36] It adducts the hip and assists with flexion of the hip.[33]
Adductor magnus originates on the edge of the entire ramus of the pubis and the ischium and ischial tuberosity and inserts on the whole length of the linea aspera, inner condyloid ridge, and adductor tubercle.[36] It adducts and externally rotates the hip (during adduction).[33]

The muscles mentioned above, amongst others, all function together in a closed kinetic chain to produce locomotion. Certain muscles have dual actions, for example the hamstring muscles that are responsible for both flexion at the knee joint and extension at the hip joint or the rectus femoris that in addition to knee extension also flex the hip.[33, 36]

2.3 MUSCULAR STRENGTH TESTING

Muscular strength is defined as a muscle's ability to exert force whereas muscular endurance is defined as the muscle's ability to sustain contraction or perform repeated contractions.[37] Various methods are utilised to evaluate muscular strength. These include isometric, isotonic and isokinetic techniques.

Muscle contractions can be classified as isotonic, isometric or isokinetic. The term isotonic ("iso" meaning same; "tonic" meaning tension) implies that the force created by a muscle throughout its range of motion is constant.[39] The term is however a misnomer because it is practically impossible to attain this within the human musculoskeletal system.[40] In reality the force, or tension, within a contracting muscle does vary throughout the range of motion even if the resistance is constant. This variance is due to the change in muscle length and angle of pull as the bony lever is moved. This in turn creates a unique strength curve for each muscle group.[39]

Dynamic contraction is therefore suggested as a more accurate term than isotonic. Dynamic contractions can be subdivided into concentric and eccentric contractions. Concentric muscle contractions occur when there is a shortening of a muscle while it is generating tension and an eccentric contraction when the muscle is lengthening under tension.[3] Concentric contractions are responsible for acceleration during movement whereas eccentric contraction assist in decelerating movement.[39] For example, the quadriceps group concentrically extends the knee while its antagonist the hamstrings simultaneously eccentrically decelerates the joint on the opposite side.

Eccentric contractions are associated with delayed onset muscle soreness (DOMS).[41] High load eccentric exercise can damage myofibrils and connective tissue components leading to the characteristic soreness. Human muscle tissue is capable of generating greater tension at a lower energy cost during eccentric contraction as opposed to concentric contraction.[39] The decelerating function of eccentric muscle contraction is of particular interest when investigating orthopedic injury. For example, eccentric activation of the hamstring muscle during knee extension reduces load on the anterior cruciate ligament.[5] It has been suggested that measurement of eccentric muscle performance be included in a thorough rehabilitation program with the purpose of correcting imbalances that could predispose athletes to injuries.[42]

Isotonic techniques allows for the measurement of both concentric and eccentric strength, permits simultaneous examination of multiple joints, quantifies measurement of strength and can be utilised to measure strength in a closed chain weight bearing position.[43] Disadvantages of this technique includes that maximal strength examination can only be done at the weakest point in the ROM, other parameters of muscle performance for example torque, work or power cannot be quantified and it allows stronger muscles to compensate for weaker muscles during multi-joint tests. The 1-repetition maximum (1RM) and 10RM tests are examples of isotonic tests.[43]

When there is tension in a muscle but no change in length an isometric contraction occurs. In this type of contraction the contractile force is equal to the resistive force.[44] Isometric examination techniques are useful when joint motion is contraindicated and requires minimal or no equipment. It does however lack objectivity and only measures strength at a specific joint position. Examples include grip and pinch dynamometers, hand held dynamometers and cable tensiometers.[43]

During normal human movement the velocity throughout a limb's range of motion will vary. Through the use of specialised equipment it is possible to keep the velocity of a contracting muscle constant.[39] This type of muscle contraction is known as isokinetic. Isokinetic testing is discussed in detail below. Its main advantage is that it evaluates a muscle's maximal capabilities throughout the entire ROM.[43]

2.4 ISOKINETICS

Isokinetic movement can be defined as movement that occurs at a constant angular velocity with accommodating resistance.[45] Movement will take place at a constant speed regardless the amount of effort exerted, throughout the full range of motion (ROM). Isokinetic dynamometry made the objective quantification of hamstring to quadriceps muscle group ratios possible.[46] Therefore, muscle balance around the PFJ can be expressed as a ratio.

Traditionally the reciprocal ratio, the hamstring concentric value divided by the quadriceps concentric value ($H_{concentric}/Q_{concentric}$ x 100 = %), was analysed as an indication of normal balance around the knee joint and in injury prevention strategy.[4] Balanced coactivation of these groups is necessary to maintain joint stability and movement efficiency.[2] The reciprocal ratio however does not include an eccentric value in the formula. A more functional ratio based on both eccentric and concentric contraction is suggested.[4, 11] This ratio takes into account what is happening eccentrically in the hamstring group while the quadriceps group is responsible for concentrically extending the knee. When extending the knee the quadriceps and hamstring groups have to interact. The quadriceps group has to concentrically contract while its antagonist the hamstring group contracts eccentrically to control and slow the movement down. This means that the eccentric hamstring value can be divided by the concentric quadriceps value and yields a new formula ($H_{eccentric}/Q_{concentric}$ x 100 = %).[4] The more functional dynamic control ratio (DCR) being the result. It has been suggested that this ratio be investigated with regards to functional tasks specific to a sport (for example: vertical jump for rugby players).[47]

Testing is done by means of specialised equipment called isokinetic dynamometers. The resistance is provided by the lever arm of a specialised machine and the subject's effort recorded via an integrated computer system. Modern commercially available dynamometers including the Biodex System 3™, 4, Cybex NORM™ and Kin-Kom™ have both concentric and eccentric muscle testing and training capabilities.

2.4.1 Advantages and Disadvantages of Isokinetic devices

Advantages of isokinetic devices include: maximal muscle resistance is achieved throughout the range of motion, maximal and submaximal muscle output can be controlled, permitting exercise without increasing injury or to increase stress to the muscle as healing progresses, diagonal patterns can be performed to produce a more functional form of movement, which can assist in relearning functional movement patterns, the machine can be used for testing and exercise, the results are measurable and reproducible, immediate visual feedback to the patient and clinician, progress can be accurately monitored, speed can be varied, and exercises performed to improve strength, muscle endurance, coordination and speed of movement.[35, 43] Disadvantages include: high cost, exercise is primarily open kinetic chain therefore functional applications are minimal, consistency with regards to set-up is critical, set-up of machine can be time consuming, complicated and impractical, machines cannot achieve speeds attained in functional activities.

The ability to predict or relate isokinetic variables to athletic performance could be useful and in theory is possible. This relationship has previously been investigated. For example, a significant relationship exists between concentric isokinetic knee strength and anaerobic as well as jumping ability.[48]

Anderson et al. (1991)[49] found that the best predictor of 40-yard dash time was peak isokinetic concentric hamstring force at 60°/sec. The mean isokinetic eccentric hamstring force at 90°/sec was the best predictor of performance on an agility test. It was concluded that although isokinetic eccentric quadriceps and hamstring forces were no better of a predictor of athletic performance than muscle forces assessed by other methods, they may be more predictive of specific components of performance.[49]

Similar research found a significant correlation between concentric isokinetic knee open and closed chain strength and functional performance amongst varsity athletes. Isokinetic knee extension, leg press and single leg squat strength significantly correlated to single leg hop, vertical jump and a speed/agility test.[50]

A group of football players from 3 different codes (soccer, rugby league and rugby union) have been investigated for repeated sprint ability and its relationship to isokinetic knee strength.[50] Single sprint performance correlated with peak extensor and flexor torque, the strongest relationship however was found between knee extensor torque at 240°/sec and the initial acceleration phase of single sprint performance. The data suggested that factors other than strength contribute to repeated sprint ability. The action of sprinting involves multiple joints functioning as part of the kinetic chain, therefore isolating a specific muscle group e.g. the knee extensors and flexors does not take into account the relative contribution of other joints' muscles e.g. the hip extensors and flexors in sprinting action.[38]

A study comparing isokinetic dynamometry and functional field tests found no significant relationship between ratios in a group of college level athletes when comparing the two methods.[52] The authors state that although field tests are capable of detecting imbalances the magnitude could not be accurately determined. Field tests unlike isokinetic dynamometry, which isolates muscle groups, evaluates functional capacity more accurately because multiple joints are involved.[52]

Clearly advantages and disadvantages exist with the utilisation of isokinetic equipment as a testing modality. The ability to objectively quantify strength in muscle groups is a major advantage specifically within the research setting. The software collects and stores data in real time which enables the clinician to compare data points between tests.[53] Measurement parameters extracted from the data include coefficient of variance, bilateral percent deficit, peak torque (PT), peak torque/body weight (PT/BW), time to peak torque, angle of peak torque, torque at thirty degrees (30˚), torque at 0.2 seconds, max repetition total work, max work repetition number, work to body weight ratio, total work, work first 1/3 and last 1/3, work fatigue, average power, acceleration time, deceleration time, range of motion, agonist to antagonist ratio and gravity effect torque.[53]

Biodex Medical Systems, Inc. defines the above mentioned measurement parameters in their manual for the Biodex System 3™ isokinetic dynamometer. The following definitions were adapted from the manual and supplemented with additional resources:

Gravity effect torque (GET) is necessary for standardisation between subjects and tests.[53] It is used to eliminate the additional torque produced by the weight of the limb and dynamometer lever arm and therefore allows for an accurate measurement of true torque. Additional force is required by a limb to accelerate while working against gravity which could lead to a reduction in the amount of torque recorded.[43] The opposite is true when a limb accelerates with gravitational assistance. Therefore the GET should be added to torque when the limb works against gravity for example, when testing the quadriceps during knee extension and subtracted when the limb is working with gravity for example during testing of the hamstrings during flexion. Neglecting to account for GET could confound reciprocal muscle group ratios and undermine the accuracy of the test.[43]

Before interpreting test data it is important to determine if the test is valid. The coefficient of variance, which determines the reproducibility of the test based on the amount of variation between repetitions, is used for this purpose.[53] Acceptable coefficient of variance for large muscle groups should be ≤15% and ≤20% for small muscle groups. The knee, hip, shoulder, back and elbow joints are defined as large muscle groups because they produce primary movements in a large range of motion. Small muscle groups include the wrist and ankle.[53]

By comparing the involved to the uninvolved or dominant to non-dominant limb bilateral deficits in muscular performance can be compared.[43] A difference of between 1 to 10% is considered acceptable.[53] The percent deficit is calculated using the following formula: Bilateral deficit = (PT of dominant limb – PT of non-dominant limb)/PT of dominant limb x 100.[35]

Peak torque is synonymous with maximal strength and is defined as the highest muscular force output at any moment during a repetition.[35, 53] It is an absolute value that does not consider the subject’s body weight. It is therefore difficult to compare strength between individuals with different body weights. For example, if two subjects with significantly different body weights are able to produce the same amount of peak torque the subject who weighs less would be relatively stronger.

As previously mentioned isokinetic dynamometers have the capability of testing and recording the amount of force generated by the muscular contraction of antagonistic groups. The computer software then translates it into torque expressed in Newton-meters (Nm).[35] Use of the values of flexion and extension through the following equation, flexion/extension x 100 = %, allows for the computation of a ratio value. The flexion value being the force recorded for the hamstring muscles and extension the force recorded for the quadriceps muscles in torque expressed in Nm. Quantification of antagonistic activity is therefore possible.[4]

Absolute strength values can be normalised according to a subject's weight and consequently produces a peak torque to body weight value.[35] This value is more applicable to functional activity and enables the comparison of subjects with different body size.

A truly maximal effort by a subject will result in more work being produced during the first 1/3 of the repetitions than during the last 1/3 of the repetitions.[53] If the work completed in the last 1/3 of repetitions is higher than in the first 1/3 and the coefficient of variance (CV) is too high this will compromise the validity of the test. It could therefore indicate poor effort by the subject due to pain, lack of effort or poor instruction by the tester. As endurance increases the work done in the last 1/3 should increase.[53]

Range of motion (ROM) indicates the greatest ROM the limb achieved during the test and allows analysis of the test curve in relation to ROM.[53] The achieved ROM might not be the same as the actual ROM achieved during the test.

The agonist to antagonist ratio is represented by the following formula: Reciprocal muscle group ratio (%) = Peak torque (agonist)/Peak torque (antagonist) x 100.[35] Antagonistic muscles provide dynamic joint stability and imbalances between them could predispose a joint to injury.[1, 2]

2.4.2 Position Specific Isokinetics

It has previously been determined that isokinetic hamstring to quadriceps peak torque ratio can be influenced by sporting modality, gender, and angular velocity.[54, 55] The idea that these differences could in part be due to the different functional requirements imposed by a specific sporting modality is supported by research.[56]

Hamstring to quadriceps ratio was found to be significantly higher on the dominant leg at 60˚/sec in college level athletes participating in field sports opposed to those competing in courts sports.[57] Similar research comparing football and volleyball also found significantly lower hamstring to quadriceps ratios for court activity, as opposed to field activity.[58] The study could however not find a difference in hamstring to quadriceps ratios when comparing different positions within the sport. Only concentric testing was conducted and eccentric isokinetic testing could have yielded different results.[58]

A study comparing the hamstrings to quadriceps ratio of football players with sedentary individuals found no significant difference when comparing the conventional Hcon/Qcon ratio between the groups.[59] When the DCR was taken into account the football players presented with a significantly lower ratio of 0.80 at 60˚/sec to the 0.90 of sedentary subjects.[59]

If the hamstrings to quadriceps ratios vary between sporting modalities as a result of functional demands it is reasonable to assume that differences could exist between positions within the same sport if functional tasks differ significantly. Differences in hamstrings and quadriceps isokinetic strength parameters according to playing position have previously been reported.[60, 61]

Research into football found that isokinetic knee parameters vary as a function of playing position (forwards, midfielders and defenders).[60] Similarly peak torque at 60°/sec was used to differentiate between athletic specialities within a group of high level track and field athletes.[61] The reciprocal ratio could not discriminate between speciality and it was suggested that it be discontinued for this use. Including eccentric values through the DCR could yield different results. The above mentioned differences in positional demands could therefore, theoretically, also possibly cause differences in the muscle group ratios in rugby players specifically in the lower limb and patellofemoral joint (PFJ).

2.4.3 Peak Torque and DCR in rugby

Peak torque and mean power have previously been investigated in the rugby playing population. These variables were found to be higher in forwards than in backline players.[62] In this study, however, backline players presented with higher relative strength throughout the isokinetic test.[62]

A group of elite South-African rugby players were tested both concentrically and eccentrically.[63] Results indicated that the concentric (Hcon/Qcon) and eccentric (Hecc/Qecc) hamstring to quadriceps ratios at a slow velocity of 60˚/sec were similar (63.67% to 66.53%). The DCR of 80.5% however, was found to be significantly higher compared to the conventional ratio. This means that the functional ratio was higher than the conventional ratio. The authors suggest that calculating the additional functional ratio could be useful in the prevention of injuries and that further research should focus on establishing norms for different positions.

The DCR in the previous study is similar to that found by another South-African study.[64] In this study the DCR was 0.79 ± 0.16 and 0.77 ± 0.14 on the right and left side respectively. There was no differentiating between playing position or functional tasks.[64] Subjects with ratios close to 1:1 tended to have small bilateral eccentric and concentric differences.

Similar research on rugby players found a DCR of 0.66 ± 0.09 at 60˚/sec and 0.86 ± 0.23 at 180˚/sec respectively.[65] No differentiation was made between forwards and backline plyers. Eccentric hamstring peak torque strength at 60˚/sec was 179Nm ± 45 and 272Nm ± 49 for concentric quadriceps. The study highlighted the effect that hip position has on strength values obtained from isokinetic testing. The authors suggest utilising a hip angle closer to 80° and including eccentric testing which better approximates functional movement.

Neither of these studies differentiated between forwards and backline players. Comparing the forwards to the backline players could in theory yield different results for the two groups.

A study comparing rugby union and rugby league found no significant difference ($p > 0.05$) in the concentric hamstring to quadriceps ratio of rugby union forwards compared to backline players on either the dominant (0.66 ± 0.09 vs. 0.64 ± 0.10) or the non-dominant side (0.68 ± 0.10 vs. 0.64 ± 0.08). Forwards produced significantly greater peak torque during knee flexion on the dominant (184 ± 27Nm vs. 157 ± 27Nm) and non-dominant limb (180 ± 20Nm vs. 156 ± 27Nm) compared to backline players. No significant difference were found in knee extension peak torque on the dominant (281 ± 45Nm vs. 244 ± 29Nm) and non-dominant limb (268 ± 44Nm vs. 247 ± 38Nm) between forwards and backline players. If eccentric action was to be taken into account via the DCR comparing the forward and backline players in rugby union could theoretically produce differences in hamstring to quadriceps ratios.[66]

A study comparing football, rugby league and rugby union found a concentric knee extension peak torque of 230 ± 34.9Nm at 60˚/sec for rugby union players.[51] Rugby league and football had strength values of 196.8 ± 19.6Nm and 199.9 ± 22.9Nm respectively. No significant difference was found in peak torque between the three groups. Although both limbs were tested, only the trail that produced the greatest peak torque value was analysed.

None of the above mentioned studies have strict exclusion criteria that prohibit subjects with major previous knee injuries from participating in their studies. Major knee articulation trauma could affect isokinetic strength values even when a player has made a successful return to play.[8]

2.4.4 Effect of Injury on Muscle Balance around the Knee Joint

After injury the agonist-antagonist muscle balance of the knee is disturbed.[8] A group of 28 elite football players (23 ± 3.3years; 74 ± 7.5kg; 178 ± 6.5cm) was tested concentrically and eccentrically at 60˚/sec.[12] Eleven of these players suffered moderate or major hamstring injuries in the preceding two years. They were compared to 17 players without previous hamstring injuries. Players actively participating in football with eccentric hamstring-to-concentric quadriceps ratio slower than 0.6 was identified as having previously sustained hamstring injury (probability: 77.5%). With a recurrence rate of 30% (three out of 10) and new injury rate of 31% (five out of 16)($p > 0.05$) this ratio could not predict a recurrence or future injury.[12]

Persistent strength deficits could cause recurrent hamstring injuries and discomfort.[13] A group of twenty-six male athletes (mean age, 25 ± 8 years; height, 180 ± 7cm; weight, 74 ± 7kg) actively participating in either football (n = 14), track and field (n = 7), or martial arts (n = 5) underwent concentric and eccentric isokinetic testing. Results indicated a significant ($p < 0.05$) reduction in concentric and eccentric muscular strength in the injured hamstrings. The eccentric hamstrings-to-concentric quadriceps ratio was significantly reduced (0.73 ± 0.24) when compared to the uninjured limb (0.90 ± 0.16). After following an individualised rehabilitation program focusing on eccentric strengthening to correct imbalances players reported a decrease in symptoms.[13]

The DCR could also play a role in the prevention of hamstring injuries.[14] In a group of 462 football players, 246 (53%) presented with normal isokinetic profiles, and 216 (47%) with imbalances. The DCR was found to be significantly reduced in 187 of 216 (87%) players with imbalances. Players with no preseason imbalances had an injury frequency of 4.1% as opposed to a significantly ($p < 0.05$) higher rate of 16.5% in players with untreated imbalances. Correction of imbalances reduced injury frequency to 5.7%.[14]

Research comparing the strength profile of patients with partial ACL tears (males aged 31 ± 5.09 years) to asymptomatic subjects (males aged 31 ± 7.8 years) found no significant difference ($p > 0.05$)(47.7% - 52.2% at 60°/sec) in H/Q ratio between groups.[10] No eccentric testing was conducted. It was concluded that one year post surgery hamstring strength was significantly less than quadriceps strength and that angle to peak moment offers information for determining of individual performance in post ACL injury patients.

Other studies have found no difference comparing only concentric hamstring to quadriceps ratios but when eccentric action was included significant differences were found.[11, 12] Dvir et al. (1989)[1] found that patients with ACL insufficiency (4 females and 31 males between 19 to 41 years, mean = 22.1 years) showed significant differences ($p < 0.05$) in H/Q ratio when eccentric contraction of the hamstring was included in the ratio. The DCR of the healthy knee (0.67 ± 0.18) compared to the injured knee (0.76 ± 0.21) was significantly different ($p < 0.05$). The conventional ratio without eccentric consideration on the other hand showed no significant difference between the healthy knee (0.52 ± 0.16) and injured knee (0.53 ± 0.18).[11]

CHAPTER 3: RESEARCH DESIGN AND METHODOLOGY

3.1 RESEARCH DESIGN

This study employed a cross-sectional study design comparing the DCR of forwards and backline rugby union players.

3.2 SITE OF STUDY

The study was conducted at the Wits Centre for Exercise Science and Sports Medicine, Johannesburg and the Institute for Biokinetics, Potchefstroom.

3.3 STUDY POPULATION

3.3.1 Sampling

A sample of convenience was selected from rugby union players from the WITS, NWU and UJ rugby clubs' first team squads, willing to participate, were included in this study. All these teams compete at Varsity Cup level.

3.3.2 Recruitment of Subjects

The management of the Universities of the Witwatersrand (WITS), North West University Potchefstroom campus (NWU) and Johannesburg (UJ) rugby clubs were approached and informed of the study and its possible benefits. They were presented with a letter of introduction which described the reasons for the study and the background of the researcher (Appendix A). After permission was granted by management, players received a letter detailing the study and inviting them to participate (Appendix B). Those willing to participate were screened for eligibility. All eligible subjects were informed of the requirements of the research project in terms of participation in isokinetic measurements. Informed consent was obtained from all subjects before testing (Appendix C). Testing was conducted at the WITS Centre for Exercise Science and Sports Medicine, Parktown, Johannesburg and the NWU Institute for Biokinetics, Potchefstroom.

3.3.3 Inclusion and Exclusion Criteria

Only players with no previous or current knee articulation trauma were included in the study. Players with current or recent (within the last 6 months) thigh or hamstring injuries were excluded.

3.4 ETHICAL CONSIDERATIONS

Ethical clearance (certificate number: M110343) to perform isokinetic testing on club rugby players from WITS, UJ and NWU was granted by the Human Research Ethical Committee of the University of the Witwatersrand (Appendix D), Johannesburg. Permission to perform testing on subjects from the respective clubs was also obtained.

3.5 TESTING PROCEDURES, MEASURING TOOLS AND INSTRUMENTS

3.5.1 Anthropometry

Anthropometric data was collected before testing commenced (Appendix E). This included age, stature in centimeters (cm) and body weight in kilograms (kg). Dominant limb and playing position was also recorded.

3.5.2 Injury History

An injury history form with the subject's patellofemoral joint injury history was completed (Appendix F). For the purpose of this study the consensus statement definition of an injury by Fuller et al. (2007)[67] was used. It states that an injury in rugby union can be defined as; *"Any physical complaint, which was caused by a transfer of energy that exceeded the body's ability to maintain its structural and/or functional integrity, that was sustained by a player during a rugby match or rugby training, irrespective of the need for medical attention or time-loss from rugby activities. An injury that results in a player receiving medical attention is referred to as a 'medical attention' injury and an injury that results in a player being unable to take full part in future rugby training or match play as a 'time-loss' injury."*

3.5.3 Isokinetic Testing

The researcher, a qualified biokineticist who had received training on the Biodex for testing the hamstring and quadriceps muscles and regularly uses this equipment in clinical practice, conducted testing and data collection on three separate occasions. Participants recruited from WITS and UJ were tested towards the end of the season (August, September) whilst participants from NWU were tested pre-season (January, February). Prior to conducting the test, participants completed a ten minute warm-up on a cycle ergometer. During the warm-up the subjects were informed of the testing procedure. It was also stressed that the test was a maximal muscle strength test and that they were required to generate 100% muscle strength throughout the test.

A Biodex System 3 Isokinetic Dynamometer™ (Shirley, New York) was used to test concentric and eccentric hamstring and quadriceps muscle strength. The Biodex System 3 has been found to be valid and reliable for strength testing.[68] A study comparing the Biodex and Lido dynamometers found the Biodex to be highly reliable.[69]

3.5.4 Positioning and Stabilisation of Participants

Positioning and stabilisation of the participants took place in the seated position with the chair reclined at 85 degrees and the thigh supported by the seat. This allows testing along a range of motion (ROM) which extends from 75 to 90 degrees of flexion, towards maximal allowable extension.[35] The thigh of the tested leg, pelvis and thorax was stabilised using the stabilisation belts of the Biodex. Subjects were instructed to cross their arms across their chest area and not to grasp any handles. Alignment of biological and mechanical axes was done by aligning the lateral femoral epicondyle of the side being tested with the mechanical rotation axis of the dynamometer's lever arm. The resistance pad was positioned at a level immediately superior to the medial maleolus. Range of motion (ROM) was set by taking the subject's limb through full flexion and extension, after which the anatomical reference position was set at 0 degrees (full extension).

3.5.5 Gravity Correction

After the reference position was set a gravity effect torque correction was performed by weighing the limb that was secured to the lever arm. For this procedure the lever arm was set at 30 degrees of knee flexion.

3.5.6 Testing Procedure

The concentric hamstrings and quadriceps strength of the dominant limb was tested first at a velocity of 60°/sec through the athlete's full range of motion after which the non-dominant limb was tested using the same protocol. The eccentric hamstring and quadriceps strength was tested next using the reactive eccentric function of the dynamometer also starting with the dominant limb at 60°/sec through the athlete's full range of motion.

Before initiation of the test each participant was given three trial repetitions of eccentric and concentric isokinetic contractions. Participants were again reminded to work maximally. Five maximum effort contractions were then recorded. They received verbal encouragement.

After completion of both concentric and eccentric testing participants underwent a standard cool-down that included five minutes of cycle ergometry followed by stretching of the quadriceps, hamstring and calf musculature. Test results were saved and printed for statistical analysis. Results were also recorded on a separate data sheet (Appendix G).

3.5.7 Risks and Benefits

Isokinetic testing is a safe method of loading the musculoskeletal system when performed by a trained clinician. Due to the maximal effort required subjects experienced local muscular fatigue. In addition, DOMS may be experienced 24 or 48 hours after testing. However, due to the conditioning of the athletes being tested, DOMS was expected to be mild. These risks were minimised by performing warm-up exercises prior to taking the test and performing appropriate stretching exercises thereafter to prevent soreness. If a participant became injured during the season, knowledge of the pre-injury functional hamstring to quadriceps ratio profile could benefit him by helping the clinician set rehabilitation goals.

3.6 DATA ANALYSIS

The statistical test that was applied to compare the two group means was the student's t-test for independent samples. Means, standard deviations, frequencies and percentages were computed in Microsoft Excel 2007. A significance level of $p < 0.05$ was used to indicate significant differences between groups. All data was normally distributed. A sample size of between 15 and 20 per group was required to determine if there was a statistical difference between the two groups.

The coefficient of variance is an indication of the validity of a test. For the knee joint a value $\leq 15\%$ is deemed acceptable. Only results adhering to this criteria were included, thus test results in this study are valid and reliable.[53]

CHAPTER 4: RESULTS

4.1 PARTICIPANT CHARACTERISTICS

Thirty-one club level, male, rugby players from three university clubs in the North West and Gauteng regions participated in this study. The players had a mean age of 20.9 ± 1.7 years, were 183.2 ± 7.9cm tall and weighed an average of 95.3 ± 15.4kg (Table 4.1). The forwards were found to be significantly taller (p = 0.001)(187.5 ± 8.5cm) and heavier (p = 0.000002)(106.2 ± 12.9kg) than the backline players (Height: 178.6 ± 3.8cm; Weight: 83.7 ± 7.0kg). Limb dominance was defined as the player's favoured kicking leg, with the majority (n = 28) being right dominant.

Table 4.1: Demographic information for Forward (n=16) and Backline (n=15) rugby players (n=31)

	Total (n=31)	Forwards (n=16)	Backline (n=15)	p-value
Age (years)	20.9 ± 1.7	20.5 ± 1.3	21.5 ± 2.0	0.13
Height (cm)	183.2 ± 7.9	187.5 ± 8.5 *	178.6 ± 3.8	0.001
Mass (kg)	95.3 ± 15.4	106.2 ± 12.9 #	83.7 ± 7.0	0.000002

** Forwards vs. backline: p=0.001*
 # Forwards vs. backline: p = 0.000002

4.2 DYNAMIC CONTROL RATIO

Table 4.2 shows the dynamic control ratio for the total group and comparison between forwards and backline players. No significant differences were found for the DCR between the forward and backline players on the dominant (F: 0.72 ± 0.1; B: 0.71 ± 0.07; p = 0.38) or non-dominant (F: 0.73 ± 0.09; B: 0.71 ± 0.08; p = 0.30) sides. When the DCR was compared regardless of positional grouping there were also no differences found between the dominant (0.72 ± 0.09) and non-dominant (0.72 ± 0.09)(p = 0.48) sides.

Table 4.2: Mean dynamic control ratio at 60°/sec for Forward (n=16) and Backline (n=15) rugby players

	Total (n=31)	p-value	Forwards (n=16)	Backline (n=15)	p-value
DCR dominant	0.72 ± 0.09	0.48	0.72 ± 0.1	0.71 ± 0.07	0.38
DCR non-dominant	0.72 ± 0.09		0.73 ± 0.09	0.71 ± 0.08	0.30

Abbreviations: DCR: dynamic control ratio

4.3 PEAK TORQUE

Table 4.3 shows the mean concentric and eccentric peak torque values for the total group and comparison between forwards and backline players. The forward players were found to have a greater mean peak torque compared to the backline players for the concentric quadriceps on the dominant (F: 314.5 ± 36.1Nm; B: 282.2 ± 45.9Nm; p = 0.02) and non-dominant (F: 307.3 ± 44.7Nm; B: 271.9 ± 38.4Nm; p = 0.013) sides. Similarly, the forward players were significantly stronger than the backline players when comparing eccentric hamstring peak torque on both the dominant (F: 227.9 ± 41.9Nm; B: 199.6 ± 24.6Nm; p = 0.015) and non-dominant (F: 222.5 ± 41.5Nm; B: 191.2 ± 22.8Nm; p = 0.01) sides.

When comparing the dominant and non-dominant peak torque for the eccentric hamstrings (214.23 ± 37Nm; 207.35 ± 6.79Nm; p = 0.47) and concentric quadriceps (298.88 ± 43.67Nm; 290.2 ± 44.81Nm; p = 0.44) there were no differences found between the sides.

Table 4.3: Mean concentric and eccentric quadriceps and hamstring peak torque (Nm) at 60º/sec for Forward (n=16) and Backline (n=15) rugby players

	Total (n=31)	p-value	Forwards (n=16)	Backline (n=15)	p-value
Hamstring PT CON D (Nm)	154.7 ± 29.5	0.53	161.1 ± 30.4	147.8 ± 27.8	0.11
Hamstring PT CON ND (Nm)	150.1 ± 27.2		157.2 ± 32.2	142.5 ± 18.9	0.07
Quadriceps PT CON D (Nm)	298.9 ± 43.7	0.44	314.5 ± 36.1 *	282.2 ± 45.9	0.02
Quadriceps PT CON ND (Nm)	290.2 ± 44.8		307.3 ± 44.7 #	271.9 ± 38.4	0.013
Hamstring PT ECC D (Nm)	214.2 ± 37.0	0.47	227.9 ± 41.9 @	199.6 ± 24. 6	0.015
Hamstring PT ECC ND (Nm)	207.3 ± 6.8		222.5 ± 41.5&	191.2 ± 22.8	0.01

Abbreviations: CON: concentric; ECC: eccentric; PT: peak torque; Nm: Newton meters; D: dominant; ND: non-dominant

**Forwards > backline: CON dominant quadriceps PT: p = 0.02*
 # Forward > backline: CON non-dominant quadriceps PT: p = 0.013
@ Forwards > backline: ECC dominant hamstrings PT: p = 0.015
& Forwards > backline: ECC non-dominant hamstring PT: p = 0.01

4.4 KNEE PEAK TORQUE TO BODY WEIGHT

Table 4.4 shows the peak torque to body weight (PT/BW) values for the total group and the comparisons between forwards and backline players. Relative to body weight, backline players produced a significantly greater concentric quadriceps peak torque on the dominant (p = 0.02)(337.18 ± 38.25%) and non-dominant (p = 0.04)(325.48 ± 34.44%) limbs when compared to the forwards (D: 301.14 ± 43.41%; ND: 292.11 ± 51.01%). Similarly, the backline players produced significantly greater concentric hamstring peak torque to body weight on the dominant (176 ± 22.8%)(p = 0.046) and non-dominant (170.4 ± 16%)(p = 0.047) side compared to forward players (D: 154.1 ± 34.6%; ND:150.3 ± 34.3%). There was no significant difference between forwards and backline players when comparing eccentric hamstring strength on the dominant (F: 221.53 ± 45.45%; B: 246.7 ± 30.54%; p = 0.19) and non-dominant limbs (F: 213.32 ± 48.73%; B: 230.06 ± 30.01%; p = 0.26).

There was no significant difference (p = 0.5428) in the hamstring concentric PT/BW on the dominant (164.7 ± 31.0%) and non-dominant (160.1 ± 28.5%) sides; hamstrings eccentric PT/BW on the dominant (p = 0.38)(230.4 ± 39.4%) and non-dominant (221.4 ± 41.0%) sides or concentric quadriceps PT/BW on the dominant (p = 0.37)(318.6 ± 44.3%) and non-dominant (308.3 ± 46.3%) sides for the group.

Table 4.4: Peak torque relative to body weight (%) of Forward (n=16) and Backline (n=15) rugby players at 60°/sec

	Total (n=31)	p-value	Forwards (n=16)	Backline (n=15)	p-value
Hamstrings PT/BW CON D(Nm/kg)	164.7 ± 31.0	0.54	154.1± 34.6	176 ± 22.8@	0.046
Hamstrings PT/BW CON ND (Nm/kg)	160.1 ± 28.5		150.3 ± 34.3	170.4 ± 16&	0.047
Hamstrings PT/BW ECC D(Nm/kg)	230.4 ± 39.4	0.38	221.53 ± 45.5	246.7 ± 30.5	0.19
Hamstrings PT/BW ECC ND (Nm/kg)	221.4 ± 41.0		213.32 ± 48.7	230.06 ± 30.0	0.26
Quadriceps PT/BW CON D(Nm/kg)	318.6 ± 44.3	0.37	301.14 ± 43.4	337.18 ± 38.3*	0.02
Quadriceps PT/BW CON ND (Nm/kg)	308.3 ± 46.3		292.11 ± 51.0	325.48 ± 34.4#	0.04

Abbreviations: CON: concentric; ECC; eccentric; PT/BW: peak torque to body weight; Nm/kg: Newton meters per kilogram, D: dominant; ND: non-dominant

**Backline > Forwards CON dominant quadriceps PT/BW: p = 0.02*

#Backline > Forwards CON non-dominant quadriceps PT/BW: p = 0.04

@Backline > Forwards CON dominant hamstrings PT/BW: p = 0.046

&Backline > Forwards CON non-dominant hamstrings PT/BW: p = 0.047

4.5 RECIPROCAL RATIO (H/Q RATIO)

Table 4.5 shows the reciprocal ratio (H/Q) values for the total group and the comparison between forwards and backline players. No significant differences were found for the H/Q ratio between forwards and backline players on the dominant (F: 51.0 ± 6.2%; B: 52.4 ± 5.5%; p = 0.26) and non-dominant (F: 51.2 ± 7.8%; B: 52.8 ± 6.4%; p = 0.27) sides. When the H/Q ratio is compared for the group on the dominant (51.7 ± 5.8%) and non-dominant (52.0 ± 7.1%) side there is no significant difference (p = 0.42) between limbs either.

Table 4.5: Mean reciprocal ratio at 60˚/sec for Forward (n=16) and Backline (n=15) rugby players

	Total (n=31)	p-value	Forwards (n=16)	Backline (n=15)	p-value
RR dominant (%)	51.7 ± 5.8	0.42	51.0 ± 6.2	52.4 ± 5.5	0.26
RR non-dominant (%)	52.0 ± 7.1		51.2 ± 7.8	52.8 ± 6.4	0.27

Abbreviations: RR: Reciprocal ratio

4.6 BILATERAL DEFICIT

Table 4.6 shows the bilateral deficit (%) for the total group and the comparisons between forwards and backline players. There was no difference in bilateral strength deficits between the forward and backline players when comparing the concentric hamstrings (F: 2.6 ± 6.0%; B: 2.5 ± 9.1%; p=0.48), concentric quadriceps (F: 2.4 ± 7.8%; B: 3.2 ± 6.5%; p=0.39). Nor when comparing the eccentric hamstrings (F: 2.0 ± 8.1%; B: 4.0 ± 6.2%; p=0.23).

Table 4.6: Bilateral deficit (%) at 60˚/sec for Forward (n=16) and Backline (n=15) rugby players

	Total (n=31)	Forwards (n=16)	Backline (n=15)	P-value
Hamstrings PT CON (%)	2.6 ± 7.5	2.6 ± 6.0	2.5 ± 9.1	0.48
Quadriceps PT CON (%)	2.8 ± 7.1	2.4 ± 7.8	3.2 ± 6.5	0.39
Hamstrings PT ECC (%)	3 ± 7.2	2.0 ± 8.1	4.0 ± 6.2	0.23

Abbreviations: CON: concentric; ECC: eccentric; PT: peak torque

CHAPTER 5: DISCUSSION

The results will now be discussed under the following headings; Participant characteristics, Dynamic control ratio, Peak torque, Peak torque relative to body weight and the Bilateral deficit. There was no significant difference between forwards and backline players in the DCR, therefore hypothesis that the DCR will be higher for forwards compared to backline players was rejected.

5.1 PARTICIPANT CHARACTERISTICS

A total of 31 male rugby players from the WITS, UJ and NWU clubs participated in the study. As in previous studies[66, 70, 71] this study also found that rugby union forwards are in general significantly taller (187.5 ± 8.52 vs. 178.6 ± 3.76cm) and heavier (106.18 ± 12.97 vs. 83.73 ± 7.0kg) than backline players. Specific positional demands are placed on forwards compared to backline rugby union players.[17, 18, 28, 70] Forwards, specifically the locks and loose forwards, have to compete in the lineouts where height is an advantage. An increased body mass enables forwards to produce greater force in the scrum[72], while backline players are seen as ball carriers that try to evade opponents and are therefore lighter and more agile.

5.2. DYNAMIC CONTROL RATIO (DCR)

5.2.1 Group DCR

There were no significant differences found between the dominant (0.72 ± 0.09) and non-dominant (0.72 ± 0.09) sides for the DCR assessing the whole group (forwards + backline) of rugby players. This is comparable to previous research that also found no differences between the dominant and non-dominant sides.[63, 64] However, the DCR in rugby union vary greatly between studies, with the average values being between 0.66 and 0.81.[63-65] This variance could in part be accounted for by the differences in testing procedures utilised by the different studies, dynamometer make, the level at which these players competed and their individual injury histories. Standardised testing protocols will lead to results from different studies being more accurately comparable.

Results also vary in field sports similar to rugby union. Previous research has found a DCR that varies between 0.70 and 0.87 in rugby league players.[73, 74] Football research has found a DCR that varies between 0.76 and 0.87. Rugby union players outperform football players with regards to concentric knee extension strength but not on eccentric knee flexion.[60, 75]

Furthermore, research conducted on football players, did indeed find significant differences between the dominant and non-dominant sides.[75] A possible explanation for rugby union players not presenting with significant differences between dominant and non-dominant sides is that they do not depend on their dominant limb in the same way (i.e. kicking the ball) as football players.[60, 75]

5.2.2 DCR Forwards vs. Backline Players

There was no significant difference found in the DCR between the forwards and backline players. It is difficult to compare these results to previous research as, studies investigating the DCR in rugby union players usually group the positions together and do not make any distinction between positional groupings. There are several possible reasons why the current study could not find a significant difference between the forward and backline players with regards to the DCR. The way in which the modern game is played requires players to fulfil interchangeable roles. Forwards are required to be more skilful ball players and backline players have become heavier and more capable of performing at rucks and mauls.[17] Rugby union requires a great deal of strength and power for players to be able to compete effectively and the conditioning programs reflect this regardless of playing position.[18, 31, 76]

The present study did not take conditioning programs into account. It could be that strength and conditioning coaches do not differentiate between positional groupings (forwards and backline) when designing programs. If a generic program is followed by both groups this could influence the DCR and consequently produce similar ratios regardless of positional demands. The conditioning program could therefore exert a greater influence on the DCR than playing position alone and subsequent research should try and control for this.

5.3 PEAK TORQUE

5.3.1 Peak Torque Group

In accordance with expectations the hamstrings concentric PT in the present study is lower than the hamstrings eccentric PT and quadriceps PT.[60, 77, 78] There was no significant difference found for the total group with regards to concentric quadriceps and hamstrings or eccentric hamstrings on either the dominant or non-dominant side. The dominant side had a greater average PT than the non-dominant side. Similar results were found in South African university level rugby union players[64, 71, 79] with concentric PT ranging between 252.38Nm –

291.2Nm and 139.7Nm – 189.3Nm for quadriceps and hamstrings respectively. In the study by Surmon (1999)[64] an eccentric hamstrings PT of between 198.58 ± 52.46Nm and 188.29 ± 41.62Nm were found on the right and left limb respectively. Including studies outside of South Africa, average PT values of between 189.3Nm and 133.0Nm for concentric hamstrings, 214.32Nm and 179.0Nm for eccentric hamstrings and 298.99Nm and 230.0Nm for concentric quadriceps have previously been recorded for rugby union players.[51, 64, 65, 71, 79] The current study found high average PT values for concentric hamstrings (D: 154.7 ± 29.5Nm, ND: 150.1 ± 27.2Nm), eccentric hamstrings (D: 214.2 ± 37Nm, ND: 207.3 ± 6.8) and concentric quadriceps (D: 298.9 ± 43.7, ND: 290.2 ± 44.8Nm) compared to previous research. The high average values found in the current study could be a result of the conditioning phase the players were in when tested. Testing was conducted at the end or after the pre-season conditioning phase when the muscles surrounding the knee joint had ample time to strengthen.

Compared to other field sports such as football[60, 75] rugby union players present with high concentric knee extension strength. A possible reason for this could be that a predominant biomechanical action involved in rugby is the simultaneous triple extension of the hips, knees and ankles.[76] This triple extension is associated with high-force and high-power activities associated with contesting and retaining the ball in open play and with jumping and tackling. Similarly the forces produced within the rugby union scrum correlates significantly with isokinetic knee extension.[72] The combination of the triple extension movement, scrumming and the high conditioning status of players in the current study could have led to the high average PT values.

5.3.2 Peak Torque Forwards vs. Backline Players

University level rugby union forwards produced a significantly greater peak torque for eccentric hamstrings on the dominant (227.9 ± 41.9Nm vs. 199.6 ± 24.6Nm, $p = 0.015$) and non-dominant limbs (222.5 ± 41.5Nm vs. 191.2 ± 22.8Nm, $p = 0.01$) when compared to backline players. The average PT on the dominant side had a trend of being greater than the non-dominant side.

Similarly, the peak torque for the concentric quadriceps on the dominant (314.5 ± 36.1Nm vs. 282.2 ± 45.9Nm, $p = 0.02$) and non-dominant limbs (307.3 ± 44.7Nm vs. 271.9 ± 38.4Nm, $p = 0.013$) of forwards were significantly greater when compared to backline players. The average PT on the dominant side had a trend of being greater than the non-dominant side. A recent South African study by Kruger (2014)[79] found a significant difference in concentric quadriceps strength on the dominant (F: 288.4 ± 60.4Nm, B: 253.5 ± 45.4Nm, p = 0.024) but not on the non-dominant (F: 274.3 ± 76.1Nm, B: 248.8 ± 44.0Nm, p = 0.152) side.

Contrary to the present study, Barnard et al. (1991)[71] did not find any significant difference between forwards and backline players for concentric quadriceps (F: 291.2 ± 57.9Nm, B: 271.6 ± 60.8Nm) strength. The study by Barnard et al. (1991)[71] was conducted before the start of the professional era. More recently position-specific training, conditioning and rehabilitation have become the norm[15, 16] possibly leading to differences in strength between positional groupings found in the current study.

Comfort et al. (2011)[74] found that rugby league forwards achieved greater concentric knee extension on the left side compared to backline players. No other significant differences were found bilaterally. The differences between rugby union and league PT/BW strength could possibly be attributed to the different demands of each code.[66] Both forwards and backline players in rugby league train and play, offensively and defensively, in an upright position at medium to high speeds.[66, 76] Rugby union backline players are involved in high-speed side on tackling and contact evasion. Rugby union forwards have to perform at a lower speed in activities such as front-on tackling, scrumming, rucking and mauling that requires high strength. High average absolute strength was found for rugby union forwards in the current study which reflects the requirements of this positional grouping.

Although forwards tended to have higher average concentric hamstrings PT, no significant difference between positional groupings were found on the dominant (F: 161.1 ± 30.4Nm, B: 147.8 ± 27.8Nm, p = 0.11) or non-dominant (F: 157.2 ± 32.2Nm, B: 142.5 ± 18.9Nm, p = 0.07) sides. Kruger (2014)[79] again found a significant difference in concentric hamstrings strength between forwards and backline players on the dominant (F: 151.0 ± 28.5Nm, B: 127.6 ± 23.6Nm, p = 0.002) but not on the non-dominant (F: 138.5 ± 29.3Nm, B: 127.2 ± 22.3Nm, p = 0.128) side. Contrary to the present study, Barnard et al. (1991)[71] did not find any significant difference between forwards and backline players for concentric hamstrings (F: 189.3 ± 32.4Nm, B: 160.8 ± 34.3Nm) strength.

Contrary to the present study Brown et al. (2013)[66] found significantly greater concentric knee flexion strength amongst forwards (D: 184.0 ± 27Nm, ND: 180 ± 20Nm) compared to backline (D: 157 ± 27Nm, ND: 156 ± 27Nm) players. Brown et al. (2013)[66] suggests that the increased time that forward players spend performing high intensity activities (scrumming, rucking, mauling) combined with position specific training and/or demands could lead to them developing greater strength in concentric knee flexion.

Rugby union forwards are involved in strength dominated low speed actions such as rucking, mauling, scrumming and front on tackling.[76] Backline players are involved in high speed side-on tackling and contact evasion. This could lead to the forward players presenting with greater absolute knee extension concentric and eccentric knee flexion PT in the present study. As mentioned above there is a significant correlation between the forces produced in the rugby union scrum and isokinetic knee extension.[72] This concentric knee extension is then controlled by the antagonistic action of the eccentrically contracting hamstring muscles. Muscle balance around the knee joint is important for normal biomechanics and the prevention of injury.[1,4] If the hamstrings were significantly weaker than the quadriceps it could lead to a hamstring strain.[5] Dynamic joint stabilisation would also be compromised placing the ACL at increased risk for injury.

5.4 PEAK TORQUE RELATIVE TO BODY WEIGHT (PT/BW)

The maximal contractile capability of a muscle is proportional to its cross-sectional area and its mass proportional to its volume.[80] This results in body mass increasing more rapidly than muscle strength with increases in body size. Therefore smaller athletes tend to have greater strength-to-mass ratios than larger athletes. Strength-to-mass ratio is important during activities such as sprinting because it is directly relates to the athlete’s capability to rapidly accelerate a body part. In order to compare subjects with different body mass to each other it is necessary to normalise peak torque (Nm) to body weight (BW). This produces a peak torque to body weight value (PT/BW) that is more applicable to functional activity.[35]

5.4.1 PT/BW Group

When corrected for body weight, the total group, showed no significant difference in concentric hamstrings (D: 164.7 ± 31.0Nm/kg, ND: 160.1 ± 28.5Nm/kg, $p = 0.54$) or quadriceps (D: 318.6 ± 44.3Nm/kg, ND: 308 ± 46.3Nm/kg, $p = 0.37$). Neither was there a significant difference in eccentric hamstrings (D: 230.4 ± 39.4Nm/kg, ND: 221.4 ± 41.0Nm/kg, p = 0.38). The average PT/BW for the total group on the dominant side had a trend of being greater than the non-dominant side.

Previous studies found similar results, but lower average PT/BW values for concentric hamstrings (135.3Nm/kg – 141.9Nm/kg) and quadriceps (265.2Nm/kg – 280.7/kg/Nm) than the present study.[79, 81] Players were tested near the end or after their pre-season conditioning phase and this could have led to the present study finding higher average PT/BW values. One of the above mentioned studies[79] were conducted after the off-season which could have led to the lower values due to deconditioning and the other[81] used subjects with known gluteal dysfunction that could also influence results.

5.4.2 PT/BW Forwards vs. Backline Players

There was no significant difference between forward and backline players in the dominant (F: 221.53 ± 45.45Nm/kg; B: 246.7 ± 30.54Nm/kg; p = 0.19) and non-dominant (F: 213.32 ± 48.73Nm/kg; B: 230.06 ± 30.01Nm/kg; p = 0.26) side for eccentric hamstring PT/BW strength although the backline players tended to have higher average values. Controlled decelerating of the knee joint requires hamstring muscles to eccentrically contract. Although not found to be significant in the present study, backline players tended to on average, have higher eccentric hamstrings PT/BW than forwards. This makes sense because backline players are faster than forwards and would therefore require slightly higher eccentric hamstrings PT/BW to be able to control knee extension specifically during the late recovery phase.[80]

Relative to body weight, backline players in the current study were able to produce significantly greater PT/BW for concentric knee flexion on the dominant (B: 176.0 ± 22.8Nm/kg, F: 154.1 ± 34.8Nm/kg, p = 0.046) and non-dominant sides (B: 170.4 ± 16Nm/kg, F: 150.3 ± 34.3Nm/kg, p = 0.047) compared to forward players. The triple extension movement that comprises simultaneous hip, knee and ankle extension is present in the sprinting action. The hamstring group contributes to sprinting through its function as a concentric hip extensor, specifically during the propulsive phase[36] which in turn could have led to the significantly higher concentric PT/BW values for backline players.

Relative to body weight, backline players in the current study were able to produce significantly greater PT/BW for concentric knee extension on the dominant (B: 337.18 ± 38.3Nm/kg, F: 301.14 ± 43.4Nm/kg, p = 0.02) and non-dominant (B: 325.48 ± 34.4Nm/kg, F: 292.11 ± 51.0Nm/kg, p = 0.04) sides compared to forward players. The average PT/BW for both forwards and backline players on the dominant side had a trend of being greater than the non-dominant side. Baker and Nance (1999)[82] noted that measuring strength relative to body weight is more likely to correlate with sprint ability than absolute measures. Comfort et al. (2011)[74] demonstrated that when body weight is taken into account, backline players generally outperform forwards in rugby league, a field sport similar to rugby union. Backline players are usually faster, cover more distance and have to accelerate and sprint more frequently during a match than forwards.[24, 70, 83] This could be a possible reason why backline players produced significantly greater PT/BW during concentric knee extension. Concentric knee extension is critical in propelling the center of gravity forward during the late support phase of the sprinting action.[80] The ability of backline players to produce greater acceleration and speed could therefore be related to their greater strength-to-mass ratio (i.e. their greater concentric PT/BW during knee extension) and the role they are required to perform during play. A previous study found that sprint ability correlated highly with concentric isokinetic knee extension when PT was normalised to body weight.[51]

Similar results for concentric knee flexion (B: 166.5 ± 21.5Nm/kg, F: 131.8 ± 27.8Nm/kg, p= 0.008) and extension (B: 345.1 ± 61.4Nm/kg, F: 254.2 ± 56.1Nm/kg, p = 0.002) were found in another rugby union study[81] whereas Kruger (2014)[79] found a significantly greater concentric knee flexion PT/BW for backline players on the non-dominant side (B: 143.8 ± 25.2Nm/kg, F: 127.1 ± 30.5Nm/kg, p = 0.038) only. The study by Kruger (2014)[79] was conducted straight after the off-season on players that were possibly deconditioned and could have led to different results.

5.5 BILATERAL DEFICIT

The bilateral deficit is used to compare muscular performance between the dominant and non-dominant limb.[43] Normally the dominant side will be stronger than the non-dominant side.[57] A deficit of less than 10% is considered acceptable, however if higher, may indicate possible knee joint pathology or increased risk of injury.[53]

5.5.1 Bilateral Deficit Group

Bilateral strength differences in field sports have previously been reported[13, 60, 84] and could lead to recurrent hamstring problems[13] of which the incidence has been found to be high within the rugby playing population.[6] The mean bilateral deficits between concentric hamstrings PT, quadriceps concentric PT and hamstrings eccentric PT were all below 10% in the present study thus indicating the group was not at risk to injury. Furthermore, bilateral eccentric strength deficits could potentially have a negative effect[85] on the multi-directional speed requirements of rugby union.[17] Therefore, the group of players in the current study are likely not at a disadvantage with regards to generating multi-directional speed.

5.5.2 Bilateral Deficit Forwards vs. Backline Players

Bilateral strength differences according to playing position have previously been reported by Tourny-Chollet et al. (2000).[60] In the current study there was no significant bilateral strength deficit between forward and backline players when comparing the concentric hamstrings (F: 2.6 ± 6.0%, B: 2.5 ± 9.1%, $p = 0.48$), concentric quadriceps (F: 2.4 ± 7.8%, B: 3.2 ± 6.5%, $p = 0.39$), and eccentric hamstrings (F: 2.0 ± 8.1%, B: 4.0 ± 6.2%, $p = 0.23$), on the dominant and non-dominant sides. Therefore the means are all within the normal range of less than 10% indicating no likely risk of injury. Amongst the players in the present study positional grouping does not predispose a player to a higher risk of knee joint pathology. This concurs with Brooks and Kemp (2009)[86] that found high average knee joint injury risk regardless of playing position. Rugby is a high impact collision sport and it is likely that many acute injuries to the knee joint would occur regardless of an increased bilateral strength deficit.

CHAPTER 6: CONCLUSION, RECOMMENDATIONS AND LIMITATIONS

6.1 CONCLUSION

In conclusion, this study found no difference in the DCR between rugby union forwards and backline players. The hypothesis that the DCR will be higher for forwards compared to backline players has thus been rejected. Differences in isokinetic strength parameters between forward and backline players do exist in the knee joint with forward players tending to have greater absolute strength for eccentric hamstrings and concentric quadriceps but relative to body weight backline players outperformed them on concentric quadriceps, and hamstrings strength.

6.2 RECOMMENDATIONS AND LIMITATIONS

This study made a clear distinction between forwards and backline players but it should be noted that the groups could be further sub divided into the tight five (players 1-5), loose forwards (players 6-8), inside backs (players 9-13) and outside backs (players 11-15). If the DCR within these four groups were to be compared it could yield different results. The sample size in this study was too small to further sub-divide the groups. Further sub-division of groups within this sample would reduce the statistical power and therefore not produce statistically significant results. It is therefore suggested that further studies compare these four groups with each other and not only the two major groups namely the forward and the backline players.

The fact that groups were tested on two different occasions (pre-season and toward the end of season) could possibly confound the results. It is suggested that future studies investigate the seasonal effects on differences in isokinetic parameters.

Previous experience of participants with isokinetic testing and training could also confound the results. Those with prior experience with isokinetic testing could produce higher test values. This study did not enquire about participant familiarity with the testing equipment which is acknowledged as a limitation of this study. Future research in this area should document this information.

Further research into the DCR in this population should try and control for the variability that occur with regards to conditioning programs. It would be advisable to only utilise players from the same squad thereby insuring homogeneity of the conditioning program and eliminating the possible influence diverse programs could have on the DCR.

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APPENDICES

Appendix A:

Information letter to University of Witwatersrand/Potchefstroom/Johannesburg Rugby Club

Functional Isokinetic Hamstring to Quadriceps Ratio Profile of Rugby Union Players: A Comparison between Forward and Backline Players

To whom it may concern

Request for permission for test subjects from WITS/NWU/UJ Rugby Club

I am currently completing my Masters degree in Biokinetics at the University of the Witwatersrand. As part of my degree, I am conducting a study. The aim of my study is to evaluate the muscle groups crossing the knee joint, namely the quadriceps and hamstrings and to assess specific functional muscle strength comparisons. An isokinetic dynamometer will be used to evaluate the strength of the thigh muscles. Should a player consent to participate in the study he will be required to report for testing on a pre-arranged date. The facilities at the University of the Witwatersrand/NWU will be used for testing purposes. Research has shown that imbalances between the functional strength of the quadriceps and hamstring muscles of the thigh could lead to injury. Early detection of these imbalances could therefore possibly identify players at increased risk of sustaining an injury. The Club medical staff would be able to act preventatively. Less time will be spent in rehabilitation and more on the field. It would be greatly appreciated if coaches would refer athletes who are eligible and interested to participate in the study to me.

To be eligible to participate the athlete must:

1) Have no history of injury to both knees,
2) No current or recent (within the last 6 months) previous thigh or hamstring injury,
3) Be actively participating at club level or higher in ruby union.

Players will receive a comprehensive report on the results of their tests.

I would therefore like to request that the WITS/NWU/UJ rugby Club allow me to present the opportunity for the players of the club to participate in this study. I will do this at one of their training sessions or any other convenient time.

Please confirm your decision with me in writing.

For further information, I can be contacted on:
Cell: 072 212 0054
Email: jeanstofberg@hotmail.com

Your participation in this study would be greatly appreciated.

Thank you,
Jean Stofberg

____

Biokineticist

Appendix B: Letter to players

Functional Isokinetic Hamstring to Quadriceps Ratio Profile of Rugby Union Players: A Comparison between Forward and Backline Players

Dear player

I would like to invite you to participate in this study. Please be aware that you may decide not to take part in the project without any disadvantage to yourself of any kind. You may withdraw from participation in the project at any time and without any disadvantage to yourself of any kind.

I am currently completing my Masters degree in Biokinetics at the University of the Witwatersrand. As part of my degree, I am conducting a study to evaluate the muscle groups crossing the knee joint, namely the quadriceps and hamstrings and to assess specific functional muscle strength comparisons. Research has shown that imbalances between the strength of the quadriceps and hamstring muscles of the thigh could lead to injury. Early detection of these imbalances and the application of corrective exercise could therefore decrease the risk of sustaining an injury. Less time will be spent in rehabilitation and more on the field.

An isokinetic dynamometer will be used to evaluate the strength of the thigh muscles. The facilities at the University of the Witwatersrand will be used for testing purposes. Should you consent to participate in the study you will be required to report for testing on a pre-arranged date. You will be required to undertake some anthropometrical measurements for the purpose of the study which will include height and weight. The testing procedure will include a ten minute warm-up on a stationary cycle ergometer, followed by maximal isokinetic concentric and eccentric knee flexion and extension. As this is a maximal performance test it will require you to produce 100% muscle strength output and will therefore be strenuous. You may experience some muscle soreness about 24 or 48 hours after the test, this is normal, however, being a highly conditioned athlete the muscle soreness is expected to be minimal. After completion of the isokinetic test battery you will undergo a cool-down which will include cycle ergometry and stretching. The whole testing process will take approximately one hour.

To be eligible to participate you must:

1) Have no history of injury to both knees,
2) No current or recent (within the last 6 months) previous thigh or hamstring injury,
3) Be actively participating at club level or higher in ruby union.

Your prompt reporting of unusual feelings of discomfort with effort during the test protocol is also of great importance. You are responsible to fully disclose such information when requested by the tester.

The computer generated report will be saved and a hard copy will also be printed for analysis. The data collected will be securely stored in such a way that only the researcher will be able to gain access to it. Therefore all data collected will be kept confidential. At the end of the project any personal information will be destroyed immediately except that, as required by the University's research policy, any raw data on which the results of the project depend will be retained in secure storage for five years, after which it will be destroyed. Results of this project may be published but any data included will in no way be linked to any specific participant.

Following the analysis of results, you will receive a report on the results of your test. As the information is confidential you have the choice whether to provide the club with the results of your testing. At the end of the testing your club, however, will receive the combined results of the whole group, which in no way will specifically identify you as a participant. You are most welcome to request a copy of the results of the project should you wish.

For further information, I can be contacted on:
Cell: 072 212 0054
Email: jeanstofberg@hotmail.com

Your participation in this study would be greatly appreciated.

Thank you,
Jean Stofberg

Biokineticist

Appendix C: Informed consent

Functional Isokinetic Hamstring to Quadriceps Ratio Profile of Rugby Union Players: A Comparison between Forward and Backline Players

I hereby declare that:

- Jean Stofberg nor the Centre for Exercise Science and Sports Medicine at University of the Witwatersrand, will be held liable for any injury obtained during the testing procedure.
- The testing procedures have been explained to me by the tester,
- To the best of my knowledge I am currently free from any existing medical condition/other complaint/injury that would preclude me from full participation in this particular study,
- I understand that I may withdraw from participation in the project at any time and without any disadvantage to myself of any kind,
- I understand that my test results are confidential,
- I give my written consent to Jean Stofberg, the tester, to undertake the battery of tests which form part of the above mentioned study.

__________________________ __________________________

Subject’s signature Date

__________________________ __________________________

Jean Stofberg Date

Appendix D: Ethical clearance

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG
Division of the Deputy Registrar (Research)

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)
R14/49 Mr Johannes Jean Stofberg

CLEARANCE CERTIFICATE	M110343
PROJECT	Functional Isokinetic Hamstring to Quadriceps Ratio Profile of Rugby Union Players: A Comparison between Forward and Backline Players
INVESTIGATORS	Mr Johannes Jean Stofberg
DEPARTMENT	Centre for Exercise Science and Sports Medicine Medical School
DATE CONSIDERED	25/03/2011
DECISION OF THE COMMITTEE*	Approved unconditionally

Unless otherwise specified this ethical clearance is valid for 5 years and may be renewed upon application.

DATE 19/11/2014 CO-CHAIRPERSON ....
(Professor A Dhai)

*Guidelines for written 'informed consent' attached where applicable
cc: Supervisor : Dr Kerith Aginsky

DECLARATION OF INVESTIGATOR(S)
To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10004, 10th Floor, Senate House, University.
I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to a completion of a yearly progress report.**
PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES...

Appendix E: Anthropometric data sheet

FUNCTIONAL KNEE RATIO PROFILE STUDY SUBJECT INFORMATION AND ANTHROPOMETRICAL DATA

SUBJECT INFORMATION	
Code:	
Position:	
Level:	

ANTHROPOMETRY	
Dominant limb:	
Age:	
Stature (cm) :	
Body weight (kg):	

PERSONAL DETAILS	
Name:	
Tel:	
Code:	

Appendix F: Injury history form

The definition of an injury was adopted from Fuller et al. (2007).[67] This definition will be used to exclude subjects that are not eligible to take part. To be eligible to take part the subjects must have no history of injury to both knees and no current or recent (within the last 6 months) previous thigh or hamstring injury.

FUNCTIONAL KNEE RATIO PROFILE STUDY SUBJECT INJURY HISTORY DATA

Have you ever injured your knee joint?		yes		no
Do you currently or in the past 6 months sustained a hamstring or thigh injury?		yes		no

Appendix G: Test recording sheet

TEST RESULTS	
Right knee concentric extension peak torque	Nm
Right knee concentric flexion peak torque	Nm
Left knee eccentric extension peak torque	Nm
Left knee eccentric flexion peak torque	Nm
(DCR right leg) Right knee eccentric flexion peak torque/Right knee concentric extension peak torque=	%
(DCR left leg) Left knee eccentric flexion peak torque/Left knee concentric extension peak torque=	%

Appendix H: Plagiarism declaration

UNIVERSITY OF THE WITWATERSRAND
JOHANNESBURG

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PLAGIARISM DECLARATION TO BE SIGNED BY ALL HIGHER DEGREE STUDENTS

SENATE PLAGIARISM POLICY: APPENDIX ONE

I JOHANNES P J STOFBERG (Student number: 333580) am a student registered for the degree of MSc (Med) Biokinetics in the academic year 2014.

I hereby declare the following:

- I am aware that plagiarism (the use of someone else's work without their permission and/or without acknowledging the original source) is wrong.
- I confirm that the work submitted for assessment for the above degree is my own unaided work except where I have explicitly indicated otherwise.
- I have followed the required conventions in referencing the thoughts and ideas of others.
- I understand that the University of the Witwatersrand may take disciplinary action against me if there is a belief that this in not my own unaided work or that I have failed to acknowledge the source of the ideas or words in my writing.

Signature: ______________ Date: 15/12/2014