Associations among lumbar multifidus muscle characteristics, body composition and injury in university rugby players

Abstract:

Context: Smaller lumbar multifidus (LM) muscle was reported to be a strong predictor of lower limb injury in professional Australian Football League (AFL) players. However, despite the high prevalence of low back pain (LBP) and lower limb injury in rugby players, LM characteristics have yet to be examined in this group of athletes.

Objectives: 1) To examine LM characteristics in male and female university rugby players and their possible associations with LBP and lower limb injury, and 2) to investigate the relationship between LM characteristics and body composition in this group of athletes.

Design: Cross-sectional study

Setting: University Research Centre

Patients or Other Participants: Thirty-four university level rugby players (14 males, 20 females).

Main outcome measure(s): Ultrasound measurements of LM cross-sectional area (CSA), thickness and thickness % change during contraction were obtained bilaterally, at the L5-S1 level, in prone and standing positions. Body-composition measures were obtained using dual-energy X-ray absorptiometry (DEXA). Self-reported questionnaires were used to obtain LBP and lower limb injury history.

Results: Players who reported LBP in the previous 3-months showed a significantly smaller % thickness change during contraction in the standing position (F=5.21, p=0.03). LM CSA side-to-side asymmetry (right vs. left) was significantly greater in players who reported

having a lower limb injury in the previous 12-months (F=4.98, p=0.03). LM CSA was significantly associated with body composition measurements. **Greater LM % thickness change during contraction was significantly associated with lower % body fat.** LM echo-intensity was strongly associated with total % body fat, and significantly greater in females. **Conclusions:** The influence of body composition on LM morphology in athletes cannot be ignored and warrants further investigation. This study also provides preliminary evidence of an association between LM morphology, LBP and lower limb injury incidence in university rugby players.

Key Words: Paraspinal muscles, low back pain, ultrasound, lower limb injury, dual-energy X-ray absorptiometry

Key Points:

- Players with a history of LBP showed decreased contractile ability of the LM muscle in the standing position.

- Greater LM CSA asymmetry in the prone position was associated with lower limb injury.

- LM characteristics were strongly correlated to body composition measurements.

Introduction

Elite rugby athletes are prone to various forms of physical stress originating from high-intensity collisions during sport-specific training and year-round physical preparation, causing high physical loads on the spine, pelvic region, and upper and lower extremities.[1] Such high physical stresses may have an impact in the development of acute and chronic spine conditions. Low back pain (LBP) is more common in contact and combat sports and often associated with sport-specific mechanical loads and movement patterns.[2] While the incidence of LBP is higher in athletes taking part in high load/intensity sports, few studies have specifically examined the prevalence of LBP in rugby players. While 40% of high school rugby players with no radiographic abnormalities reported LBP at the end of a single season,[2] 39% (9 out of 23) former professional players were found to have chronic LBP.[3] LBP is also very common in elite Australian Football League (AFL) players.[4]

It is well recognized that LBP leads to motor control impairments and altered body kinematics, which can be presented as a wide array of dysfunctions including hypo or hypermobility of the involved lumbar segments, changes in paraspinal muscle recruitment and coordination, as well as movement fear/avoidance.[5] Paraspinal muscle morphological changes (e.g. atrophy,[6-8] asymmetry,[6,9] fatty infiltration,[10-11] especially of the lumbar multifidus (LM) muscle, and functional deficits[12] (e.g. altered muscle activity) have also been reported in subjects with LBP. The LM muscle plays a critical role to provide spinal stability during trunk movement and spine proprioception,[2] which are likely impaired when atrophy and/or fatty infiltration is present. Such degenerative changes were reported in both athletic and non-athletic populations with LBP. More specifically, localized LM muscle atrophy and side-to-side asymmetry was observed in elite cricketers [8] and off-road cyclists with LBP.[13] LM muscle atrophy and/or functional deficits have also been identified in elite ballet dancers,[14] ice hockey players[15] and gymnasts with sway-back posture.[2] Smaller LM CSA and greater side-to-side asymmetry were also found to be strong predictors of lower limb injuries in elite Australian football league (AFL) players.[9] **Proper function of the trunk muscles is critical to maintain the integrity of the kinetic chain and distribute forces to the lower limbs. We are not aware, however, of any studies that have assessed LM muscle morphology and/or function in elite rugby players, despite the high incidence of LBP and lower limb injury in this population. Previous evidence reporting** structural and functional changes highlights the importance of assessing LM muscle morphology and neuromuscular control in elite athletes, **which may have important implications for the susceptibility to injury.**

While most imaging studies have assessed the LM in a prone position, reports from non-athletic populations have shown an increased LM CSA from prone lying to upright standing.[16-17] Such findings suggest that the assessment of LM may be more accurate when performed in a standing or functional position, when LM is contracted in a stabilizing role.[17] **Indeed, LM % thickness change in the standing position (e.g. LM thickness while standing compared to LM thickness while standing and performing a contralateral arm lift) is also expected to be much smaller as compared to the prone position.[15]** However, very few ultrasound-imaging studies have assessed LM muscle characteristics and function in such positions, [15-17] **and it remains unclear whether LM morphology and function while assessed in a more functional position, such as standing, differ between players with and without LBP and/or lower limb injury.** Furthermore, while it is well established that paraspinal muscle morphology and composition (e.g. fatty infiltration) are confounded by factors such as age, sex, physical activity level and body composition,[11] body mass index (BMI) remains the most frequently used variable to adjust for inter-subject variability in both anthropometric and body composition differences. However, this measure remains a poor indicator of body composition, especially in athletic populations, as it does not differentiate between lean and fat mass.[18] Accordingly, in a previously study of elite ice hockey players,[15] it was demonstrated that body composition measurements obtained from Duel-energy X-ray absorptiometry (DEXA) were strongly correlated to LM muscle size (e.g. cross-sectional area) and echo-intensity (EI) (e.g. indicator of fatty infiltration and connective tissue using the ultrasound brightness scale), as opposed to BMI. Such findings suggest that the influence of body composition measurements on LM muscle morphology and function is an area for further investigation, especially in athletes.

The purpose of this study was, therefore, to: 1) examine LM muscle morphology and function (e.g. in prone and standing) in male and female university level rugby players, 2) compare LM muscle morphology and function **(in prone and standing)** in players with and without LBP and with a history of lower limb injury, and 3) investigate the relationship between LM muscle morphology, function and body composition in this group of athletes. We hypothesized that players with LBP will have a smaller LM muscle, greater CSA side-to-side asymmetry and a higher risk of lower limb injuries. We also hypothesized that greater lean muscle mass and greater %body fat will be associated with LM CSA and EI, respectively.

Methods

Participants

Thirty-seven rugby players (21 females, 16 males) from the XX University varsity teams volunteered to participate in this study. Three players were excluded (1 female, 2 male) due to missing data and poor ultrasound image quality, for a final sample of 34 players (20 females, 14 males). All available players were invited to participate in this study and thus players' positions (e.g. forward, back) were not taken into consideration in order to maximize the sample size. Exclusion criteria included previous history of severe trauma or spinal fracture, spinal surgery, spinal abnormalities (e.g. scoliosis >10°) and pregnancy. The study was approved by XX. Players provided informed consent prior to the assessment.

Procedures

All players were tested during the preseason (one session ~30 minutes) and completed a self-administered questionnaire in order to collect demographic information and history of injury. Players were asked whether they had LBP (e.g. pain between T12 and gluteal fold) during the past 3 months ("yes" or "no"), and complete a Visual Numerical Pain Scale (0-10 scale, 0=no pain, 10=worst imaginable pain) if they reported the presence of LBP. Players with LBP were also asked to report the pain location (e.g. centered, right side, left side) and pain duration (in months). Similarly, players were also asked about their history of lower limb injury in the previous 12 months, and provide the injured body part.

Ultrasound

LM assessment were performed using a LOGIQ e ultrasound machine (GE Heathcare, Milwaukee,WI) with a 5-MHz curvilinear transducer. All imaging parameters (frequency: 5MHz, gain: 60, depth: 8.0cm) remained consistent for all acquisitions. The reliability and validity of using ultrasound for the assessment of LM muscle size and thickness has been established. [19-20]

Prone lying measurements

Players were first placed in a prone position (on a therapy table) in order to assess LM CSA. A pillow was placed under their abdomen in order relax the paraspinal musculature and minimize lumbar lordosis. Prior to imaging, the spinous process of L5 was palpated and marked with a pen. The ultrasound transducer was then placed longitudinally along the midline to confirm the location of the L5 level. Once the location was confirmed, the transducer was then rotated and transversally over the L5 spinous process of imaging. The LM muscle was then imaged bilaterally; separate images where obtained on the right and left in players with larger muscles. Three images were saved for each side. This level was chosen as prior evidence suggested that smaller LM CSA and increased side-to-side asymmetry at L5 are strong predictors of LBP and lower limb injury in professional AFL players.[9]

LM thickness measurements at rest and during submaximal contraction (e.g. function) were then acquired in the same position. Images were obtained bilaterally, in the parasagittal view to allow for the visualization of the L5/S1 zygapophyseal joints. Players were first instructed to relax while three images were acquired bilaterally, at rest. Then, players were instructed to perform a contralateral arm lift (e.g. lift the arm 5 cm off the table with shoulder in 120° of abduction and elbow in 90° of flexion) while holding a handled weight in order to induce a submaximal contraction (e.g. ~30% of maximum voluntary contraction).[20] The handheld weight was based on the players body weight:[20] 1) <68.2kg = 0.68kg weight, 2) 68.2-90.9kg=0.9kg weight, 3)

>90.9kg=1.36kg weight]. Players were instructed to maintain the contraction for 3 seconds and to hold their breath at the end or normal exhalation in order to minimize the respiration effect on the LM measurement. Each player first had a practice trial followed by 3 contralateral arm lifts on each side.

Standing measurements

For the standing measurements, players stand barefoot on the floor with their arms relaxed on each side. To achieve a habitual standing posture, participants marched on a spot for a few seconds and remained on the position where their feet landed. The same procedure as described above was used to obtain the LM measurements at rest, in this position. Then, LM muscle contraction was achieved via contralateral arm lifts (shoulder in 90° flexion, elbow in full extension, wrist in neutral position with palm facing down) [15,17] while holding the weight that was previously determined. Again, contractions were maintained for 3 seconds and each player had a practice trial followed by 3 arm lifts on each side.

Imaging assessment

Ultrasound images were analyzed offline using OsiriX imaging software (OsiriXLiteVersion 9.0, Geneva, Switzerland). LM CSA measurements were obtained by tracing the muscle borders on both sides (refer to Figure 1 for specific anatomical landmarks). The relative % CSA asymmetry between the right and left side was calculated using the following formula: [(larger side – smaller side)/larger side x 100]. LM muscle thickness was obtained using linear measurements from the tip of the L5/S1 zygapophyseal joint to the inside edge of the superior muscle border, both at rest and during contraction (Figure 2), in prone and standing. The average of 3 measurements (on 3 different images) for each side were used in the analyses. The % thickness change was used to assess LM function and contractile ability (in prone and standing) using the following formula: [(thickness contraction – thickness rest)/thickness rest) x100]. LM muscle EI measurements were obtained with ImageJ imaging software (National Institute of health, USA, Version 1.49) using the standard histogram grayscale analysis function (e.g. pixels expressed as value between 0 (black) and 255 (white)). Greater EI is indicative of a higher amount of intramuscular fat and connective tissue. EI measurement was acquired by tracing the region of interest (ROI) representing the LM muscle CSA from the prone images, while avoiding the inclusion of bone or surrounding fascia.[15] Again, the average value of the 3 measurements from 3 different images were used in the analyses. An experienced athletic therapist researcher with extensive experience in spine imaging analysis acquired all the ultrasound measurements (e.g. blinded to players characteristics and history of injury). The intra-rater reliability (intra-class correlation coefficients $ICC_{3,1}$) of the same rater was reported in a previous related study,[15] and varied between 0.96-0.99 for all of the acquired ultrasound measurements.

DEXA

During the same assessment session, a full body DEXA scan (Lunear Prodigy Advance, GE) was acquired for each player and performed by a certified medical imaging technologist. Prior to imaging, all players removed any metal and required to wear loose fitting clothing, to avoid any interference with the DEXA scan. The following demographic characteristics were entered in the computer software prior to imaging: age, height, weight and ethnicity. Players were lying down supine in the center of the scanner with their arms slightly away from their body, thumbs pointing upwards, and legs slightly apart with their toes pointing upwards. The following composition measurements were used in the analysis: total lean mass, total bone mass, total fat mass and total percent body fat.

Statistical Analysis

Descriptive statistics (e.g. means and standard deviations) were calculated for players' characteristics, **and independent t-tests were used to compare demographic and anthropometrics characteristics between male and females players**. Paired t-tests were used to assess the difference in LM characteristics between the right and left side (within male and female players). Analysis of variance (ANOVA) was used to assess differences in LM characteristics between male and female players. **Potential differences in LM muscle measurements between players with and without LBP or lower limb injury were examined** using analysis of covariance (ANCOVA) using "weight", "height" and "total percent body fat" **to adjust for anthropometric differences.** Finally, the relationship between LM muscle characteristics and body composition measurements was assessed Pearson correlation and linear regression models. All analyses were performed using STATA software (version 12.0, StataCorp, LP, College Station, Texas).

Results

The players' characteristics are presented in Table 1. The mean±SD age, height and weight was 21.4±1.8 years old, 171.2±7.4 cm and 75.0±10.1 kg, respectively. **Significant differences in anthropometric and body composition measurements were found between male and females players (Table 1).** The average number of years playing rugby at a competitive level was 5.1±2.9 years, and being in their first to fifth year [range 1 to 5 years] at the university level.

LM muscle characteristics

LM muscle prone and standing measurements of interest for the right and left side, in female and male players are presented in Table 2. LM CSA, thickness at rest and during contraction, both in prone and standing, were significantly greater in male as compared to female players. LM EI was significantly greater in female ($p<0.002$). There was no significant difference in CSA asymmetry and % thickness change during contraction, in prone or standing, between female and male players. LM CSA in prone and standing was significantly greater on the left side as compared to the right side in female players. While LM thickness at rest and during contraction in prone and standing was significantly greater on the left as compared to the right side in male players.

LBP and lower limb injury comparisons

The % thickness change during contraction in the standing position was significantly smaller in players who reported LBP in the previous 3-months ($F=5.21$, $p=0.03$), as compared to players with no LBP (Table 3). While LM CSA side-to-side asymmetry (right vs. left) was significantly greater in players who reported having a lower limb injury in the previous 12-months ($F=4.98$, $p=0.03$), as compared with players with no recent history of lower limb injury (Table 4).

Associations between LM muscle characteristics and body composition

LM muscle CSA was significantly correlated with height ($r=0.69$, $p<0.001$; $r=0.69$, $p<0.001$) weight ($r=0.50$, $p=0.002$; $r=0.50$, $p=0.02$), total bone mass ($r=0.75$, $p<0.001$;$r=0.75$, $p<0.001$), total lean mass ($r=0.74$, $p<0.001$;$r=0.66$, $p=0.001$) in prone and standing, respectively. Similar significant correlations were also observed for LM thickness at rest and LM thickness during contraction in both positions. BMI was not correlated with LM CSA in prone ($r=0.07$, $p=0.66$) and standing ($r=0.14$, $p=0.54$). LM EI was strongly correlated with total % body fat ($r=0.84$, $p<0.001$) and total lean mass ($r=-0.55$, $p<0.001$). The association between LM EI and total % body fat remained significant after adjusting for gender ($p<0.001$, $R^2=0.69$) (Figure 3). When adjusting for gender, a trend was also observed between greater LM EI and lower LM % thickness change during contraction (prone) ($p=0.05$, $R^2=0.31$) Finally, both % thickness change during contraction in prone and standing were significantly associated with the total % body fat ($p=0.03$, $R^2=0.12$).

Discussion

LM muscle characteristics

In accordance with a previous study,[15] our results showed that LM muscle CSA in a prone-lying position was significantly larger in male athletes than in female athletes. Our findings also suggest a hypertrophy of the LM muscle in both male and female rugby players, as resting LM CSA was greater in comparison to normal non-athletic healthy subjects of slightly greater age.[21] The resting prone LM CSA of our male rugby players was comparable to elite male weightlifters (10.95±0.31cm^2) of similar age (21.49±0.59 years) **and body size,** [22] as well as university-level male hockey players (CSA=9.84±1.39 cm^2, **age=21.4±1.4 years, height=181.8, weight=86.7±6.8 kg**) [15] and professional AFL players (age=21.9±3.6 years, CSA=9.14± 1.65cm^2, **height=188.4±7.3cm**, **weight=90.4±5.6 kg**).[9] However, results from our group of female rugby players revealed slightly lower resting LM CSA as compared to elite female weightlifters (CSA=8.65±0.32cm^2) [22] and university-level female hockey players

(CSA=8.98±1.19 cm^2, **age=21.3±1.8, height=167.7±5.6cm, weight=67.7±7.8kg**).[15] This hypertrophy likely resulted from the high physical demands and postural requirements associated with the sport. Indeed, the LM muscle is highly active when performing anticipatory postural adjustments, defined as involuntary and automatic adjustments generated during disturbance in a predictable posture.[23] Such postural adjustments are crucial in rugby as they allow the athletes to maintain their base of support while stabilizing the vertebral segments. The deep and superficial LM muscle have different activation mechanisms; the deep fibers control intervertebral movement, while the superficial fibers control spinal orientation.[24] In tasks such as tackling, rucking, and scrummaging, athletes are required to lean forward and maintain a strong position for a few seconds against external perturbations from other players. In other tasks such as passing and catching, the athletes need to keep their arms and hands up (shoulder flexion) at all times. Rapid shoulder flexion has been shown to be preceded by activation of the superficial fibers of the LM prior to muscular activity of the shoulder flexors.[23] As such, the LM hypertrophy observed is likely a response/adaptation to the specific physical demands of the sport.

The resting LM thickness in the prone position was similar to previous studies conducted in athletes,[2,8,9,13-15] and the % thickness change in male rugby athletes (17.36±7.32%) and female rugby athletes (16.64±7.81%) was congruent with values reported in healthy non-athletic subjects (17.46±9.20%),[17] as well as university-level hockey players (male=17.10±8.91%, female=13.47±5.74%).[15] LM CSA and thickness measurements were significantly greater in the standing position versus the prone position, in both male and female players. Indeed, when standing in a functional weight-bearing position, the LM contracts in order to provide stability to the spine and to maintain an upright position, allowing for the characterization of LM morphology while contracted in a stabilizing role. Accordingly, the LM % thickness change (e.g. contraction) was also significantly lower as compared to the prone position, a finding that is in accordance with previous studies in athletic[15] and non-athletic populations.[17] Our results also revealed that LM CSA was significantly greater on the left side for female players (prone and standing positions), while males had significantly greater LM thickness on the left side. It has been previously shown that handedness [25] is a factor associated with LM asymmetry at the L5-S1 level. Kicking, an asymmetrical ballistic task, is a skill required by most rugby players. When kicking with the dominant leg, the contralateral leg is planted on the ground to stabilize the athlete's motion. High number of repetitions of this movement over the years may have contributed to the observed LM hypertrophy in favor of the non-dominant side. Hides et al. [26] came to a similar conclusion and reported that the quadratus lumborum muscle in elite AFL players was significantly greater on the side contralateral to the kicking leg. While the LM was larger on the left side, the mean side-to-side asymmetry in the prone position was <5%, which corroborates with previous reports in athletes.[8,15,22] Side-to-side CSA asymmetry was slightly lower when measurements were obtained in the standing position, suggesting that the asymmetry may be more structural, rather than functional.

LBP comparisons

When assessing LM muscle characteristics according to LBP, our results showed no significant difference for LM CSA or side-to-side asymmetry between players with and without LBP. Although smaller LM CSA and greater asymmetry have been reported in elite athletes with LBP[7,14-15] other studies reported no such deficits.[22,27] The latter suggests that athletic populations may behave differently with regards to LM morphology and LBP, possibly due to competing influences including specialized movements and specific training effects.[27] However, our results revealed a decreased ability (smaller LM % thickness change) to contract the LM in the standing position in athletes who reported LBP in the previous 3 months. Given that LM plays a critical role in lumbopelvic stability, including trunk control and transfer of forces and motion through the kinetic chain, a deficit in neuromuscular control while performing a functional task may potentially have detrimental effects on the stability of the spine and contribute to the susceptibility of injury.

Lower limb injury comparisons

Our findings also showed that rugby players who sustained a lower limb injury in the previous 12-months had a significantly greater LM side-to-side asymmetry (prone position) as compared to non-injured players. This finding corroborates with a previous study from Hides et al. conducted with elite AFL players.[9] While LM CSA was also reported to relate to the severity of hip, groin or thigh injury,[28] our results do not support this finding. While athletes with LBP have a wide array of motor control impairments, including alterations in kinetics, kinematics and strength of both the trunk and lower limbs,[5] such dysfunctions should also be considered when evaluating the relationship between LM, LBP and lower limb injury. This is particularly important when evaluating the relationship between LBP and lower limb injuries. Future studies should evaluate whether LBP is a predictor of lower limb injury.

Associations between LM muscle characteristics and body composition

LM CSA and thickness were positively and significantly associated with the athletes' height, weight, total bone mass, and total lean mass, both in prone and standing positions. BMI was not correlated to LM CSA, nor with LM EI. Our findings are very similar and corroborate with a previous related study in university level hockey players.[15] Also in accordance with Fortin et al.,[15] LM EI was significantly greater in female and strongly correlated with total lean mass, total fat mass and total body fat percentage. While we only observed a trend between greater LM EI and lower % thickness change in the prone position, a significant negative correlation between % thickness change and total percent body fat was identified. This finding suggest that athletes with a greater overall percentage body fat had a lower ability to contract the LM muscle. Although previous studies showed significant associations between muscle EI, muscle strength and power in middle-aged and elderly subjects,[29-30] the relationship between LM muscle morphology, body composition and muscle function unarguably warrant further attention.

While comparable to previous studies conducted on elite-level athletes, the relatively small sample size is a limitation of the current study. Future research including larger sample size and more teams at the elite level are needed to establish the generalizability of our results. Although EI is a valid a reliable indicator of intramuscular fat and connective tissue, this measure does not provide a precise estimation/percentage of fatty infiltration.

Conclusions

The results of this study provided novel normative data on LM muscle morphology and dynamic activation **and demonstrated changes in LM characteristics at different posture (e.g. prone vs. standing)** in university level rugby players. **The muscular response to postural demands**

was different between players with and without LBP, such that players with LBP showed lower active contraction in the standing position. Lower limb injury was also associated with greater LM CSA side-to-side asymmetry. LM morphology and function were highly correlated with DEXA body composition measurements, providing additional evidence that body composition should not be ignored when studying this muscle in athletic populations. Future studies should investigate LM neuromuscular control **and thickness modulation** in functional positions such as standing in athletes, and whether targeted rehabilitation interventions are effective to ameliorate LM dynamic stability and injury rates.

References

1. Read D, Weaving D, Phibbs P, et al. Movement and physical demands of school and university rugby union match-play in England. *BMJ Open Sport Exerc Med*. 2017;2(1):e000147.

2. Trompeter K, Fett D, Platen P. Prevalence of back pain in sports: A systematic review of the literature. *Sports Med* 2017;47(6):1183-1207.

3. Meir RA, McDonald KN, Russell R. Injury consequences from participation in professional rugby league: a preliminary investigation. *Br J Sports Med. 1997; 31(2):132-4.*

4. Orchard J, Seward H, Orchard J. 20th annual injury report: season 2011, Sydney, Australia, AFL Medical Officers Association, 2012.

5. Sheikhhoseini R, O'Sullivan A, Alizabeh MH, Sadeghisani M. Altered motor control in athletes with low back pain: A literature review. *Annals Applied Sport Sci*. 2016;4(4):43-50.

6. Barker KL, Shamley DR, Jackson D. Changes in the cross-sectional area of multifidus and psoas in patients with unilateral back pain: The relationship to pain and disability. *Spine*. 2004;29(22):E515-E519.

7. Hides JA, Oostenbroek T, Franettovich Smith MM, Mendis MD. The effect of low back pain on trunk muscle size/function and hip strength in elite football (soccer) players. *J Sports Sci* 2016;34(24):2303-2311

8. Hides J, Stanton W, McMahon S, Sims K, Richardson C. Effect of stabilization training on multifidus muscle cross-sectional area among young elite cricketers with low back pain. *J Orthop Sports Phys Ther* 2008;38(3):101-108.

9. Hides JA, Warren R, Mendis D, Frnettovich S, Sexton MJ. Small multifidus muscle size predict football injuries. *Orthop J Sports Med* 2014;2(6):2325967114537588.

10. Mengiardi B, Schmid MR, Boos N, et al. Fat content of lumbar paraspinal muscles in patients with chronic low back pain and in asymptomatic volunteers: Quantification with MR spectroscopy. *Radiology*. 2006;240(3):786-792

11. Sasaki T, Yoshimura N, Hashizume H, et al. MRI-defined paraspinal muscle morphology in japanese population: The wakayama spine study. *PLoS ONE*. 2007;12(11):e0187765.

12. van Dieën JH, Selen LP, Cholewicki J.Trunk muscle activation in low-back pain patients, an analysis of the literature. *J Electromyogr Kinesiol* 2003;13(4):333-351.

13. Rostami M, Ansari M, Noormohammadpour P, Mansournia MA, Kordi R. Ultrasound assessment of trunk muscles and back flexibility, strength and endurance in off-road cyclists with and without low back pain. *J Back Musculoskelet Rehabil* 2015;28(4):635-44.

14. Gildea JE, Hides JA, Hodges PW. Size and symmetry of trunk muscles in ballet dancers with and without low back pain. *J Orthop Sports Phys Ther*. 2013;43(8):525-533.

15. Fortin M, Rizk A, Frenette S, Boily M, Rivaz H. Ultrasonography of multifidus muscle morphology and function in ice hockey players with and without low back pain. *Phys Ther Sport.* 2019; 37: 77-85.

16. Lee S, Chan CK, Lam T, et al. Relationship between low back pain and lumbar multifidus size at different postures. *Spine*. 2006;31(19):2258-2262

17. Sweeney N, O'Sullivan C, Kelly G. Multifidus muscle size and percentage thickness changes among patients with unilateral chronic low back pain (CLBP) and healthy controls in prone and standing. *Man Ther* 2014;19(5):433-439.

18. Weir CB, Jan A. BMI Classification percentile and cut off points. [Updated 2019 Apr 20]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2019 Jan

19. Larivière C, Gagnon D, De Oliveira E Jr, Henry SM, Mecheri H, Dumas J. Ultrasound measures of the lumbar multifidus: Effect of task and transducer position on reliability. *PM R*. 2013;5(8):678-687.

20. Kiesel KB, Uhl TL, Underwood FB, Rodd DW, Nitz AJ. Measurement of lumbar multifidus muscle contraction with rehabilitative ultrasound imaging. *Man Ther*. 2007;12(2):161-166.

21. Watson T, McPherson S, Starr K. The association of nutritional status and gender with cross-sectional area of the multifidus muscle in establishing normative data. *J Man Manip Ther* 2008;16(4):E93-98.

22. Sitilertpisan P, Hides J, Stanton W, Paungmali A, Pirunsan U. Multifidus muscle size and symmetry among elite weightlifters. *Phys Ther Sport* 2012;13(1):11-15. doi: 10.1016/j.ptsp.2011.04.005.

23. Abiko T, Shimamura R, Ogawa D, et al. Difference in the electromyographic onset of the deep and superficial multifidus during shoulder movement while standing. *PLoS ONE*. 2015;10(4):e0122303.

24. Moseley G, Hodges P, Gandevia S. Deep and superficial fibers of the lumbar multifidus muscle are differentially active during voluntary arm movements. *Spine*. 27(2):E29-36.

25. Fortin M, Yuan Y, Battie MC. Factors associated with muscle asymmetry in size and composition in a general population of men. *Phys Ther* 2013;93(11):1540-1550.

26. Hides J, Fan T, Stanton W, Stanton P, McMahon K, Wilson S. Psoas and quadratus lumborum muscle asymmetry among elite Australian Football League players. *Br J Sports Med*. 2010;44(8):563–567.

27. Smyers EA, Myrer JW, Eggett DL, Mitchell UH, Johnson AW. Multifidus muscle size and symmetry in ballroom dancers with and without low back pain. *Int J Sports Med* 2018;39(8):630-635

28. Hides JA, Brown CT, Penfold L, Stanton WR. Screening the lumbopelvic muscles for a relationship to injury to the quadriceps, hamstrings and adductor muscles among Australian Football League players. *J Orthop Sports Phys Ther* 2011;41(1):767-775.

29. Cadore EL, Izquierdo M, Conceição M, et al. Echo intensity is associated with skeletal muscle power and cardiovascular performance in elderly men. *Exp Gerontolol.* 2012;47(6):473-478.

30. Fukumoto Y, Ikezoe T, Yamada Y et al. Skeletal muscle quality assessed from echo intensity is associated with muscle strength of middle-aged and elderly persons. Eur *J Appl Physiol* 2012;112:1519-1525

Figure Legend

Figure 1: Lumbar multifidus cross-sectional area (CSA) measurement in a male rugby player at the L5 vertebral level. **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.**

Figure 2: Lumbar multifidus muscle thickness measurement in at L5-S1, at rest (left image) and during contraction (right image) via a contralateral arm lift in a prone position. **The facet joints (FC) of L5-S1 were used as landmarks for the lower borders of the muscle. Sacrum (S).**

Figure 3: Correlation between multifidus muscle echo-intensity (EI) and total % body fat acquired by DEXA (left image), and correlation between multifidus muscle EI and total % body fat by gender (0=female, 1=male) (right image).