Lumbar multifidus characteristics in relation to low back pain, lower limb injury, and body composition in university level athletes

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ABSTRACT

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Meagan Anstruther

Low back pain (LBP) is highly prevalent within the athletic population despite increased training and intensity. Quality activation of the lumbar musculature is crucial for proper stabilization during athletic movements. Extensive research has indicated a connection between lumbar multifidus (LM) muscle morphology (cross-sectional area (CSA), echo intensity (EI), and CSA asymmetry) and function and the presence of LBP and lower limb injury (LLI) in athletes. However, LM has only been examined in small sample sizes through single sport investigations. Furthermore, body composition has been closely related to skeletal muscle characteristics, yet few studies have examined the influence of body composition parameters on LM morphology and function. Therefore, the purpose of this work was to 1) investigate if LM morphology and function are predictors of LBP and LLI in a large sample of university varsity athletes and 2) examine the relationship between LM characteristics and the body composition in university athletes.

A total of 134 university level athletes were included in this study and completed a self-reported questionnaire to acquire data on demographics and history of LBP and LLI. LM characteristics at the 5th lumbar vertebra were assessed via ultrasound and body composition was assessed via dual energy x-ray absorptiometry (DEXA). Manuscript 1 investigated LM morphology and function via ultrasound and the presence of LBP and LLI in the past year via questionnaire. Manuscript 2 examined body composition via DEXA, LM morphology and function via ultrasound, and type of sport via questionnaire.

Overall, LM was larger and thicker on the non-dominant side of the lower limb in males. LM thickness was the best predictor of the presence of LBP and type of sport was the best predictor of the presence of LLI. LM cross-sectional area and thickness were both positively correlated with several body composition measurements and echo intensity, and total fat mass, and % body fat were negatively correlated with % thickness change of the LM.

This study investigated the relationships between LM, LBP, LLI, and body composition. Using ultrasound to assess LM characteristics may be a tool for team health professionals to perform preseason

screening to identify athletes at risk for injury and develop individualized rehabilitation programs for injury prevention.

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List of Abbreviations

LBP – Low Back Pain

CSA – Cross-Sectional Area

TLF – Thoracolumbar Fascia

QL – Quadratus Lumborum

ES – Erector Spinae

TA – Transverse Abdominus

LM – Lumbar Multifidus

MRI – Magnetic Resonance Imaging

US - Ultrasound

EMG – Electromyography

EI – Echo Intensity

LLI – Lower Limb Injury

AFL – Australian Football League

BMI – Body Mass Index

DEXA – Dual Energy X-ray Absorptiometry

CHAPTER 1: THEORETICAL CONTEXT

1.1 LOW BACK PAIN

Low back pain (LBP) is a leading cause in disability globally and affects a wide range of individuals.[1,2] The financial burden of LBP on society and the healthcare system continues to increase.[1] This is largely due to increases in population size and age globally and not from a higher prevalence of LBP.[1] Although LBP stems from a wide range of known and unknown abnormalities or diseases, it is typically determined to be non-specific.[3] Specific causes of LBP include, but are not limited to, vertebral fractures, inflammatory disorders, malignancies, infections, or intra-abdominal problems.[1–3] The location of LBP has been defined by any pain between T12 and the gluteal fold which may be accompanied by pain or neurological symptoms in one or both legs, such as weakness, loss of sensation, or loss of reflexes associated with one or more nerve roots.[1–3] There are several types of LBP, but acute and chronic are the most commonly investigated in the literature. Acute LBP is associated with sudden onset of pain lasting less than 3 months.[4,5] Chronic LBP is LBP lasting longer than 3 months and is generally non-specifc.[1,4,5] LBP has been previously associated with poor biomechanics, sport specific loads, and poor motor control of lumbar spine stabilizers.[6]

1.1.1 Prevalence

LBP has prevailed as one of the top three non-communicable diseases worldwide for 28 years.[7] The prevalence of LBP increased by 17.3% and 17.8% for females and males, respectively, between 2007 and 2017, with an overall higher prevalence of LBP in females as compared to males.[1,7,8] LBP is not common in children, however its prevalence increases during teenage years where 40% of the population reports LBP.[1,3,8] This prevalence peaks during mid-life, which agrees with the observation that LBP is highest in working age groups and results in more lost workdays than any other musculoskeletal condition developed at work in the United States.[1,3,8] In the global population, the mean overall prevalence of LBP was 31.0% regardless of how long the pain lasted.[8] Hoy et al.[8] found a 12 month prevalence of 38.0% and a point prevalence of 11.9% in the global population. However, these values differ when it comes to elite athletes. The prevalence of LBP in elite athletes has been investigated extensively, resulting in varying ranges (lifetime prevalence: 33-85%[9–12]; 12-month prevalence: 17-94%[9,10,12]; point prevalence: 10-67%[9–12]). These results are all higher than the prevalence of LBP in a non-athletic population.[9,10] LBP was most often reported with pain from overuse in athletes with an incidence of 20-86% depending on age, sex, performance level, and time of occurrence.[13] It is concerning that LBP is much more prevalent in an athletic population compared to a general population despite increased training time and intensity as one would expect more physically fit individuals to experience less pain.

1.1.2 Risk Factors

Pain chronification is the process by which transient pain progresses into persistent pain.[14] There are several factors that can lead to chronic or long-lasting pain including poor health status, depression, stress, fear avoidance, catastrophizing, and perceived injustice.[14] These factors are also evident in the development of chronic LBP and can be broken down into biophysical, psychological, and social factors.

1.1.2 Biophysical factors

People with other chronic conditions, such as asthma, headaches, and diabetes, are more likely to develop LBP.[1] Those who maintained or moved into awkward postures, performed heavy manual tasks, or are exhausted or distracted during an activity were also at higher risk for developing LBP.[1] Smoking, obesity, and low levels of physical activity are all related to developing LBP.[1] There has been some evidence to suggest a genetic component to LBP, however it ranges from 21-67% influence.[1] Battié et al.[15] investigated the effects of genetics and environmental exposures on twins. Familial aggregation explained 61% of the variance in disc degeneration in the T12-L4 region and 43% of the variance in the L4-S1 region.[15] Physical loading and age combined only accounted for 16% of the variance in the T12-L4 region and 11% in the L4-S1 region.[15] Changes in paraspinal muscle size or cross-sectional area (CSA)[16–23], composition (ex. fatty deposits)[24,25], and coordination (poor motor control or neural influence)[6,26–30] were demonstrated in people with LBP. Finally, people who have experienced LBP previously are at higher risk for additional bouts of LBP.[1] Specifically in athletes, risk factors for LBP include training and match load, type of sport, level of competition, poor load management, overtraining and undertraining, previous LBP, decreased lumbar extension or flexion, decreased strength and endurance of trunk extensor muscles, unilateral muscle imbalances, and high body weight.[13,31] High chronic workloads and trunk muscle strength and endurance have been shown to have a protective effect against developing LBP and other injuries.[13]

1.3.2 Psychological Factors

Depression, stress, fear avoidance, and catastrophizing are all risk factors in developing chronic pain, including chronic LBP.[1,14,32] Anxiety, low levels of self-efficacy and self-recognition, and poor coping strategies are also believed to be related to higher rates of developing LBP.[1,14,32] In athletes, higher stress levels are associated with chronification of LBP and may manifest in the form of increased physical stress on the body.[33] Heidari et al.[33] found that athletes with higher stress levels within 3 months of the initial measurement reported increased LBP at the time of the second measurement. However, the mechanisms by which psychological factors lead to LBP are not fully understood.

1.3.3 Social Factors

Individuals with poor social support from spouses, family, and friends may be at risk for developing LBP.[14] In the US, LBP is more likely to develop in people with less than a high school education.[1,14] In conjunction, people with lower educational levels tend to have lower incomes and manual labour intensive careers, which are both associated with developing LBP.[1,14]

1.2 ANATOMY OF THE LUMBAR SPINE

The lumbar spine is comprised of five vertebrae and intervertebral discs that aid in the transferral and absorption of forces along the spine from the lower limbs cranially or the upper body caudally. L4/L5 and L5/S1 are common places for pain and/or poor biomechanics in the lumbar spine. Translation at the

L5/S1 junction and rotation and lateral bending through the lumbar segments are necessary for proper gait. The lower lumbar segments generally present with decreased mobility, but are highly stable because of the structures surrounding them, such as the iliolumbar ligament, thoracolumbar fascia (TLF), quadratus lumborum (QL), erector spinae (ES), transverse abdominis (TA), and lumbar multifidus (LM) muscles. Global muscles, such as ES and the abdominals, span large areas and connect the pelvic bones and thoracic cage.[34] They are considered to be primary movers that aid with torque production and trunk stabilization.[34] Local muscles, such as LM and TA, are close to the spine and directly linked to lumbar vertebrae, acting to stabilize the spinal segments and control their position during movement.[34]

1.2.1 Coactivation

TA and LM co-contract to increase the stability of the lumbar spine during movement and the ability to contract LM is directly related to the ability to contract TA.[35–38] In fact, the odds of a good LM contraction was 4.45 times greater in people with a good contraction of TA compared to those with a poor contraction.[35] This co-dependent mechanism uses the TLF to connect the balancing tension between TA and LM.[36–38] This method creates force closure and leads to what is known as the "bracing" mechanism.[38] If there is dysfunction in either the paraspinal or deep abdominal musculature, tension would be distributed unevenly across the TLF and lead to decreased spinal stability.[35,37,38] Decreased spinal stability may lead to injuries of the lumbar spine. Thus, there has been extensive research into both TA and LM morphology (CSA, asymmetry, EI) and function (thickness and % thickness change) to understand the bracing mechanism and their roles in LBP (refer to section 1.5 for more detail).

1.2.2 Lumbar Multifidus (LM)

LM is a deep local spinal muscle and is the most medial of the paraspinals.[34,39] It provides segmental stabilization at rest and proprioceptive control during movement due to high muscle spindle density, short muscle fibres, and a large CSA that helps create large forces over a small distance.[34,40,41] LM is such a dominant factor in spinal stiffness that it accounts for more than two thirds of spinal stiffness in neutral posture.[34,42] LM also plays a key role in force transferral from the extremities through the kinetic chain.[6,27] It spans one to three segments along the entire spine and has superficial, middle, and deep layers. The superficial fibres are suitable for orientation and are capable of providing torque and increased stiffness during co-contraction with TA.[34,41,42] The intermediate fibres are believed to provide some control of intersegmental movement.[42] The deep layers span a single segment and have the greatest role in proprioceptive feedback and position control.[34,41,42] LM morphology is typically determined by investigating the size (CSA) of the muscle and its composition (i.e. fatty infiltration) using imaging (e.g. magnetic resonance imaging (MRI) or ultrasound (US)). LM function is commonly assessed by examining the % change in thickness from a resting state to a contracted state using ultrasound imaging. The association between LM morphology and function with LBP has been investigated both in athletic[16–19,22,23,28,43] and non-athletic populations.[44–46] Previous studies have also examined whether asymmetry exists between right and left sides of LM and whether it has any connection to LBP in both general[47,48] and athletic populations.[16–19,21,49,50]

1.3 ULTRASOUND IMAGING

While magnetic resonance imaging (MRI) is the gold standard for obtaining skeletal muscle measurements, it is expensive and difficult to gain access to as it is non-portable.[34,51–54] Electromyography (EMG) has also been used to examine LM activity and to validate the use of US as a means to measure LM thickness as changes in muscle thickness are associated with muscle activation.[34,39,52,54,55] US is a non-invasive, cost-effective, portable, and safe way to obtain images of various tissues and determine muscle thickness as compared to MRI and EMG.[34,51–54] There is a significant positive correlation for LM CSA measurements (muscle size)[55] and a poor to moderate correlation for LM thickness measurements[53] between US and MRI in a general population with and without LBP. Sions et al.[64] and Hides et al.[69] found no significant difference between US and MRI when measuring LM CSA in an older population with and without LBP and young females without LBP, respectively. There was also excellent agreement between LM CSA measurements obtained via MRI and US in older adults at rest at L4.[64] One study demonstrated an intra-class correlation coefficient (ICC) of 0.84-0.94 when comparing US to MRI of TA thickness.[58] In athletes, ICCs for reliability of LM characteristic measurements (CSA and thickness) ranged from 0.96-0.99 in a prone position and 0.96-0.98 in a standing position when measured by an experienced researcher.[16] LM thickness measurements via US were also found to have moderate to high correlation (r=0.36-0.79) with EMG amplitudes (e.g., reflecting muscle activity) in prone in a general population.[39,54,55,59] A strong correlation (r=0.79) between LM thickness change via US and EMG activity was observed during graded contralateral arm lift tasks (19-34% maximum contraction) in healthy individuals in a prone position.[54] A review study found ICC values of 0.89-0.93 when comparing LM measurements between US and EMG.[52] Skeie et al.[66] produced intra- and inter-rater reliability ICCs of 0.94-0.99 when measuring LM thickness in prone in a general population. Fortin et al.[16] found excellent intra-rater reliability of LM thickness measurements at rest and contracted in both prone (ICC=0.96-0.99) and standing positions (ICC=0.96-0.98). Thus, US is a reliable and valid method to use for measuring LM CSA and thickness and can differentiate between individuals with and without LBP as well as monitor rehabilitation outcomes.

US is a modality used for both diagnostic imaging and rehabilitation of injuries. In diagnostic imaging, US uses soundwaves that reflect off tissues to create a grayscale image. US has been widely used to document muscle atrophy and hypertrophy[34,55,61], thickness changes between resting and contracted states[34,42,54,55,61,62], echo intensity (EI)[16–19,34,62], blood flow[34], and muscle stiffness[34] depending on the US mode used (B-mode, Doppler, or Shear-wave Elastography) and provide biofeedback during exercise.[58,59] US is a feasible method to provide a visualization of the lumbar spine and its surrounding structures.[34,42,52] Curved or curvilinear transducers are recommended for transverse imaging and to expand the field of view (typically used to assess CSA), whereas curvilinear or linear transducers are recommended for longitudinal imaging (typically used to assess thickness).[39,60] LM morphology and function measurements are most commonly taken at L5. A general population of individuals with LBP presented with a significantly smaller LM CSA at L5 on the affected side compared to other levels[35] and decreased LM CSA and increased side-to-side asymmetry at L5 were predictors of LBP and lower limb injury (LLI) in elite Australian Football League (AFL) players.[61–63] Previous studies have found intra- and inter-rater reliability of LM CSA and thickness measurements to range from moderate to excellent, with values increased when measurements were performed by experienced individuals and when multiple measurements were averaged.[52,53,64,65] Few studies have examined within day and between day reliability, though results range from good to excellent.[66,67]

1.3.1 Ultrasound Measures for Lumbar Multifidus Morphology

1.3.1.1 Cross-sectional Area (CSA)

LM CSA is generally assessed through US in a prone position.[39,54,60] The level of interest is identified manually by a trained professional and confirmed through US.[39,54] Images are taken bilaterally and LM CSA is traced manually on the image offline. Although there has been recent work into investigating the creation of an algorithm to detect the boundaries of LM, it is not fully developed, tested, or ready for use.[68]

1.3.1.2 Echo Intensity (EI)

EI, the mean pixel intensity of a specific region on an ultrasound image, can be used as an indicator of intramuscular fat in a region of interest.[56,57,71] The soundwaves transmitted from the US transducer reflect back to reveal hyperechoic or hypoechoic regions, which are represented by lighter or darker pixels, respectively.[56] The region of interest is traced on an US image and a grayscale based on a histogram function (e.g. brightness of the image) is used to provide an indication of intramuscular fat. LM EI is greater in females as compared to males in both general and athletic populations, which coincides with females having higher % body fat than males.[24,25,37,56,72] Older populations also have increased intramuscular fat compared to younger populations.[24,25,37,56] LM EI measurements have an intra-rater reliability ICC of 0.99 in university level athletes.[16]

1.3.2 Ultrasound Measures for Lumbar Multifidus Function

LM thickness is typically measured in a prone position and resting and contracted states are compared.[25,41,42,60,61,66] A contralateral arm lift is one of the most common methods used to elicit a contraction of the LM in both general[25,41,42,73–75] and athletic populations.[16–20,61,76,77] The bracing mechanism has also been used in the general population[78], and a contralateral leg lift has been used in athletic populations.[79] The contralateral arm lift is used to produce a submaximal contraction of LM.[74] In the general population, LM thickness has rarely been investigated in other positions, such as standing and stooped over positions.[76,79,81] Few studies have examined LM thickness in a standing position in an athletic population.[16–19,77]

1.4 FACTORS AFFECTING LUMBAR MULTIFIDUS MORPHOLOGY AND FUNCTION

1.4.1 Age

A 15-year longitudinal study found LM CSA decreased and side-to-side asymmetry increased in a population of twins[82] with similar observations in a population of healthy females[83] and age was independently associated with the relative CSA of LM in symptomatic individuals with intervertebral disc degeneration.[84] Increased fatty infiltration of LM is associated with older populations compared to younger populations[56,83,85–87] and fatty infiltration of LM is also higher in those with LBP.[24,85] However Hides et al.[88] found no association between age and LM CSA or asymmetry in a general population. Many studies use different modalities (e.g., US, MRI, CT) and segmentation protocols, which may contribute to the inconsistencies observed in the literature. In other muscles (e.g. in the upper and lower limbs), age was a predictor of muscle thickness and EI in females was correlated with age.[57]

1.4.2 Sex

LM CSA is larger in males, but sex did not have an effect on asymmetry in the general population.[86,88] Furthermore, healthy males have been shown to have greater lumbar paravertebral atrophy as they age when compared to females.[86] Males also have larger LM CSA in both prone and standing positions as compared to females, in addition to having greater LM thickness at rest and during a contracted state in an athletic population.[16,18,77,89] However, Fortin et al.[16] found no difference in LM thickness at rest and contracted in both prone and standing positions between sex in university level hockey players. There was also no difference in side-to-side asymmetry in males or females in ice hockey and rugby players[16,77], yet Nandlall et al.[18] found male soccer players to have greater CSA side-to-side asymmetry. Sex also had no significant effect on LM % thickness change in prone or standing in rugby and soccer players.[18,77]

1.4.3 Height and Weight

In a general population, muscle thickness of quadriceps, tibialis anterior, biceps brachii, forearm flexors, and sternocleidomastoid was positively associated with weight, while height was not a predictor of muscle thickness.[57] Leung et al.[90] found that height was a factor in the % change in piriformis CSA and that taller athletes were at higher risk for sustaining a LLI. Other studies have also found taller and heavier athletes were more likely to sustain a LLI during the playing season.[28,62] In an athletic population, height and weight were significantly correlated with LM CSA and thickness both at rest and in contracted states in both prone and standing.[16–19,77]

1.4.4 BMI

Body mass index (BMI) is commonly used to adjust for inter-body anthropometric differences between individuals. Although BMI is accepted for the general population, BMI is not a good indicator of body composition in athletes as it does not differentiate between muscle and fat mass. BMI has been both correlated with increased fat infiltration in LM[82,91] and not correlated with LM fatty infiltration in the general population.[56,92] BMI was not correlated with LM CSA or with EI in prone or standing positions in an athletic population.[16–18,24,77]

1.4.5 Body Composition

Body composition has been found to influence muscle morphology and function. Dual-energy X-ray absorptiometry (DEXA) is a useful tool to determine body composition values such as lean muscle mass and fat mass. While DEXA is the gold-standard to assess body composition, few studies have used it to investigate the relationship between LM morphology and function as it is not readily accessible. EI and % intramuscular fat in LM are not correlated with BMI or LM function in both general and athletic populations[16,24,25] however LM EI is correlated with total % body fat, total lean mass, and total fat mass in an athletic population.[16–18] Additionally, % thickness change of LM in prone and standing positions are correlated with LM EI[17], total % body fat and total fat mass in an athletic population.[17,77] Football and soccer university players have also shown correlations between LM CSA and thickness and total % body fat.[17,18] LM CSA[16–19,77] and LM thickness[16–19,37,77] at rest and contracted in both prone and standing positions were significantly correlated with total bone mass and total lean mass in athletic populations. While body composition has been heavily investigated in athletes and has been shown to differ between sports[73,93–98] and even between positions within the same sport[93,99–102], connections between body composition and LM have not been investigated in this population.

1.4.6 Activity Level

Atrophy due to decreased motor control and physical activity is typically seen in Type I or slow-twitch fibres in muscles designed for stabilization and long-term use (i.e. LM), whereas age-dependent atrophy targets Type II or fast-twitch fibres in muscles designed for explosive movements.[24] Thus, people who live sedentary lifestyles are at risk of LM atrophy (decreased LM CSA), which can lead to imbalances during co-activation with TA and possible injury. This could also explain why athletes or individuals who are physically active have larger LM CSA and thickness as compared to the general population and older or sedentary individuals.[25,86,103] Teichtahl et al.[104] found that lower levels of physical activity resulted in narrower intervertebral disc height in the lumbar spine and increased fat content in LM, however there was no association between physical activity levels and LM CSA. Yet, other research indicates a positive association between physical activities levels and LM CSA regardless of whether the participants did or did not have LBP.[56]

1.4.7 Position Prone vs. Standing

There is limited research on LM morphology and function in positions other than prone or supine, yet most individuals do not spend much of their time in prone and supine, and this is especially true for athletic populations. There was no difference in LM thickness between painful and non-painful sides or those with LBP compared to no LBP from prone to standing in a general population.[75] There is an overall trend for LM CSA and thickness at rest to increase and LM asymmetry and % thickness change to decrease from prone to standing positions in an athletic population.[16–18,77] Thus, the position an individual is in will affect LM morphology and function.

1.4.8 Spinal Level

LM CSA increases caudally in a general population with and without LBP.[88,105] Furthermore, individuals with unilateral LBP showed increased asymmetry at L4 and L5, but had no differences at L2 or L3.[88] Fat infiltration varies from one level to another, with the amount of fatty infiltration typically increasing caudally.[86,105–108] According to Crawford et al.[107], there was no association between fat infiltration and BMI at any spinal level in females. Males showed decreased fat infiltration as BMI increased, but maintained higher levels of fat infiltration caudally.[107] Paraspinal muscle degeneration has also been shown to be affected by the segment level and age, with the majority of degeneration beginning at the L5/S1 level.[108,109]

1.5 LUMBAR MULTIFIDUS AND LOW BACK PAIN

There is a large body of evidence suggesting a link between LM degenerative changes and LBP.[42,56] While the role of LM is dynamic stability and force transferral in the lumbar spine, it is still unclear as to whether deficits in LM cause LBP or if LBP leads to changes in LM. However, most studies investigating the link between LM characteristics and LBP in athletes have been conducted with small samples sizes. Two studies by Teyhen at al.[89,113] had large sample sizes, however they only examined healthy individuals who were in the military. Studies involving athletes only investigated a single sport[16–23,50,77,110,114], making it difficult to generalize the findings to a larger population. There is a general trend for LM CSA to increase from prone to standing in people with and without LBP in the general population, which may be related to the need for increased stabilization during standing compared to prone.[81] LM CSA is smaller overall in those with LBP in both general[56] and athletic populations.[16–23] However, rowing athletes and ballroom dancers with LBP showed increased LM CSA or no relationship, respectively.[50,110] In a general population, LM CSA was significantly smaller on both the side with LBP and poor LM contraction.[35,42,81] In addition, individuals with unilateral LBP had increased asymmetry (average side-to-side difference of 11.6%) as compared to those with bilateral or central LBP (0.01%) in addition to poor LM contraction on the affected side.[35] LM CSA asymmetry was also observed in athletes with LBP, indicating the two may be related.[16,21] In the athletic population, football and hockey athletes with LBP and gymnasts with sway-back posture presented with decreased LM thickness.[16,17,20] Hockey and soccer athletes with LBP showed increased % thickness change in LM in prone[16,18] and rugby athletes with LBP demonstrated smaller % thickness change in standing.[19,77] In addition to LM CSA, asymmetry, thickness, and % thickness change being associated with LBP, individuals with chronic LBP and those who are less physically active are more likely to have increased fatty infiltration in LM in a general population.[24,37,85,111] Increased fatty infiltration was correlated with the frequency of LBP episodes and individuals with LBP had a higher percentage of fat content in LM (23.6%) compared to those without LBP (14.5%).[39,41] However, Almazán-Polo et al.[112] found no association between EI and LBP in male athletes. This was corroborated in other studies with both male and female athletes.[16–18,77] Hodges and Danneels[41] attributed LBP to LM atrophy and fat infiltration in addition to the superficial fibres of LM taking on stabilization roles normally fulfilled by the deeper fibres. This may aid in the short-term, but increased loads over long periods of time and decreased movement could lead to ongoing pain.

1.6 LUMBAR MULTIFIDUS AND LOWER LIMB INJURY

Given its implication to transfer forces through the lower kinetic chain, LM has been hypothesized to be associated with LLI in athletes.[6,27] Previous studies in athletic populations have determined that LM morphology at the L5 segment is consistently the best predictor for LLI.[23,61–63] These studies examined changes over the course of a preseason and playing season. Players with decreased LM CSA at L5 had a 25% increased chance of obtaining a LLI during preseason and a 43% increased chance during the playing season.[61] Another study found that each $1cm^2$ decreased below the mean CSA measured at the start of preseason was associated with a 108% increase in the odds of a LLI in preseason and a 143% increased odds during the playing season when LM CSA was smaller at the start of the playing season.[62] LM CSA at L5 was also able to predict 83.3% of hip, groin, and thigh injuries in Australian Football League (AFL) players.[63] Side-to-side asymmetry of L5 LM also predicted LLI in the preseason in football athletes,[61] however asymmetry was not a predictor for LLI in elite AFL players.[63] Decreased LM thickness at L5 was associated with LLI in soccer athletes in both the preseason and playing season and elite AFL players with LBP were 98% more likely to sustain a LLI in the preseason.[18,61] Athletes with previous LLI in the past year were more likely to have LM CSA asymmetry and increased LM thickness in a contracted state at L5.[18,77] However, Roy et al.[19] found no associations with LM CSA, asymmetry, and thickness and the presence of LBP during the preseason and playing season in university level rugby athletes. The same study reported that a decreased % thickness change (e.g. decreased contraction) in standing was associated with the presence of LBP and obtaining a LLI during the preseason in rugby athletes.[19] Therefore, LM morphology screening may be useful to determine individuals at risk for LLI and who may benefit from a preventative exercise program to lessen the risk of LLI.

1.7 RATIONALE

Although LM morphology and function and its connections to LBP and LLI have been examined previously, almost all studies had small samples and were conducting using a single sport. Larger sample sizes are needed to determine if LM morphology and function are translatable across sports at the university level and to provide normative data for both female and male university athletes. Furthermore, while body composition has been investigated extensively in university athletes[73,93–96,98,99,101], there have been no studies examining body composition and LM morphology and function, nor comparing these results between sports to our knowledge. Previous studies with athletes have focused solely on LM morphology and function in a prone position.[20,21,23,50,61,62,76,110,115] Few studies with athletes have examined LM morphology and contractibility in a functional position (standing).[16–19,75] It is imperative to observe changes in LM in functional positions because of the increased forces placed on LM through the kinetic chain during competition. Understanding how LM morphology and function changes in a general sample of athletes with and without LBP may result in observable trends within the athletic population. This information could direct clinicians and team therapists towards providing more specific rehabilitation exercises and treatments to benefit athletes. Furthermore, examining LM morphology and function in standing may also help screen for athletes most at risk for injury during the playing season. Thus, this information could provide insight into determining which athletes may benefit from a preventative rehabilitation program.

1.8 OBJECTIVES AND HYPOTHESES

The objectives of this thesis are:

1. Examine and compare US imaging of LM morphology (i.e., CSA, asymmetry, EI) and function (i.e., %thickness change) across a general sample of male and female university level varsity athletes, both in prone and standing positions.
2. Investigate if LM morphology and function data obtained from US imaging are predictors of LBP and LLI in university level varsity athletes.
3. Examine relationships between body composition via DEXA and LM characteristics via US imaging in male and female university varsity athletes.
4. Evaluate differences in LM characteristics via US imaging and body composition via DEXA between sports in male and female university varsity athletes.

We hypothesized that:

1. Males will have greater LM CSA than females both in prone and standing positions, females will have greater LM EI than males, and LM % change in thickness will be smaller in the standing position compared to the prone position.
2. Smaller LM CSA and greater LM asymmetry and % change in thickness will be predictors of LBP and LLI in university level varsity athletes.
3. Increased LM EI and % change in thickness will have a positive correlation with total fat mass and % body fat and a negative correlation with total lean mass.
4. LM CSA will be larger in football and hockey players compared to soccer and rugby, while male and female soccer athletes will have the lowest fat mass and % body fat compared to football, hockey, and rugby.

CHAPTER 2

Manuscript 1:

Lumbar multifidus characteristics in university level athletes are predictors of low back pain and lower limb injury

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2.1 ABSTRACT

Introduction: Low back pain (LBP) is more prevalent in athletes compared to the general population. Previous studies in athletes with LBP have reported a decrease in lumbar multifidus (LM) cross-sectional area (CSA) and increase in side-to-side CSA asymmetry. Similar change in LM morphology were also associated lower limb injury (LLI) in athletes. However, previous studies mostly investigated small samples in a single sport. Therefore, the primary aim of this study was to examine LM morphology and function across a general sample of male and female university level varsity athletes. A secondary aim was to investigate if LM morphology and function are predictors of LBP and LLI in this population.

Methods: A total of 134 university varsity athletes (50 female, 84 male) from hockey, rugby, soccer, and football were retrospectively selected (e.g., secondary analysis study). A self-reported questionnaire was used to acquire player demographics information and history of LBP and lower limb injury in the previous 3 months and 12 months, respectively. Ultrasound images of LM at L5 were obtained bilaterally, and measurements of interest included: CSA, echo-intensity (EI) and thickness at rest and contracted, and % thickness change (from rest to contracted) in both prone and standing positions. DEXA was used to assess body composition. Paired t-tests were used to examine difference in LM measurements between the dominant and non-dominant side, and independent t-tests were used to compare LM measurements between sex. Univariate and multivariate logistic regression analyses were performed to assess if LM characteristics were predictors of LBP and LLI. Sex and players' body composition measurements were tested as possible covariates.

Results: Males had significantly larger LM CSA and thickness at rest and contracted in both prone and standing positions (all $p<0.001$). Females had significantly higher EI than males ($p<0.001$). The LM CSA on the non-dominant side was significantly larger in both males and females in prone and standing (all $p<0.05$). Similarly, LM thickness at rest and contracted was significantly larger on the non-dominant side both in males ($p<0.001$) and females ($p<0.05$) in prone, while contracted in standing was significant for

males only ($p<0.05$). There was no significant difference in the percentage change in thickness between or within males and females in prone or standing. Increased LM thickness was associated with decreased odds of LBP in the previous 4-weeks (OR=0.49 [0.27, 0.88], p=0.02) and 3-months (OR=0.43 [0.21-0.89], p=0.02), while a greater number of years playing at the university level was associated with increased odds of LBP (OR=1.29 [1.01, 1.65], p=0.04). Greater LM CSA asymmetry (OR=1.14 [1.01, 1.28], p=0.03) and sport (OR=1.44 [1.04, 1.96], p=0.02) were significant predictors of LLI in the previous 12 months, with football having the strongest association.

Conclusion: The results provide novel insights regarding LM morphology and function in a large sample of male and female university-level athletes. Significant differences in LM morphology in prone and standing were observed between male and female athletes. LM thickness in prone was a significant predictor of LBP and increased LM CSA asymmetry was a significant predictor of LLI in the last year.

2.2 INTRODUCTION

Low back pain (LBP) has been one of the top three medical complaints for nearly three decades[7], with a 12 month prevalence of 38% globally, reaching as high as 94% in the athletic population despite increased training time and intensity.[8–12] LBP is defined as any pain between T12 and the gluteal fold which may be accompanied by neurological symptoms in one or both legs.[1–3,16–19,22,26,35] In the majority of cases, LBP is of unknown origin and classified as nonspecific LBP.[1–3] In athletes, risk factors for LBP include type of sport, level of competition, over- and under-training, previous LBP, decreased lumbar extension or flexion, decreased strength and endurance of trunk extensor muscles, unilateral muscle imbalances, high body weight, and increased stress levels.[13,31,33]

The lumbar multifidus (LM) is a deep local spinal muscle that provides segmental stabilization of the lumbar spine at rest and proprioceptive control during movement[34,40,41] and plays a key role in force transferal from the extremities through the kinetic chain.[6,27] Previous imaging studies noted that some athletes with LBP had decreased CSA of the LM indicating muscle atrophy[16–21,23] in addition to increased LM CSA asymmetry.[16,21] However, rowers[110] and ballroom dancers[50] with LBP showed increased LM CSA or no relationship, respectively. Football and hockey athletes with LBP[16,18] and gymnasts with sway-back posture[20] presented with decreased LM thickness. Thus, changes in LM morphology in athletes with LBP may be sport dependent. Anthropometric factors such as sex, height, weight, % body fat, and lean mass were also reported to affect LM characteristics both the general population[57,86,88,89], and in athletes.[16–19,77] Furthermore, LM morphology at the L5 segment was consistently reported as a strong predictor of lower limb injury (LLI) in elite Australian Football League (AFL) players[23,61–63], with LM CSA predicting up to 83.3% of all hip, groin, and thigh injuries.[63] Elite AFL players with LBP are also 98% more likely to sustain a LLI in the preseason.[61]

Given the prevalence of LBP and LLI in athletes, defining the role and LM characteristics in different sports warrants additional attention. To date, most studies examined LM morphology and function in a prone lying position[16–19,77] and there is a lack of data with regards to more functional positions. It is imperative to examine how LM morphology modulates in response to increased forces placed through the kinetic chain as it would during competition. In addition, previous studies have only examined single sports and had small sample sizes, making it difficult to translate findings across various sports. Therefore, the primary aim is to examine LM morphology (CSA, asymmetry, EI, thickness) and function (% thickness change) across a general sample of male and female university level varsity athletes in prone and standing positions at rest and in contracted states. A secondary aim is to investigate if LM morphology and function are predictors of LBP and LLI in university level varsity athletes. We hypothesize that males will have greater LM CSA and thickness than females both in prone and standing positions and at rest and contracted states, females will have greater LM EI than males, and LM % change in thickness will be smaller in the standing position compared to prone. We also hypothesize that smaller LM CSA and greater LM asymmetry and % change in thickness will be predictors of LBP and LLI in university level varsity athletes.

2.3 METHODS

2.3.1 Study Design

This was a retrospective cross-sectional study using data from varsity players at Concordia University (e.g., secondary analysis). The study was approved by the Research Ethical Committee of the Institution and by the Central Ethics Committee of the Quebec Minister of Health and Social Services. All players provided an informed consent.

2.3.2 Participants

Ice hockey players (32; 18 female, 14 male), football players (41; all male), soccer players (27; 12 female, 15 male), and rugby players (34; 20 female, 14 male) varsity team players were included in the current study for a total of 134 participants (50 female, 84 male). The exclusion criteria included previous severe trauma or spinal fracture, previous spinal surgery, and observable spinal abnormalities.[16–19] Pregnancy was an additional exclusion criterion as participants were required to undergo a DEXA scan.

2.3.3 Self-reported outcomes

At the start of the preseason, participants completed a self-administered questionnaire regarding player demographics and history of LBP prior to assessment. Athletes were also asked about leg dominance (e.g., right, left or either) with those choosing "either" being considered right leg dominant for analysis.[23,63] LBP was defined as pain localized between T12 and the gluteal fold. Players were asked to answer "yes" or "no" to the presence of LBP in the past 3 months (off season)[16–19]. Players who answered "yes" to the presence of LBP completed Numerical Pain Rating Scale (NPRS)[16–19] to assess average LBP intensity in addition to indicating LBP location (centered, left, right) and duration (in months). Participants were also asked to fill out whether they experienced or suffered a LLI within the last 12 months causing them to miss at least one practice or game as well as the location of the injury.

2.3.4 Ultrasound assessments

Ultrasound B-mode images of LM were acquired using a LOGIQ e ultrasound machine (GE Healthcare, Milwaukee, WI) with a 5MHz curvilinear transducer. The imaging parameters were kept consistent for all acquisitions (frequency: 5MHz, gain: 60, depth: 8.0cm). Bilateral transverse images of the right and left LM CSA at L5 were obtained simultaneously in both prone and standing positions, except for athletes with larger muscles, where the right and left sides were imaged separately. Three images per side were obtained. Parasagittal images of the right and left were used to assess L5 LM thickness at rest and during a submaximal contraction via contralateral arm lift (CAL) in both prone and standing positions. The handheld weight used for the CAL was based on the participant's body weight (<68.2kg = 0.68kg weight, 68.2-90.9kg = 0.9kg weight, >90.0kg = 1.36kg weight). The measurement techniques used are described in detail elsewhere.[16] Three images at rest and contracted for the right and left sides were obtained. Ultrasound images were stored and analyzed offline using OsiriX imaging software (OsiriXLiteVersion 9.0, Geneva, Switzerland). LM CSA were obtained by tracing the muscle borders on both sides on each image (Figure 1) and the average of the 3 measurements (on 3 different images) was used in the analysis (LM borders: paraspinals, laminae, and thoracolumbar fascia).[16–19] The relative % asymmetry in CSA between right and left sides was calculated using the following formula: [(larger side – smaller side)/larger side]x100%. LM thickness at rest and contracted in both prone and standing was obtained using linear measurements from the tip of the L5/S1 zygoapophyseal joint to the inside edge of the superior muscle border (Figure 2).[16–19] Each measurement was performed on 3 different images and the average was used in the analyses. The following formula was used to assess LM contraction: [($thickness_{contraction}$ – $thickness_{rest}$)/$thickness_{rest}$]x100. LM EI was measured using grayscale analysis imaging (ImageJ, National Institute of Health, USA, Version 1.49) by tracing a region of interest representing LM CSA in prone. A standard histogram function of pixels was used (0=black, 255=white). All measurements were taken by an experienced researcher and the rater was blinded to the players' characteristics and LBP history.

Figure 1 – LM CSA at L5. *Transverse ultrasound image showing the CSA LM measurement. Spinous process (SP) in the center of the image, echogenic laminae (La), longissimus (Lo), and thoracolumbar facia (TLF) were used as landmarks to define the LM muscle borders*.[17]

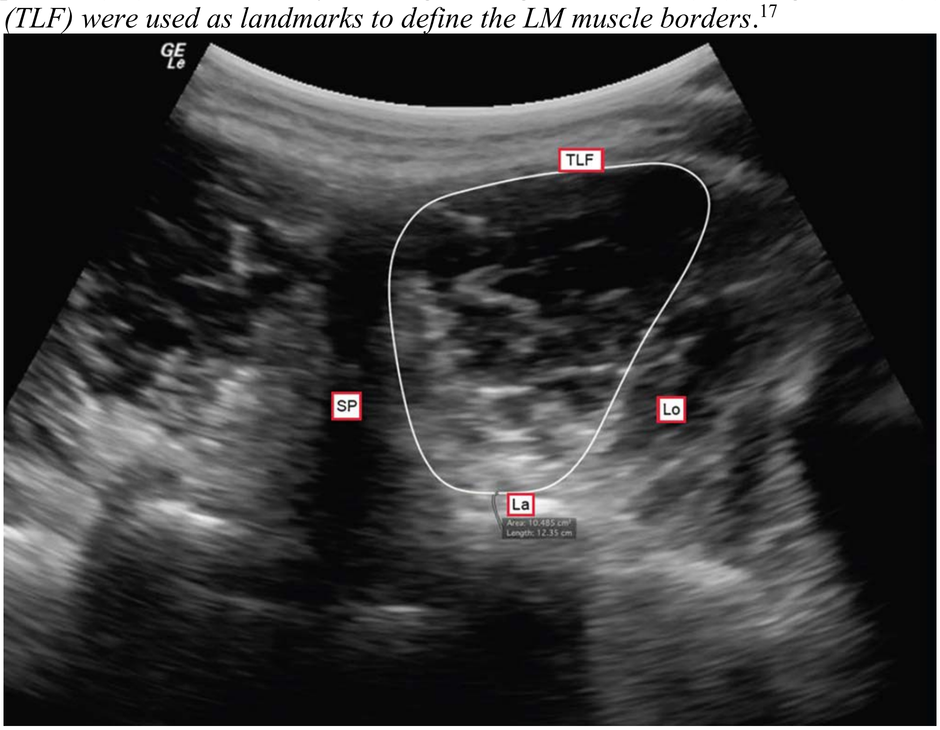
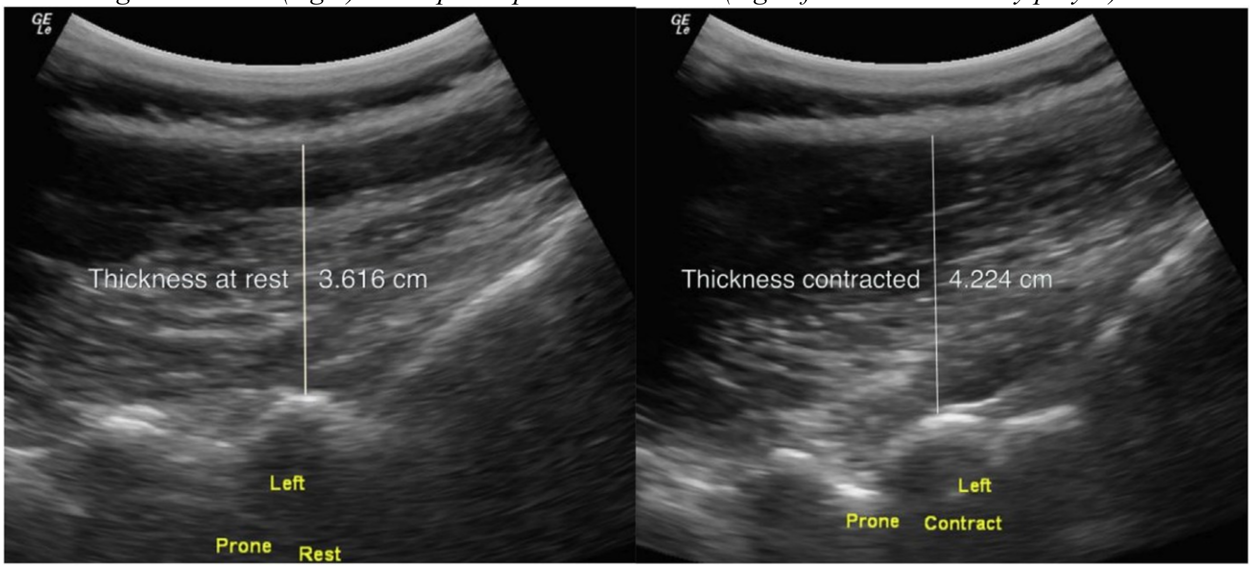


Figure 2 – LM thickness at rest and contracted at L5. *LM thickness muscle measurements at rest (left) and during contraction (right) in the prone position at L5-S1 (e.g. left side male hockey player).*[16]



2.3.5 DEXA

All participants had a full body DEXA scan (Lunear Prodigy Advance, GE) performed by a certified medical imaging technologist. Participants removed any metal and wore loose fitting clothing to avoid interference with the scan. Age, height, weight, and ethnicity were entered into the computer program prior to imaging. Participants were supine in the centre of the scanner. Their arms were held slightly away from the body with thumbs pointed upwards and their legs were slightly apart with toes pointed upwards. Total lean mass, total bone mass, total fat mass, and total % body fat were obtained.

2.3.6 Statistical Analysis

Means and standard deviations were calculated for athletes' characteristics and LM measurements of interest. Paired t-tests were used to examine the difference in LM characteristics (e.g. CSA, EI, CSA asymmetry, thickness at rest and during contraction both in prone and standing positions) and between the dominant and non-dominant sides, separately by sex. Independent t-tests were used to assess the difference in LM characteristics between male and female athletes. Logistic regression was used to determine if LM characteristics of interest were predictors of LBP. Similarly, a separate logistic regression analysis was conducted for LLI. To account for inter-individual anthropometric difference, a ratio variable was created of LM characteristics using the strongest body composition predictor. Accordingly, LM CSA and thickness measurements were divided by lean body mass or weight and LM EI by % body fat. Associations were first examined using univariate logistic regression. Sex, sport, number of years playing sport at a competitive level, and body composition measurements were also tested as possible covariates. A purposeful selection strategy was used and variables with a p-value <0.02 in the univariate analysis were tested for the multivariate logistic regression models. Variables with a p-value >0.05 were then removed from the models after being assessed as possible cofounders (e.g., variable leading to ±15% change in regression coefficients of significant variables in the model). The assumptions were tenable for each model and model's collinearity was verified.

2.4 RESULTS

2.4.1 Player Characteristics

Participants' characteristics are presented in Table 1. The mean ± SD age, height, and weight in females were 21.2±1.8 years, 166.6±6.5 cm, and 68.4±8.5 kg, respectively. The mean ± SD age, height, and weight in males were 20.9±1.4 years, 179.6±6.4 cm, and 86.7±17.0 kg, respectively. The average number of years playing at a competitive level was 9.0 years, with an average of 2.0 years playing at the university level. A total of 41% (n=55) reported having LBP in the previous 4 weeks and 39.5% (n=53) reported the presence of LBP in the previous 3 months. A total of 44% (n=59) of players reported having a LLI within the last year, with 26.1% (n=35) reporting a LLI in the previous 4 weeks.

Table 1: Participants' characteristics (mean ± SD).

	All (n = 134)	Female (n = 50)	Male (n = 84)
Age (yr)	21.0 ± 1.5	21.2 ± 1.8	20.9 ± 1.4
Height (cm)	174.8 ± 9.0	166.6 ± 6.5	179.6 ± 6.4
Weight (kg)	79.9 ± 16.9	68.4 ± 8.5	86.7 ± 17.0
Total lean mass (kg)	59.6 ± 12.1	47.3 ± 5.5	66.9 ± 8.6
Total bone mass (kg)	3.4 ± 0.6	2.8 ± 0.3	3.7 ± 0.5
Total fat mass (kg)	17.5 ± 9.0	18.7 ± 5.8	16.8 ± 10.4
Total body fat %	22.3 ± 8.0	28.0 ± 6.2	19.0 ± 7.1
BMI	26.0 ± 4.1	24.6 ± 2.7	26.8 ± 4.6
Dominant leg (n)[a]			
Right	109	42	67
Left	17	7	10
Either	7	0	7
Competitive level (yr)	9.0 ± 3.7	7.3 ± 3.7	8.6 ± 3.9
University level (yr)	2.0 ± 1.5	2.2 ± 1.5	1.5 ± 1.6
LBP 4 weeks prior (n)	55	19	36
LBP location 4 weeks prior (n)[b]			
Centered	21	6	15
Bilateral	12	4	8
Unilateral	21	9	12
VAS LBP (0-10) 4 weeks prior	4.2 ± 1.9	4.1 ± 1.4	4.3 ± 1.8
LBP 3 months prior (n)	53	16	37
LBP location 3 months prior (n)[b]			
Centered	23	8	15
Bilateral	14	4	10
Unilateral	15	4	11
VAS LBP (0-10) 3 months prior	4.4 ± 1.9	4.0 ± 2.0	4.7 ± 1.7
LBP last competitive year (n)[c]	39	14	25
LLI 4 weeks prior (n)[d]	35	9	26
LLI 12 months prior (n)	59	22	37

[a] – One missing data from the female group
[b] – One missing data from the male group
[c] – Five missing data from the male group
[d] – Two missing data from the female group

2.4.2 LM Characteristics in Male and Female Players

LM characteristics of dominant and non-dominant leg in males and females are presented in Table 2. LM CSA was significantly larger on the non-dominant side in prone in both males and females ($p<0.05$). The same trends were observed in standing; however they were not significant. LM thickness was significantly greater on the non-dominant side in prone both at rest ($p<0.05$) and contracted (females: $p<0.05$; males: $p<0.001$). Similarly, LM thickness in standing was also greater on the non-dominant side both at rest and contracted, however it was not significant. There were no significant differences in % thickness change on dominant and non-dominant sides in either prone or standing.

Table 2: Dominant and non-dominant leg LM characteristics in female and male athletes (mean ± SD).

	Female		Male	
	Dominant	Non-Dominant	Dominant	Non-Dominant
PRONE				
CSA (cm^2)	8.11 ± 1.33*	8.26 ± 1.32	10.34 ± 1.58*	10.54 ± 1.55
CSA asymmetry (%)	3.82 ± 3.33		4.50 ± 3.09	
EI	72.39 ± 17.21	70.82 ± 16.64	51.88 ± 15.61	51.99 ± 15.13
Thickness (cm)				
Rest	2.77 ± 0.40*	2.85 ± 0.41	3.34 ± 0.54*	3.41 ± 0.54
Contracted	3.20 ± 0.46*	3.26 ± 0.45	3.80 ± 0.54**	3.90 ± 0.54
% change	15.52 ± 6.81	14.74 ± 7.47	14.57 ± 8.68	15.11 ± 8.68
STANDING				
CSA (cm^2)	9.57 ± 1.58	9.65 ± 1.44	11.77 ± 1.51	11.91 ± 1.62
CSA asymmetry (%)	3.54 ± 2.84		2.92 ± 2.56	
Thickness (cm)				
Rest	3.22 ± 0.46	3.26 ± 0.43	3.85 ± 0.57	3.85 ± 0.57
Contracted	3.32 ± 0.46	3.36 ± 0.47	3.98 ± 0.56	4.01 ± 0.58
% change	3.55 ± 4.69	3.31 ± 4.66	3.58 ± 4.13	4.32 ± 4.99

* = p<0.05 within female or male
** = p<0.001 within female or male

Overall LM characteristics (e.g., average of dominant and non-dominant sides) in prone vs. standing in male and female players are presented in Table 3. LM CSA was significantly smaller in prone compared to standing (p<0.001). LM CSA asymmetry was greater in the prone position compared to standing but was only significant in males (p<0.001). LM thickness at rest and contracted were significantly greater in the standing position compared to prone (p<0.001). The % thickness change was significantly smaller in the standing position compared to prone (p<0.001). Males had significantly larger LM CSA and thickness at rest and contracted in both prone and standing positions compared to females (p<0.001). Females had significantly higher EI than males (p<0.001). There was no significant difference in CSA asymmetry or % change in thickness between male and female athletes in prone or standing.

Table 3: LM characteristics in female and male athletes in prone vs standing (mean ± SD).

	Female		Male	
	Prone	Standing	Prone	Standing
CSA (cm^2)	**8.18 ± 1.31***	**9.35 ± 1.40**	10.41 ± 1.55*	11.86 ± 1.52
CSA asymmetry (%)	3.82 ± 3.33	3.56 ± 2.87	4.53 ± 3.11*	2.97 ± 2.57
EI	**71.61 ± 16.31**		52.14 ± 15.30	
Thickness (cm)				
Rest	**2.81 ± 0.40***	**3.24 ± 0.43**	3.37 ± 0.53*	3.82 ± 0.55
Contracted	**3.24 ± 0.45***	**3.35 ± 0.45**	3.85 ± 0.52*	3.97 ± 0.55
% change	15.16 ± 6.66*	3.51 ± 3.56	15.20 ± 8.22*	3.98 ± 3.73

bold = p<0.001 between female and male
* = p<0.001 within female or male

2.4.3 LM Characteristics and LBP

Univariate and multivariate logistic regression for LBP in the previous 4 weeks and 3 months is presented in Table 4. Univariate logistic regression analysis revealed years played at the university level and LM thickness at rest in prone were significant predictors of LBP in the previous 4 weeks ($p \leq 0.05$) and weight, BMI, and LM CSA, thickness at rest and contracted in prone and standing were significant predictors of LBP in the previous 3 months ($p \leq 0.05$). Thickness at rest in prone (OR=0.49 [0.27, 0.88], p=0.02) and years played at the university level (OR=1.29 [1.01, 1.65], p=0.04) remained significant in the multivariable analysis and associated with a 51% decreased and 29% increased odds of having LBP in the previous 4 weeks, respectively. While smaller side of LM thickness at rest in prone (OR=0.43 [0.21-0.89], p=0.02) remained significant in the multivariable analysis model and was associated with a 57% decreased odds of having LBP in the previous 3 months, along with weight (OR=1.01 [0.99, 1.04], p=0.27) and years played at the university level (OR=1.26 [0.97, 1.61], p=0.08) which were confounders.

Table 4: Player and LM characteristics in athletes with and without LBP in the previous 4 weeks and 3 months.

	LBP 4 Weeks				LBP 3 Months			
	Univariate		Multivariate		Univariate		Multivariate	
	OR (95% CI)	p-value	OR (95% CI)	p-value	OR (95% CI)	p-value	OR (95% CI)	p-value
Age	1.07 (0.85-1.34)	0.58			1.07 (0.85-1.34)	0.58		
Sex	1.22 (0.60-2.50)	0.58			1.67 (0.80-3.49)	0.17		
Sport	1.01 (0.75-1.35)	0.97			1.01 (0.75-1.36)	0.96		
Height (cm)	1.01 (0.97-1.05)	0.54			1.04 (1.00-1.08)	0.08		
Weight (kg)	1.01 (0.99-1.03)	0.37			**1.03 (1.00-1.05)**	**0.02**	1.01 (0.99-1.04)	0.27
BMI	1.04 (0.95-1.13)	0.42			**1.09 (1.00-1.19)**	**0.05**		
Yrs Competitive	1.07 (0.97-1.17)	0.17			1.01 (0.92-1.11)	0.81		
Yrs Concordia	**1.27 (1.00-1.61)**	**0.05**	**1.29 (1.01-1.65)**	**0.04**	1.24 (0.98-1.57)	0.08	1.26 (0.97-1.62)	0.08
% body fat	2.45 (0.03-178.19)	0.68			0.66 (0.01-50.00)	0.85		
PRONE								
CSA (cm^2)								
Average[a]	0.88 (0.76-1.01)	0.06			**0.86 (0.75-0.99)**	**0.04**		
Asymmetry (%)	1.05 (0.94-1.17)	0.37			0.99 (0.89-1.11)	0.90		
Small side[a]	0.88 (0.77-1.01)	0.08			0.87 (0.76-1.01)	0.06		
EI[b]	0.92 (0.57-1.48)	0.73			1.12 (0.70-1.80)	0.64		
Thickness at rest (cm)								
Average[c]	**0.50 (0.28-0.89)**	**0.02**	**0.49 (0.27-0.88)**	**0.02**	**0.37 (0.20-0.69)**	**<0.01**		
Asymmetry	0.36 (0.03-4.92)	0.45			5.62 (0.43-73.07)	0.19		
Small side[c]	**0.51 (0.29-0.91)**	**0.02**			**0.36 (0.19-0.67)**	**<0.01**	**0.43 (0.21-0.89)**	**0.02**

Thickness contracted (cm)				
Average[a]	0.76 (0.54-1.07)	0.11	**0.62 (0.43-0.89)**	**0.01**
Asymmetry	0.34 (0.03-3.64)	0.37	1.79 (0.19-17.34)	0.62
Small side[a]	0.77 (0.55-1.07)	0.12	**0.64 (0.45-0.91)**	**0.01**
% Thickness Change				
Average	1.02 (0.98-1.07)	0.31	1.03 (0.99-1.08)	0.19
Asymmetry	1.07 (0.98-1.18)	0.15	1.10 (1.00-1.21)	0.05
Small side	1.01 (0.97-1.06)	0.67	1.02 (0.98-1.07)	0.37
STANDING				
CSA (cm^2)				
Average[a]	0.90 (0.79-1.01)	0.08	**0.87 (0.77-0.99)**	**0.04**
Asymmetry (%)	0.99 (0.87-1.14)	0.92	1.08 (0.94-1.23)	0.29
Small side[a]	0.89 (0.79-1.01)	0.07	**0.87 (0.77-0.99)**	**0.03**
Thickness at rest (cm)				
Average[a]	0.75 (0.53-1.06)	0.10	**0.63 (0.44-0.91)**	**0.01**
Asymmetry	0.33 (0.03-4.26)	0.40	2.36 (0.19-28.87)	0.50
Small side[a]	0.76 (0.54-1.08)	0.13	**0.63 (0.43-0.90)**	**0.01**
Thickness contracted (cm)				
Average[a]	0.77 (0.55-1.08)	0.13	**0.63 (0.44-0.90)**	**0.01**
Asymmetry	0.54 (0.04-8.07)	0.66	4.07 (0.28-59.44)	0.31
Small side[a]	0.76 (0.54-1.07)	0.11	**0.61 (0.42-0.87)**	**0.01**
% Thickness Change				

Average	0.98 (0.89-1.08)	0.69	0.95 (0.86-1.05)	0.30
Asymmetry	1.05 (0.95-1.15)	0.35	1.03 (0.94-1.13)	0.56
Small side	0.97 (0.89-1.06)	0.46	0.95 (0.87-1.04)	0.25

Bold = univariate $p<0.2$
Only multivariate with $p<0.05$ shown
[a]Adjusted for total lean body mass
[b]Adjusted for %body fat
[c]Adjusted for weight

2.4.4 LM Characteristics and LLI

Univariate and multivariate logistic regression for LLI in the previous 4 weeks and 12 months is presented in Table 5. Univariate logistic regression analysis revealed only sport was a significant predictor of LLI in the previous 4 weeks ($p=0.02$) and sport and LM CSA asymmetry in prone, were significant predictors of LLI in the previous 12 months ($p\leq0.02$). There were no significant predictors retained in the multivariate logistic regression model for LLI in the previous 4 weeks. Increased LM CSA asymmetry (OR=1.14 [1.01, 1.28], $p=0.03$) in prone and type of sport (OR=1.44 [1.04, 1.96], $p=0.02$) were significant predictors in the multivariable model for LLI in the previous 12 months, and associated with 14% and 44% increased odds of having a, respectively, with football having the strongest association.

Table 5: Player and LM characteristics in athletes with and without LLI in the previous 4 weeks and 12 months.

	LLI 4 Weeks				LLI 12 Months			
	Univariate		Multivariate		Univariate		Multivariate	
	OR (95% CI)	p-value	OR (95% CI)	p-value	OR (95% CI)	p-value	OR (95% CI)	p-value
Age	1.11 (0.86-1.43)	0.44			1.09 (0.87-1.37)	0.45		
Sex	1.94 (0.82-4.59)	0.13			1.00 (0.50-2.03)	1.00		
Sport	**1.51 (1.06-2.14)**	**0.02**	**1.51 (1.06-2.14)**	**0.02**	**1.47 (1.09-2.00)**	**0.01**	**1.44 (1.05-1.96)**	**0.02**
Height (cm)	1.02 (0.98-1.07)	0.30			0.99 (0.96-1.03)	0.73		
Weight (kg)	1.00 (0.98-1.03)	0.79			1.00 (0.98-1.02)	0.73		
BMI	0.99 (0.90-1.09)	0.86			1.03 (0.95-1.15)	0.53		
Yrs Competitive	1.06 (0.96-1.18)	0.25			1.05 (0.96-1.15)	0.33		
Yrs Concordia	0.90 (0.69-1.17)	0.42			1.00 (0.80-1.25)	0.99		
% body fat	0.29 (0.00-37.44)	0.62			0.50 (0.01-35.54)	0.75		
PRONE								
CSA (cm^2)								
Average[a]	0.97 (0.84-1.13)	0.72			0.92 (0.80-1.05)	0.21		
Asymmetry (%)	1.10 (0.97-1.23)	0.13			**1.14 (1.02-1.28)**	**0.02**	**1.14 (1.01-1.28)**	**0.03**
Small side[a]	0.95 (0.82-1.11)	0.55			0.91 (0.80-1.04)	0.17		
EI[b]	0.59 (0.32-1.09)	0.09			0.67 (0.41-1.10)	0.11		
Thickness at rest (cm)								
Average[c]	1.10 (0.60-2.01)	0.77			1.22 (0.71-2.10)	0.46		
Asymmetry	0.61 (0.03-11.24)	0.74			4.29 (0.34-54.70)	0.26		
Small side[c]	1.12 (0.61-2.08)	0.71			1.20 (0.70-2.07)	0.51		
Thickness contracted (cm)								

Average[a]	1.04 (0.72-1.50)	0.83	1.06 (0.76-1.47)	0.73
Asymmetry	0.28 (0.02-4.49)	0.37	0.66 (0.07-6.45)	0.72
Small side[a]	1.08 (0.75-1.55)	0.67	1.08 (0.78-1.49)	0.63
% Thickness Change				
Average	1.03 (0.98-1.08)	0.29	0.99 (0.95-1.04)	0.75
Asymmetry	1.05 (0.95-1.16)	0.36	1.03 (0.94-1.13)	0.53
Small side	1.02 (0.98-1.08)	0.34	0.99 (0.95-1.04)	0.78
STANDING				
CSA (cm^2)				
Average[a]	0.89 (0.78-1.03)	0.11	0.93 (0.83-1.04)	0.22
Asymmetry (%)	0.96 (0.82-1.12)	0.60	0.98 (0.86-1.12)	0.80
Small side[a]	0.89 (0.77-1.02)	0.09	0.93 (0.83-1.04)	0.19
Thickness at rest (cm)				
Average[a]	1.04 (0.72-1.52)	0.82	1.11 (0.80-1.55)	0.55
Asymmetry	0.39 (0.02-7.04)	0.53	0.57 (0.05-6.90)	0.66
Small side[a]	1.06 (0.73-1.54)	0.76	1.12 (0.81-1.56)	0.50
Thickness contracted (cm)				
Average[a]	1.01 (0.70-1.45)	0.97	1.05 (0.76-1.44)	0.79
Asymmetry	1.76 (0.09-33.86)	0.71	4.76 (0.33-69.10)	0.25
Small side[a]	0.99 (0.69-1.42)	0.95	1.06 (0.77-1.46)	0.73
% Thickness Change				
Average	0.92 (0.82-1.02)	0.12	0.97 (0.88-1.06)	0.49

Asymmetry	1.02 (0.91-1.13)	0.75		0.95 (0.87-1.05)	0.34
Small side	0.92 (0.83-1.02)	0.12		0.99 (0.91-1.08)	0.80

Bold = univariate $p<0.2$
Only multivariate with $p<0.05$ shown
[a]Adjusted for total lean body mass
[b]Adjusted for %body fat
[c]Adjusted for weight

2.5 DISCUSSION

2.5.1 LM characteristics

This study investigated the morphology and function of LM at L5 in an athletic population. In accordance with previous studies in athletes[16–19,77], males had larger and thicker LM at L5 in both prone and standing positions at rest and contracted. The larger stature of male athletes likely explains the differences in LM characteristics; taller individuals have increased distance between spinal segments, requiring larger LM CSA to reach from segment to segment, and heavier individuals may have larger and thicker LM to provide increased stability to support the additional mass. Females had significantly greater EI than males. This was expected as females generally have a higher % body fat than males in both athletic and general populations[16,18,24,25,37,56,77], which is also reflected by higher intramuscular fat.[116,117] However, the role of body composition on LM morphology and function was not an objective of this study and warrants further attention.

LM CSA was significantly larger on the non-dominant side in males and females in prone. Similarly, LM thickness on the non-dominant side was significantly greater at rest and during contraction in the prone position. While LM CSA and thickness were also greater on the non-dominant side in standing, the difference did not reach statistical significance. Previous studies in athletic populations also reported larger LM CSA and thickness on the stance leg (i.e. non-dominant leg) as this leg provides a stabilizing role while kicking.[18,61,77] The observed larger and thicker LM on the non-dominant side could be explained by the need to provide increased stability and proprioceptive control for the forces going through the kinetic chain on the stabilizing leg. However, rowers and elite weightlifters showed no LM CSA asymmetry at L5[110,118] and elite cricketers had greater LM CSA on the same side as their dominant arm[49,119], indicating the differences in LM CSA asymmetry between sports may be the result of the different demands of each sport.

As expected, LM CSA and thickness at rest and contracted significantly increased from a prone to standing position in both males and females. LM CSA asymmetry at L5 was significantly lower in standing compared to prone in males. This same trend was observed in females; however, it was not statistically significant. These trends in LM morphology observed in the standing position may be attributed to the LM being already contracted in standing to provide appropriate stabilization and proprioceptive control of the lumbar segments.[81,120,121] Furthermore, % change in thickness was significantly lower in standing compared to prone in both males and females, which is corroborated in previous single sport research.[16–19,77] It is important to understand how LM modulates in more functional positions due to the increased need for stability in the lumbar spine during athletic movements (e.g. change of direction, sprinting, and tackling). The increased forces going through the kinetic chain in athletes and physical demands of the sport may also explain the hypertrophy observed in athletes when compared to nonathletic populations.[25,86,103]

2.5.2 LM Characteristics and LBP

Univariate logistic regression revealed several associations between LM characteristics (LM CSA and thickness at rest and contracted in prone and standing) and the presence of LBP in the previous 3 months in university athletes, indicating they may play a part in the etiology. In previous studies with smaller sample sizes and where sports were investigated individually, significant associations between LM characteristics and LBP were also reported, however the LM characteristics associated with LBP were inconsistent between sports[16–21,77,110,122] The inconsistent findings may be related to inconsistencies in measurement methodologies between studies.[60] When multiple sports were combined in our study, multivariate logistic regression revealed LM thickness was the only LM characteristic to remain a significant predictor of LBP in the previous 4 weeks and 3 months. This suggests that thickness is likely the strongest predictor for LBP in athletes and should be further investigated in future studies. Athletes with thicker LM may have better contractibility and a greater capacity to produce more force during contraction, leading to a protective effect and greater stabilization of the lumbar spine during movement. Previous electromyography (EMG)[41,42,123,124] and ultrasound[16–19,77] studies have found both increased and decreased activity of LM in individuals with LBP, suggesting changes in LM activity in either direction may be a maladaptive behaviour. In the current study, % thickness change in prone and standing was not a predictor of LBP. The conflicting evidence may occur because this measure is used to investigate how much change there is from rest to a contracted state but does not provide information regarding the strength or timing of the contraction. Future studies in athletes may want to include EMG measurements of the LM in functional positions to assess muscle activity and activation patterns.

Our findings suggest that athletes who played longer at the university level had increased odds of having LBP. The increased demands placed on the body through the kinetic chain due to the higher competitive level and increased training volume and loads may explain this finding. One might expect that elite athletes that have been exposed to such forces for many years have decreased injury rates, however compensations can arise with minor injuries and training habits and over time the body becomes unable to withstand these forces, leading to injury. In accordance with previous studies in both athletic and general populations,[1,13,31] increased weight was also a confounding factor for LBP. Increased body weight puts additional stress on the spine which likely leads to compensatory movements that may contribute to the presence of LBP in athletes. Additional investigations are needed to extend our findings and clarify whether our results are translatable to other university varsity athletes.

2.5.3 LM Characteristics and LLI

Our findings revealed that a player's sport was a significant predictor of LLI in the previous 4 weeks and 12 months, with football having the strongest association. In the United States, American football has the highest injury rate compared to other team sports across all playing levels.[125,126] Furthermore, LLI accounted for 60% of all injuries in the NFL[127] and knee injuries were the most common and severe at the university level in the United Kingdom.[128] The various movements required in football (i.e. sprinting, planting, twisting, etc.) and the potential for high impact from tackling leads to increased risk of injury. Greater LM CSA asymmetry in prone was also associated with LLI in the previous 12 months, which is corroborated in some[61,129] but not all AFL studies[28]. The association between LM characteristics and LLI may be sport specific or may not play as large a role in the presence of LLI as compared to LBP. When athletes are placed in more functional position (i.e. standing), there is a decrease in LM CSA asymmetry, regardless of the presence of injury or pain, suggesting LM retains the ability to contract when put under increased stress.[16–19,77] Future studies could investigate whether the longevity of LM contraction (e.g. the ability to maintain a contraction over a period of time or during application of a force) is associated with the risk of LLI in athletes. Furthermore, while LM CSA was not associated with LLI in this study or in AFL players[129], AFL players with greater quadratus lumborum CSA have an increased risk of sustaining a LLI. It stands to reason that other trunk muscles may play a part in the bigger picture of LLI in athletes due to connections through the kinetic chain and fascia of the trunk. It is imperative to take these connections into consideration in future studies.

2.5.4 Limitations

Only 4 sports were including in this study. Other sports, including non-contact sports, should be examined to provide a broader view of LM morphology and function and injury susceptibility in university varsity athletes. Furthermore, LM characteristics were only examined at one spinal level in prone and standing positions. Future studies should consider protocols for including functional positions more closely related to frequent positions the athletes are in during their sport, include additional level and trunk muscle involved in spinal stability. It may also be beneficial for future studies to examine the impact higher forces have on LM to further mimic the sport environment.

2.6 CONCLUSION

This study provides new insights on LM morphology and function in prone and standing positions in male and female university level varsity athletes and their associations with LBP and LLI. Males have larger and thicker LM compared to females in all positions. LM was also significantly larger and thicker on the non-dominant side in both males and females in the prone position, suggesting leg dominance and sport specific demands may play a role in unilateral hypertrophy. Our findings suggest that LM thickness and CSA asymmetry are significant predictors of LBP and LLI, respectively. Preseason LM ultrasound screening should focus on these parameters as possible indicators in the prevention and rehabilitation of LBP and LLI in university level athletes. Future studies should examine additional neuromuscular aspects of LM in functional positions to better understand the role of LM morphology and function in athletic populations.

CHAPTER 3

Manuscript 2:

Lumbar multifidus characteristics and body composition in university level athletes

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3.1 ABSTRACT

Introduction: Body composition is well known to affect sport performance and plays a role in lumbar multifidus (LM) morphology and function. Previous studies indicated that structural and functional LM impairments in athletes were associated with low back pain and lower leg injuries. However few studies have examined the relationship between LM characteristics and body composition in athletic populations.

Methods: This cross-sectional study included a total of 134 university varsity athletes (hockey, soccer, rugby, and football players). Ultrasound imaging was used to examined LM characteristics at the L5 bilaterally (e.g., size, thickness at rest, thickness during contraction, echo-intensity (EI) and % thickness change from rest to contraction) and body composition parameters (dual-energy X-ray absorptiometry). Pearson correlations were used to assess the relationship between LM characteristics and body composition parameters. One-way ANOVA assessed differences in LM characteristics and body composition between sports. All analyses were performed separately by sex.

Results: LM size and thickness were positively correlated with weight, height, lean body mass and total bone mass (male: $r=0.23-0.55$, $p<0.01-0.05$; female: $r=0.30-0.39$, $p<0.01-0.05$). LM EI was strongly correlated with % body fat (male: $r=0.62$, female: $r=0.71$, $p<0.01$). LM thickness at rest ($r=0.42$, $p<0.01$) and contracted ($r=0.27$, $p<0.05$) were positively correlated and % thickness change was negatively correlated with % body fat in male athletes ($r=-0.43$, $p<0.01$).

Conclusion: significant differences in body composition and LM characteristics between sports were found that may be attributed to sport specific demands. Understanding connections between body composition and LM may aid in preseason screening for athletes at risk of low back pain or lower leg injuries during the season.

3.2 INTRODUCTION

Body composition provides insights into an individual's fat tissue, lean tissue, and bone density, and can be used to determine an individual's health status. In collegiate level athletes, body composition has been investigated extensively to provide baselines in individual sports.[73,93–96] Body composition parameters are associated with both performance and incidence of injury in collegiate athletes.[97,101,130] Differences in body composition between sport[73,93–98], between positions of the same sport[93,99–102], and throughout a competitive season were also reported.[94,98] While there are several ways to measure body composition, dual energy x-ray absorptiometry (DEXA) is the gold standard. DEXA is suitable for most athletes, is fast, non-invasive, and provides regional body composition (i.e. separation into arms, legs, trunk, etc.).[131] DEXA measures bone mass (the density of bone in the body), lean mass (the amount of soft tissue that is not bone or fat), and fat mass (the amount of fat present relative to height), in addition to visceral adipose tissue, android to gynoid ratio, fat free mass index, and % body fat. As body composition is an important part of the overall health of an athlete, it can be monitored and provide useful information for coaches, trainers, and other health professionals involved in tailoring training programs to an athlete's specific needs.

Ultrasound (US) is a valid and reliable way to assess muscle characteristics.[53,69] Previously, it has been used to investigate muscle cross-sectional area (CSA), thickness, % change in thickness, and echo intensity (EI) in athletes.[16–19,77] CSA is a measure of muscle size, thickness is how thick the muscle is at rest or during contraction, % thickness change is the difference observed between a resting and contracted state of the muscle, and EI is the mean pixel intensity of a region of interest on an US image, which can be used as an indicator of muscle quality (e.g. degree of intramuscular fatty infiltration and connective tissue).[56,71] In general, muscles that are larger, thicker, and have less intramuscular fat demonstrate greater strength and power.[130,132,133] Higher EI can decrease muscle quality as muscle fibres are replaced by fat.[39] Thus, improvement in muscle EI and size may be important for performance and injury prevention. US imaging and body composition assessments may be a feasible way to monitor the effect of training adaptations in athletes.

Lumbar multifidus (LM) is a muscle that provides stabilization and proprioceptive feedback of the lumbar spine and force transferal of the extremities through the kinetic chain.[27,34,41] Changes in the morphology and function of LM have been investigated in both athletic[16–19,22,23,77] and non-athletic[44–46] populations with and without low back pain (LBP) and lower limb injury (LLI). While athletes with LBP and LLI tend to have decreased LM CSA and thickness and increased LM CSA asymmetry, EI, and % change in thickness[16–19,22,23,61–63,77], results remain inconsistent.[19,50,110] LM morphology is also influenced by age, gender, height, and weight, and comprehensive studies evaluating the relationship between body composition and LM characteristics in athletes are limited.[16–19,77]

Therefore, the purpose of this study was to evaluate the relationship between body composition and LM muscle characteristics in a large sample of male and female university level varsity athletes including hockey, soccer, rugby, and American football players. A secondary objective was to examine differences in body composition and LM characteristics between sports according to sex. We hypothesized that LM CSA and thickness will have a negative correlation with fat mass and % body fat and a positive correlation with lean tissue mass. We also hypothesized that increased LM EI and % change in thickness will have a positive correlation with fat mass and % body fat and a negative correlation with lean mass. Finally, we hypothesized that LM CSA would be larger in football and hockey players and that both male and female soccer athletes would have the lowest fat mass and % body fat compared to the other sports investigated.

3.3 METHODS

3.3.1 Experimental Approach to the Problem

This was a cross-sectional study. Our objective was to examine DEXA and LM morphology and function measures prior to the start of the season. From these reports, we were able to examine correlations between body composition and LM characteristics in male and female athletes and obtain differences in body composition between sports in male and female athletes.

3.3.2 Subjects

A total of 134 participants (50 female, 84 male) from four varsity teams at Concordia University were included in the current study (ice hockey players (32; 18 female, 14 male), football players (41; all male), soccer players (27; 12 female, 15 male), and rugby players (34; 20 female, 14 male). The exclusion criteria included previous severe trauma or spinal fracture, previous spinal surgery, observable spinal abnormalities, and pregnancy specifically for the DEXA scan. The average age, height, and weight for female players was 21.2 ± 1.8 years, 166.6 ± 6.5cm, and 68.4 ± 8.5kg, respectively. The average age, height, and weight for male players was 20.9 ± 1.4 years, 179.6 ± 6.4cm, and 86.7 ± 17.0kg, respectively. The average numbers of years played competitively for female and male players was 7.3 ± 3.7 and 8.6 ± 3.9, respectively. The study was approved by the Research Ethical Committee of the Institution and by the Central Ethics Committee of the Quebec Minister of Health and Social Services. All players provided a written informed consent.

3.3.3 Procedures

DEXA

All participants had a full body DEXA scan (Lunear Prodigy Advance, GE) performed by a certified medical imaging technologist. Participants wore loose fitting clothing and removed any metal to avoid interference with the scan. Age, height, weight, and ethnicity were entered into the computer program prior to imaging. Participants were supine in the centre of the scanner with their arms held slightly away from the body with thumbs pointed upwards and legs slightly apart with toes pointed upwards. Total lean mass, arm lean mass, leg lean mass, total bone mass, total fat mass, and total % body fat were obtained.

Ultrasound

Ultrasound B-mode images of LM were acquired using a LOGIQ e ultrasound machine (GE Healthcare, Milwaukee, WI) with a 5MHz curvilinear transducer. The imaging parameters were consistent for all acquisitions (frequency: 5MHz, gain: 60, depth: 8.0cm).

LM CSA & thickness measurements

Bilateral transverse images of the right and left LM CSA at L5 were obtained in prone position. In athletes with larger muscles, the right and left sides were imaged separately. Parasagittal images of the right and left were used to assess L5 LM thickness at rest and during a submaximal contraction via contralateral arm lift (CAL) in prone position. The handheld weight used for the CAL was based on the participant's body weight (<68.2kg = 0.68kg, 68.2-90.9kg = 0.9kg, >90.0kg = 1.36kg). The measurement techniques used are described in detail elsewhere.[16]

Imaging assessment

Ultrasound images were stored and analyzed offline using OsiriX imaging software (OsiriXLiteVersion 9.0, Geneva, Switzerland). LM CSA was obtained by tracing the muscle borders on both sides (LM borders: paraspinals, laminae, and thoracolumbar fascia).[16–19] The relative % asymmetry in CSA between right and left sides was calculated using the following formula: [(larger side – smaller side)/larger side]x100%. LM thickness at rest and contracted in both in prone and standing positions were obtained using linear measurements from the tip of the L5/S1 zygoapophyseal joint to the inside edge of the superior muscle border.[16–19] The following formula was used to assess LM contraction: $[(\text{thickness}_{contraction} - \text{thickness}_{rest})/\text{thickness}_{rest}]\text{x}100$. LM EI was measured using grayscale analysis imaging (ImageJ, National Institute of Health, USA, Version 1.49) by tracing a region of interest representing LM CSA in prone. A standard histogram function of pixels was used (0=black, 255=white). All measurements were performed 3 times on 3 different images and the average was used in subsequent analyses.

3.3.4 Statistical Analyses

The intra-class correlation coefficients (ICC) for LM characteristics ranged from 0.96-0.99 with a standard error of measurement (SEM) of 0.04-0.14cm^2 and LM EI measurements had a reliability of 0.99 with SEM of 1.97.[16] Means and standard deviations were calculated for athletes' body composition measurements and LM characteristics. Pearson's correlation coefficients were used to examine the correlation between body composition and LM measurements in female and male athletes, separately. A one-way ANOVA was performed to examine the differences of body composition and LM characteristics between sports in male and female athletes separately. Post-hoc tests were only completed for variables with a $p<0.05$. All significant female variables were run through a Tukey post-hoc test. In males, a Games-Howell post-hoc test was used for significant variables without equal variance and a Hochberg post-hoc test was used for significant variables with equal variance, as the sample size differed between groups.

3.4 RESULTS

Player demographics for female and male athletes are presented in Table 1.

Table 1: Participants' characteristics (mean ± SD).

	Female (n = 50)	Male (n = 84)
Age (yr)	21.2 ± 1.8	20.9 ± 1.4
Height (cm)	166.6 ± 6.5	179.6 ± 6.4
Weight (kg)	68.4 ± 8.5	86.7 ± 17.0
Total lean mass (kg)	47.3 ± 5.5	66.9 ± 8.6
Total bone mass (kg)	2.8 ± 0.3	3.7 ± 0.5
Total fat mass (kg)	18.7 ± 5.8	16.8 ± 10.4
Total body fat %	28.0 ± 6.2	19.0 ± 7.1
BMI	24.6 ± 2.7	26.8 ± 4.6
Competitive level (yr)	7.3 ± 3.7	8.6 ± 3.9
University level (yr)	2.2 ± 1.5	1.5 ± 1.6

3.4.1 Correlation analyses

The correlation matrix between body composition values and LM characteristics in females is presented in Table 2. Weight was significantly positively correlated with all body composition measurements ($p<0.01$) and LM CSA and thickness at rest ($p<0.05$). In addition to weight, CSA was also significantly positively correlated with total lean mass ($p<0.05$), total bone mass ($p<0.01$), and height

($p<0.01$). EI was only significantly positively correlated with total fat mass and total % body fat ($p<0.01$). Total bone mass was positively correlated with thickness both at rest ($p<0.05$) and contracted ($p<0.01$). There was no significant correlation between body composition measurements and % LM thickness change.

Table 2: Correlation matrix for female university varsity athletes (n=50).

	Height	Weight	BMI	Total bone mass	Total lean mass	Total fat mass	% body fat	CSA[a]	EI[a]	Thickness rest	Thickness contracted	% thickness change
Height	1	0.52**	-0.15	0.72**	0.81**	-0.01	-0.28*	0.39**	-0.15	0.24	0.21	-0.07
Weight		1	0.77**	0.65**	0.72**	0.69**	0.43**	0.30*	0.12	0.32*	0.27	-0.14
BMI			1	0.23	0.23	0.80**	0.71**	0.08	0.27	0.21	0.18	-0.11
Total bone mass				1	0.79**	0.17	-0.09	0.39**	-0.05	0.31*	0.36**	0.10
Total lean mass					1	0.09	-0.24	0.36*	-0.26	0.24	0.26	0.05
Total fat mass						1	0.94**	0.09	0.57**	0.19	0.11	-0.25
% body fat							1	-0.01	0.62**	0.12	0.04	-0.26
CSA[a]								1	0.19	0.57**	0.49**	-0.22
EI[a]									1	0.13	0.04	-0.28
Thickness rest										1	0.92**	-0.25
Thickness contracted											1	0.15
% thickness change												1

**p<0.01
*p<0.05
[a]missing one data point

The correlation matrix between body composition values and LM characteristics in males is presented in Table 3. Weight was significantly positively correlated with all body composition and almost all LM measurements ($p<0.01$). LM CSA was significantly positively correlated with all body composition measurements ($p<0.01$). Thickness at rest was significantly positively correlated with all body composition measurements ($p<0.01$), except for height. Thickness contracted was significantly positively correlated with height and % body fat ($p<0.05$) and weight, total lean mass, total bone mass, and total fat mass ($p<0.01$). In addition to weight, % thickness change was also significantly negatively correlated with total fat mass and % body fat ($p<0.01$).

Table 3: Correlation matrix for male university varsity athletes (n=84).

	Height	Weight	BMI	Total bone mass	Total lean mass	Total fat mass	% body fat	CSA	EI	Thickness rest[a]	Thickness contracted[b]	% thickness change[b]
Height	1	0.43**	0.09	0.62**	0.55**	0.23*	0.11	0.31**	0.19	0.19	0.23*	0.03
Weight		1	0.94**	0.61**	0.85**	0.89**	0.75**	0.49**	0.51**	0.55**	0.43**	-0.36**
BMI			1	0.43**	0.73**	0.89**	0.78**	0.41**	0.48**	0.53**	0.39**	-0.40**
Total bone mass				1	0.77**	0.32**	0.16	0.31**	0.19	0.30**	0.31**	-0.05
Total lean mass					1	0.53**	0.31**	0.47**	0.18	0.48**	0.43**	-0.20
Total fat mass						1	0.95**	0.39**	0.67**	0.49**	0.34**	-0.41**
% body fat							1	0.30**	0.71**	0.42**	0.27*	-0.43**
CSA								1	0.17	0.65**	0.67**	-0.19
EI									1	0.12	0.07	-0.13
Thickness rest[a]										1	0.90**	-0.49**
Thickness contracted[b]											1	-0.07
% thickness change[b]												1

**p<0.01
*p<0.05
[a]missing one data point
[b]missing two data points

3.4.2 Body composition differences between sports

The results of the ANOVA for body composition and LM measurements in female players by sport are presented in Table 4. Female soccer players had significantly less total lean mass ($F_{2,47}$=3.918, p=0.027; 43.61±4.14kg) compared to rugby (48.55±5.57kg) and hockey players (48.35±5.45) with an average of 4.94kg less lean mass (95% CI: -9.56, -0.32; p=0.034) and 4.73kg less lean mass (95% CI: -9.45, -0.02; p=0.049), respectively. There was no significant difference in weight, height, total fat mass or % body fat between sports. Hockey players had significantly greater LM CSA ($F_{2,46}$=6.665, p=0.003; 8.98±1.19cm^2) compared to rugby (7.63±1.08cm^2) and soccer (7.87±1.31cm^2) with an average increase of 1.36cm^2 (95% CI: 0.42, 2.30; p=0.003) and 1.12cm^2 (95% CI: 0.05, 2.18; p=0.038), respectively. Hockey players also had significantly thicker LM at rest ($F_{2,47}$=3.778, p=0.03; 3.00±0.37cm) compared to rugby (2.67±0.37cm) with an average increase of 0.33cm (95% CI: 0.03, 0.63; p=0.025). There was no significant difference in % thickness change or EI between sports.

Table 4: Mean (±SD) for body composition and LM measurements in females by sport.

	Sport		
	Rugby (RUG, n=20)	Hockey (HOC, n=18)	Soccer (SOC, n=12)
Weight (kg)	71.28 (8.73)	67.69 (7.82)	64.64 (8.21)
Height (cm)	167.63 (5.44)	167.72 (5.58)	163.40 (8.50)
Total lean mass (kg)	48.55 (5.57)[ǂ]	48.35 (5.45)[ǂ]	43.61 (4.14)[ǂ]
Total arm lean mass (kg)	5.46 (0.90)[§]	5.51 (0.81)[§]	4.56 (0.50)[§]
Total leg lean mass (kg)	16.89 (2.05)[ǂ]	16.70 (1.97)	15.05 (1.79)[ǂ]
Total fat mass (kg)	20.19 (6.67)	17.13 (4.53)	18.59 (5.70)
% body fat	28.94 (7.07)	25.93 (4.80)	29.38 (6.32)
Total bone mass (kg)	2.87 (0.32)[ǂ]	2.83 (0.29)	2.57 (0.34)[ǂ]
LM CSA (cm^2)	7.63 (1.08)[a§]	8.98 (1.19)[ǂ§]	7.87 (1.31)[ǂ]
EI	70.93 (17.01)[a]	72.74 (15.96)	70.98 (17.05)
LM thickness at rest (cm)	2.67 (0.37)[ǂ]	3.00 (0.37)[ǂ]	2.76 (0.40)
LM thickness contracted (cm)	3.12 (0.52)	3.39 (0.36)	3.16 (0.38)
% thickness change	16.62 (7.27)	13.48 (5.75)	15.00 (6.29)

[a]missing one data point
[ǂ] = significant difference ($p<0.05$); total lean mass = SOC < RUG, HOC; total leg lean mass = SOC < RUG; total bone mass = SOC < RUG; LM CSA = SOC < HOC; LM thickness at rest = RUG < HOC
[§] = significant difference ($p<0.01$); total arm lean mass = SOC < RUG, HOC; LM CSA = RUG < HOC

The results of the ANOVA for body composition and LM characteristics in males by sport are presented in Table 5. Overall, football players had significantly larger values in all body composition measurements compared to soccer players, except for height. There was a statistically significant different in weight between groups ($F_{3,80}$=9.120, p<0.001). A Games-Howell post-hoc test revealed that football players (94.20±19.44kg) were significantly heavier than rugby (80.26±9.91kg) and soccer players (72.07±7.74kg), with an average increase of 13.94kg (95% CI: 3.19, 24.69; p=0.006) and 22.13kg (95% CI: 12.49, 31.77; p<0.001), respectively. Hockey players (86.69±6.78kg) were also significantly heavier than soccer players, with an average increase of 14.62kg (95% CI: 7.24, 22.00; p<0.001). Total fat mass also had a significant difference between groups ($F_{3,80}$=4.460, p=0.006). A Games-Howell post-hoc test revealed that soccer players (10.04±2.34kg) had significantly less fat mass than rugby (15.54±5.43kg), hockey (14.74±4.05kg), and football players (20.32±13.18kg), with an average of 5.50kg less (95% CI: -9.96,-1.05; p=0.013), 4.69kg less (95% CI: -8.15, -1.23; p=0.006), and 10.28kg less (95% CI: -16.00, -4.56; p<0.001), respectively. There was also a significant difference in % body fat between groups ($F_{3,80}$=3.518, p=0.019). A Games-Howell post-hoc test revealed that soccer players (14.50±2.88) had significantly less % body fat compared to rugby (19.88±5.30) and football players (20.85±8.65), with an average of 5.38% less (95% CI: -9.86, -0.90; p=0.015) and 6.36% less (95% CI: -10.44, -2.27; p<0.001), respectively. There was no significant difference in height between sports. There was a significant difference in LM thickness at rest between groups ($F_{3,79}$=4.582, p=0.005). A Hochberg's post-hoc test revealed that football players had significantly thicker LM at rest (3.56±0.54cm) compared to hockey players (3.05±0.49cm) with an average increase of 0.50cm (95% CI: 0.09, 0.92; p=0.009). Furthermore, there was a statistically significant difference in LM thickness contracted between groups ($F_{3,78}$=3.293, p=0.025). A Hochberg's post-hoc test revealed that football players had significantly thicker LM during a contracted state (4.01±0.52cm) compared to hockey players (3.56±0.57cm), with an average increase of 0.45cm (95% CI: 0.03, 0.87; p=0.29). There was no significant difference in LM CSA, EI, or % thickness change between sports

Table 5: Mean (±SD) for body composition and LM measurements in males by sport.

	Sport			
	Rugby (RUG, n=14)	Hockey (HOC, n=14)	Soccer (SOC, n=15)	Football (FB, n=41)
Weight (kg)	80.26 (9.91)[§]	86.69 (6.78)[¶]	72.07 (7.74)[¶]	94.20 (19.44)[§¶]
Height (cm)	176.30 (7.04)	181.75 (6.19)	179.50 (7.35)	179.97 (5.65)
Total lean mass (kg)	61.90 (7.52)[¶]	68.82 (4.90)[§]	59.06 (6.49)[§¶]	70.74 (7.95)[¶]
Total arm lean mass (kg)	8.45 (1.32)[¶]	9.47 (0.79)[¶]	7.03 (1.17)[¶]	10.12 (1.40)[¶]
Total leg lean mass (kg)	21.45 (2.83)[§]	23.90 (2.17)[ǂ]	20.84 (2.39)[ǂ¶]	24.95 (3.45)[§¶]
Total fat mass (kg)	15.54 (5.43)[ǂ]	14.74 (4.05)[§]	10.04 (2.34)[ǂ§¶]	20.32 (13.18)[¶]
% body fat	19.88 (5.30)[ǂ]	17.50 (4.11)	14.50 (2.88)[ǂ¶]	20.85 (8.65)[¶]
Total bone mass (kg)	3.41 (0.37)[§]	3.73 (0.50)	3.38 (0.44)[¶]	3.91 (0.38)[§¶]
LM CSA (cm^2)	10.33 (1.19)	9.84 (1.39)	9.93 (1.23)	10.81 (1.71)
EI	53.27 (12.07)	51.09 (13.96)	44.89 (15.39)	54.34 (16.07)
LM thickness at rest (cm)	3.18 (0.31)	3.05 (0.49)[§]	3.37 (0.52)[a]	3.56 (0.54)[§]
LM thickness contracted (cm)	3.72 (0.40)	3.56 (0.57)[ǂ]	3.80 (0.46)[a]	4.01 (0.52)[aǂ]
% thickness change	17.36 (7.55)	17.06 (8.98)	13.72 (9.33)[a]	13.61 (7.71)[a]

[a]missing one data point
[ǂ] = significant difference ($p<0.05$); total arm lean mass = SOC < RUG; total leg lean mass = SOC < HOC; total fat mass = SOC < RUG; % body fat = SOC < RUG; LM thickness contracted = HOC < FB
[§] = significant difference ($p<0.01$); weight = RUG < FB; total lean mass = SOC < HOC; total leg lean mass = RUG < FB; total fat mass = SOC < HOC; total bone mass = RUB < FB; LM thickness at rest = HOC < FB
[¶] = significant difference ($p<0.001$); weight = SOC < HOC, FB; total lean mass = RUG, SOC < FB; total arm lean mass = SOC < RUG < FB and SOC < HOC ; total leg lean mass = SOC < FB; total fat mass = SOC < FB; % body fat = SOC < FB; total bone mass = SOC < FB

3.5 DISCUSSION

3.5.1 Correlation analysis

Our results showed a significant positive correlation between weight and LM CSA and thickness at rest in female athletes. LM CSA was also significantly positively correlated with total lean mass, total bone mass, and height in females. In male athletes, Pearson correlation revealed weight was significantly positively correlated with all LM measurements, except % change in thickness. A significant positive correlation in males was observed between LM CSA and thickness at rest and contracted with all body composition measurements, except for thickness at rest and height, which were not significant. Previous single sport investigations also found similar positive correlations between LM CSA and thickness, height and weight[16–18,77], however these studies did not indicate if male and female analyses were completed separately similar to the current study. Heavier and taller individuals may require larger and thicker muscles to support the additional weight carried and to traverse the distance from segment to segment. Total bone mass was also significantly correlated with both thickness at rest and contracted in both females and males, which was previously observed in rugby and soccer players.[18,77] Increased force production may be required for stabilization of heavier bones during movement, thus a thicker LM may be necessary to produce a stronger contraction during stabilization. However, the increased total bone mass observed with a thicker LM may be the result of Wolff's Law, whereby bone is laid down to adapt to the forces being placed on it.[134]

Total fat mass and % body fat were significantly positively correlated with EI in both female and male athletes. Previously, EI was also strongly positively correlated with total % body fat[16–18,77] and total fat mass.[16,17] A larger amount of fat present in the body may lead to increased intramuscular fat, thus leading to a greater EI. The same three body composition variables were significantly negatively correlated with % thickness change, meaning that less fat resulted in a greater contraction, which indicates that the function of LM may be affected by the presence of fat in the body. EI and % thickness change were also negatively correlated, however it was not significant. In single sport research, a significant negative correlation between LM EI and % thickness change was also observed in football[17], while hockey had no association.[16] Previous research in rugby athletes found a weak positive correlation between LM % thickness change and % body fat[77] and a study investigating elite athletes competing at an international level found a negative correlation between % body fat and fat mass and torso muscle strength.[130] These results may also explain why football athletes had decreased LM % thickness change, as they also had the greatest % body fat, total fat mass, and EI. Interestingly, previous studies with football and cross-country collegiate athletes found a significant negative correlation between vastus lateralis (VL) muscle CSA and EI, yet no correlation between EI and % body fat and fat mass.[100,135] This may indicate the association between EI and % body fat and fat mass may be muscle specific. Previously, paraspinal muscles have been found to be more susceptible to age-related increases in fat fraction compared to thigh muscles.[136] In addition, fat typically deposits around the mid-section which may explain why LM EI and % body fat are more closely related compared to VL EI. Furthermore, LM is a small muscle compared to VL, thus the presence of intramuscular fat may have a greater impact on muscle function than would be observed in VL.

3.5.2 Body composition differences between sports

Overall, body composition values observed in our study for male rugby and soccer athletes were comparable to references values from a previous study that investigated body composition in collegiate athletes.[72] That same study did not include football athletes and had a sample of two male hockey athletes, which may explain why values observed in the present study differed for hockey athletes.[72] Recently, a study compared body composition in male football, hockey, and rugby athletes.[93] Football and male rugby athletes had similar total fat mass and % body fat values to those observed in our study, however our football and male rugby athletes had less total lean mass.[93] Hockey was the opposite with similar total lean mass values in males and our male hockey athletes having greater total fat mass and % body fat compared to Currier et al.[93]

Our results showed that female soccer players had the smallest values for all lean mass measurements when compared to other varsity sports, which is in accordance with previous investigations.[94] In males, soccer players had significantly lower fat mass compared to the other sports investigated and had significantly less % body fat than rugby and football players, in addition to having the smallest body composition values overall. Soccer is an endurance sport that requires longer and more frequent bouts of running compared to power-focused sports like football, rugby and hockey, which tends to result in leaner and lighter musculature. Our results are comparable to other endurance sports that require large amounts of running with minimal stoppage, such as cross country[135] and sprinters in track and field[94,98,99], as well as other studies including soccer athletes.[73,94]

Female hockey players had a larger and thicker LM than both rugby and soccer players in addition to having the greatest total lean and bone mass. While reference values for a variety of sports have been obtained, there has been a lack of comparison between female hockey and rugby athletes to other sports in the literature when it comes to lean mass, fat mass, and % body fat.[72,98] The increased muscle size and thickness may be explained by the explosive nature of the sport. Increased forces through the kinetic chain during powerful, short shifts on the ice will require increased stability through the core and trunk, potentially resulting in a larger and thicker LM to handle the increased forces during movement. Furthermore, hockey requires the athlete to maintain a stooped position for both skating and defensive stances, as compared to rugby and soccer where athletes spend more time in upright running positions. One study showed LM CSA to increase as the trunk stoops forward in labourers, indicating the LM may be more activated in this position for stabilization.[81] Interestingly, while female hockey players had the largest and thickest LM of the sports investigated, male hockey players had the smallest and thinnest, and thickness at rest and contracted was significantly different from football players. The differences observed in sex may be the result of sport specific biomechanics due to pelvic differences, however there is currently a lack of research investigating biomechanical sex differences in hockey players.

Our results in male athletes revealed that football players had significantly greater values in all body composition measurements compared to rugby and soccer players and had significantly thicker LM compared to hockey players. In general, football athletes tend to be larger than many other athletes. The greater size and stature may allow these athletes to handle the forces they experience during tackling from other large opponents as well as to have greater strength and power for the explosive movements required for quick bursts, change of direction, and blocking. In general, offensive and defensive linemen tend to be the heaviest positions on a football team.[100,137] The varying demands of each sport requires the body to adapt and is also reflected in position specific changes, which are most evident in football. Offensive and defensive linemen had higher fat mass, lean mass, and % body fat than other positions[100,137], with offensive and defensive positions that mirror each other having similar body compositions.[137] However, only 24% of our sample from football played these positions, accounting for 12% of the total male sample, thus the differences previously observed between positions likely did not play a major role in the results of this study.

Body composition has been linked to injury in sports, with obesity being a large predictor of sports injury in general population adolescents.[138] In addition, significant negative correlations were observed between % body fat and endomorphy rating, and the incidence of injury in a preliminary study in ballet dancers.[139] This indicates that both excessively overweight and underweight individuals may be at greater risk for injury during sport. While the association between body composition and history of injury was outside the scope of the current study, investigating body composition in athletes from a variety of sports and how it relates or predicts injury is imperative to better identify athletes who may be most at risk.

3.5.3 Limitations

While this is the first study investigating the connection between body composition values and LM characteristics across a general sample of male and female university varsity athletes, only four sports were included (rugby, hockey, soccer, and football), three of which included female athletes. There are several other varsity sports that exist at the university level that were not included, which is a limitation from only sampling from a single university. In future studies, additional sports should be included to obtain a broader view of how body composition influences LM characteristics in varsity athletes. Furthermore, no reference group was included in this study for sport comparison. Future studies should include a control group from the general population to be able to infer differences between the general population and athletes.

3.6 CONCLUSION

This study provides novel insights into the connection between LM characteristics and a university varsity athlete's body composition. Female hockey players had the largest and thickest LM compared to rugby and soccer players. In males, football players had the largest body composition values and almost all LM characteristic values compared to rugby, hockey, and soccer player. Positive correlations between LM CSA and thickness and body composition measurements were observed in both males and females. Males had a negative correlation between muscle function (e.g., % thickness change) measures and weight and fat-related body composition measures. Overall, our findings revealed that there are differences in body composition and LM characteristics between sports in males and females, which are likely due to sport specific requirements. The results of the current study further support that body composition measures likely play a role in LM morphology and function and should be considered when investigating paraspinal musculature and exploring links with the presence of spinal pathologies.

Through preseason screening, coaches and clinicians may be able to identify athletes with body composition values that are related to poor LM characteristics, since LM characteristics have previously been associated with the presence of low back pain and lower limb injury during the playing season. Targeting these athletes at risk and guiding them through specific exercise intervention or dietary programs may aid in the prevention of injury during the season.

CHAPTER 4 – REFERENCES

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