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Factors associated with the ultrasound characteristics of the lumbar multifidus: a systematic review.

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Abstract

Objective

The first aim of this review was to investigate the association between age, sex, height, weight, physical activity level, posture, lumbar level and body side, and structural characteristics (cross-sectional area (CSA), thickness, linear dimensions and echo intensity) of the lumbar multifidus (LM) measured by ultrasound (US). Secondly, differences between healthy subjects and patients with chronic low back pain (CLBP) were investigated.

Type

Systematic review.

Literature Survey

Pubmed, Embase and Web of Science were searched until September 2018.

Methodology

Studies were included if (a) full text was available in English, Dutch or French, (b) subjects were aged over 18 years and were asymptomatic or had nonspecific CLBP and (c) the relation between structural characteristics of the LM, measured by US, and at least one of the above-mentioned factors was described, and/or a comparison between a CLBP and control group was made. Data was extracted independently by two reviewers. Quality of studies was assessed using an adapted version of the Downs and Black checklist.

Synthesis

Twenty-seven studies were included. Thickness and CSA of the LM do not correlate with age. Males have a larger LM size than females. Thickness and CSA of left and right LM are highly correlated in healthy subjects. More significant side-to-side differences are present in subjects with CLBP than in those without. Muscle size increases from proximal to caudal lumbar levels. The presence of CLBP is associated with muscle size and function.

Conclusions

The association between the factors age, sex, height, weight, physical activity level, posture, lumbar level, body side, and presence of CLBP, and the US characteristics of the LM is discussed. These factors should be taken into account in future research on structural muscle characteristics, or for example when correlating with functional behavior or investigating the effect of a targeted intervention.

Level of evidence

I

Key words: Low back pain, multifidus, paraspinal muscles, ultrasound

Introduction

Low back pain (LBP) is the main contributor to disability worldwide, with important personal, professional and socioeconomic implications.[1–3] In up to 85% of patients with LBP, pain cannot be attributed to a specific cause and is considered to be nonspecific.[4,5] Macintosh et al. previously suggested a role for the lumbar multifidus (LM) in the etiology of LBP.[6,7] The LM is the largest and most medial of the lumbar back muscles, consisting of a repeating series of fascicles originating from the laminae and spinous processes of the lumbar vertebrae with a consistent pattern of caudal insertions.[7] Functional impairments, such as decreased proprioception,[8–10] and decreased strength and endurance of the lumbar musculature,[11–13] have been identified in people with LBP. Moreover, the relation between these functional impairments and the development of LBP was demonstrated in several studies.[10,14,15] However, the role of structural alterations of the LM in LBP, such as changes in thickness and cross-sectional area (CSA), is less understood. A recent review indicated a negative relationship between CSA of the LM and LBP,[16] while other reviews showed only a weak or even no association between lumbar muscle characteristics (morphometry, fat infiltration) and clinical outcomes in LBP.[17–19] By extending our knowledge regarding structural characteristics of the lumbar muscles, we might gain more insight into the underlying mechanisms of LBP.

Previous studies indicated that ultrasonography (US) is a reliable and valid technique for the evaluation of CSA, thickness and linear dimensions (depth and length) of the LM.[20,21] Echo intensity (EI) refers to the ability to reflect or transmit ultrasound waves in the context of surrounding tissue, whereby the structure can be characterized as hyper-echoic or hypo-echoic, representing lighter or darker pixels on the screen, respectively.[22] Echo intensity is considered to be an indicator of the ratio of adipose and connective tissue to muscle,[23–25] as a higher EI is highly correlated with a higher level of adipose tissue using a muscle biopsy[24] as well as with a higher intramuscular fat content using MRI.[25] Ultrasonography is noninvasive, radiation free, widely available and inexpensive. Moreover, real time imaging allows a dynamic evaluation which is a unique advantage compared to other imaging techniques. Because of these features, the use of US in musculoskeletal conditions has significantly increased over the last years.[26,27] To optimize the applicability of US for the evaluation of LM structural characteristics, it is essential to understand the factors associated with these measurements. Sex differences may play a role, as global skeletal muscle mass is greater in men than women.[28] Independent of sex, global skeletal muscle mass decreases with age, especially above the age of 50 years and with an increasing rate above 65 years.[29,30] Weight[31,32] and physical activity[33,34] have an influence on abdominal muscle size; hence, an impact on lumbar muscle size might be presumed. The influence of posture should also be taken into account. Only investigating lumbar muscle characteristics in a recumbent position might not be sufficient to distinguish between subjects with and without LBP.[35,36] Additionally, cadaver studies by Macintosh et al.[7] and Amonoo-Kuofi et al.[37] suggest a lumbar muscle size difference related to spinal level. Lastly, symmetry of lumbar muscle structure might be of relevance. For example, localized muscle atrophy has been demonstrated in the presence of disc or nerve root injury,[38,39] as well as in acute/subacute unilateral LBP.[40]

Therefore, the first objective of this study was to provide a literature overview of the association between age, sex, height, weight, physical activity level, posture, lumbar level, and body side, and the intrinsic structural characteristics (CSA, thickness, linear dimensions and EI) of the LM measured by US. Secondly, differences between healthy subjects and patients with chronic low back pain (CLBP) were summarized.

Methods

The review was performed following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[41] The protocol was registered in the PROSPERO database (CRD42018083743, http://www.crd.york.ac.uk/PROSPERO/display_record.php?ID=CRD42018083743). Studies were identified by searching the electronic databases Pubmed, Embase and Web of Science and scanning reference lists of the relevant articles. No restrictions were imposed regarding publication dates. The last search was applied on September, 18 2018. The following search terms were used for all databases: (“spine muscle” or “multifidus” or “lumbar muscle” or “paraspinal muscle” or “paravertebral muscle”) AND (ultrasound or ultrasonography or echography). When full text was not available, attempts to acquire it were made by contacting the authors. Table 1 shows the applied in- and exclusion criteria.

After removal of duplicates, assessment for eligibility was performed independently by two reviewers (S.R. and E.R). Disagreements were resolved by consensus or by consulting a third reviewer (A.D.G.). Using a basic spreadsheet, data was extracted by one reviewer (S.R.) and checked by a second reviewer (E.R.): author, publication year, population characteristics (number of subjects, age, sex, anthropometric parameters and LBP-related characteristics), measurement position, frequency and shape of the US probe, assessed lumbar level, structural characteristics of the LM assessed by US (thickness (mm), CSA (cm^2), EI (grey level intensity on an arbitrary units scale)), and outcome measures (measure of association or comparison between control and CLBP group). Risk of bias was assessed by two reviewers (S.R. and E.R.) by using an adapted version of the Downs and Black checklist (Appendix).[42]

This tool was identified as one of the two most useful instruments for the assessment of non-randomized studies[43] and is recommended by the Cochrane collaboration for this purpose.[44] The original tool was adapted for non-interventional studies, and has been used before.[45,46] Related questions (items 4, 8, 9, 13, 14, 17, 19, 23, 24 and 26) were omitted. Case-series studies and case studies were not assessed on items related to a control group (items 21 and 22). We maintained item 15 related to blinding of the observer measuring the outcomes, as this was possible when different subject groups were investigated. Item 27 concerning the power of the study was adapted to: "Was a sample size calculation done? (yes = 1, no = 0)". Consequently, the number of questions varied between study designs and the results on risk of bias were presented as a percentage score (Table 2). Inter-rater agreement for risk of bias assessment was measured by calculating the Kappa statistic using IBM SPSS Statistics Version 25. The following classification was used to interpret this agreement: poor (0.00), slight (0.01–0.20), fair (0.21–0.40), moderate (0.41–0.60), substantial (0.61–0.80) and almost perfect (0.81–1.00).[47] No articles were excluded based on bias assessment. Interpretation of the strength of reported correlations was done following the rule of thumb of Hinkle et al.: little if any (0.00-0.30), low (0.30-0.50), moderate (0.5-0.70), high (0.70-0.90) and very high (0.90-1.00).[48]

Results

See Figure 1 for a flowchart of study selection. 1666 articles were identified through database searching, and no additional articles were found from the reference list search. A total of 27 articles were included. Results of assessment of risk of bias are shown in Table 2. Total risk of bias scores ranged from 53 to 80% between studies. Scores from both reviewers were equal in 94% of the cases (431/459). The agreement between both reviewers was almost perfect (Kappa= 0.89; 95% confidence interval= 0.85 to 0.93, p< 0.0005). In Table 3 the extracted data and results of individual studies are provided.

Age

Five studies included age in their analysis.[49–53] No significant association was found between age and **CSA** of the LM at L4,[50] L5[50] nor at L2 to L5[49] in healthy subjects nor patients with CLBP. Stokes et al. reported a smaller shape ratio, which is a ratio of linear measurements (anteroposterior divided by lateral dimensions), at L5 in younger compared to older healthy persons.[50] No difference in symmetry was seen between age groups.[50] For **thickness** at rest, no association with age was reported for the LM at L4 in women without LBP.[51,52] Two studies analyzed the relation between **EI** of the LM and age in healthy subjects, one showing a moderate positive correlation,[53] the other showing no significant association.[52]

Sex

Associations with sex were investigated in eight studies.[49,50,53–58] Four studies found a significantly larger **CSA** of the LM in males compared to females at L2,[49,57] L3,[49,57] L4[49,50] and L5[50,58] in subjects with and without CLBP, although two of these studies could not confirm these findings for certain lumbar levels.[49,57] No significant difference in symmetry of CSA was observed between sexes in an asymptomatic population[50] nor in patients with CLBP.[49] In healthy subjects, Stokes et al. reported a smaller shape ratio in females compared to males.[50] A larger muscle **thickness** in males compared to females was demonstrated in healthy subjects at L4-5 at rest[53,56] and during contraction[56], as well as in patients with CLBP at L5 at rest.[54] Two studies did not show a sex effect on thickness change during contraction of the LM at L2 to L5 in subjects with and without CLBP[57] or at L4-5 in healthy subjects.[56] Cai et al. found a smaller thickness change in male runners with CLBP compared to healthy subjects, but not in females.[55] Importantly, when taking into account anthropometric parameters, the sex difference in CSA was no longer significant in the study of Stokes et al.[50] but remained significant in two other studies on CSA[58] and thickness.[56] Yoshiko et al. reported a lower **EI** of the LM in healthy males compared to females.[53]

Anthropometric parameters

In four studies, anthropometric parameters were analyzed in healthy subjects.[50,58–60] Hides et al. found positive correlations between **CSA** at L4 and weight, height and weight x height.[59] In males, these correlations were stronger than in females.[59] A strong positive correlation between CSA and weight was seen at L4 by Stokes et al., in females only.[50] A moderate positive correlation was confirmed at L4 and L5 by Nuzzo et al. in an all-male population.[60] In contrast, Watson et al. found a moderate negative relationship between percent body fat and CSA at L5.[58] Two studies did not find a relation between body mass index (BMI) and CSA at L4[50,59] and L5,[50] nor between height and CSA.[50] Nuzzo et al. demonstrated a moderate positive correlation between weight and **thickness** at rest of the LM at L4 and L5.[60]

Physical activity level

Only two studies analyzed physical activity level.[51,57] Wallwork et al. reported a positive association between weekly physical activity level and **CSA** of the LM at L3, L4 and L5 (not at L2), without any difference between subjects with or without CLBP.[57] No significant association was found with muscle **thickness** at rest and during contraction.[57] In the elderly (age 86.9 ± 6.2 years), a smaller thickness at rest of the LM at L4 was observed by Ikezoe et al. in women who were dependent (chronically bedridden) compared to those able to perform activities of daily living independently.[51] The LM was also thinner in the dependent elderly group compared with young women, but no differences in muscle thickness were seen between the young and independent elderly group.[51]

Posture

Three studies investigated the influence of posture.[61–63] Coldron et al. did not report a significant difference in the **CSA** of the LM at L5 between prone and side lying in healthy subjects.[62] In healthy subjects, two studies observed an increase in CSA of the LM at L4 from prone lying to upright standing and a gradual decrease in CSA from 25° to 45° forward stooping.[61,63] These differences in CSA were not significant at L5.[63]

Lumbar level

Four studies included lumbar level in their analysis.[20,49,50,64] Three studies on healthy subjects observed a significant difference in **CSA** of the LM between lumbar levels ranging from L2 to S1, with greater CSA at caudal levels.[20,49,50] Correlations between CSA at L4 and L5 were high and significant in healthy subjects in the study of Stokes et al.[50] In females, a smaller shape ratio was reported at L5 compared to L4, because of a larger lateral dimension of the LM at

L5.[50] Dar et al. found no significant difference in **thickness** at rest or thickness change during contraction between L4-5 and L5-S1 in healthy subjects.[64]

Symmetry

Fifteen studies investigated the difference between left and right side of the body.[20,48,49,53,55–58,63-69] Several studies found a high correlation between left and right **CSA** of the LM in healthy subjects at L5,[58,65] L2 to L5,[49] S1[68] and L2 to S1,[20] and in patients with CLBP at L5,[65] with side-to-side differences smaller than 5%. However, in two studies a larger asymmetry in CSA was observed in healthy subjects at L4 and L5.[50,67] No influence of sex, age or vertebral level on symmetry of the CSA was reported by Stokes et al.[50] Side-to-side differences larger than 10% were also seen by Hides et al. in subjects with unilateral CLBP at L4 and L5 but not at L2 and L3.[49] Side-to-side differences in patients with central or bilateral pain were lower.[49] Smaller asymmetry was found in CSA than in shape.[50,59] For **thickness** at rest, side-to-side differences were reported to be around 5% in healthy subjects[56] and around 10% in patients with CLBP.[54] There was no significant asymmetry in resting thickness in subjects with unilateral CLBP in prone or standing at L4-5 and L5-S1,[70] nor in subjects with and without CLBP at L4-5.[69] Dar et al. described a significant side-to-side difference in thickness change during contraction at L5-S1, but not at L4-5, in a subgroup of healthy subjects.[64] A small but significant asymmetry in thickness change was observed by Wallwork et al. from L2 to L5 in subjects with and without CLBP.[57] This asymmetry was not confirmed by Sweeney et al. in subjects with CLBP at L4-5 or L5-S1.[70]

Chronic low back pain

In fourteen studies, the influence of CLBP was analyzed.[49,55,71–74,57,61,63,65–67,69,70] Asymptomatic subjects had a larger **CSA** of the LM compared with subjects with CLBP at L4 and L5,[49,57,61,63,72,73] although findings were not significant for all levels[57] or in all positions.[63] In unilateral CLBP, a significant asymmetry in CSA was noted at L4 and L5,[49] as well as a strong relation between pain scores and the ratio of the CSA of the unaffected and affected side at L5.[66] However, Zhang et al. did not report a difference in CSA of the LM between unaffected and affected sides,[73] nor was a difference in CSA confirmed between subjects with and without CLBP at L2,[49] L3[49] or L5.[65] At L2, Wallwork et al. even observed a slightly larger CSA in subjects with CLBP compared to healthy controls.[57] Lee et al. reported a different change in CSA of the LM at L4 and L5 in different postures in patients with CLBP compared to healthy controls.[63] The largest CSA was observed in upright standing in healthy subjects, while in patients with CLBP the maximal CSA occurred at 25° forward stooping.[63] Yet, this group difference was not confirmed by Chan et al.[61] In the study of Rostami et al., the difference between contracted and resting CSA of the right LM at L4 was significantly smaller in patients with CLBP compared to controls.[72] Wallwork et al. confirmed this finding at L5, but not at L2, L3 and L4.[57] Regarding **thickness** of the LM, four studies showed no significant differences between subjects with and without CLBP at rest at L4,[67,74] L4-5,[68,69] L5[67] or L5-S1[70], nor at L4-5 during maximal contraction lifting the head, upper trunk and contralateral arm against static resistance.[69] Zhang et al. reported a smaller thickness at rest and during contraction in subjects with CLBP compared with healthy controls.[73] A smaller thickness change during contraction of the LM was found in subjects with CLBP compared with healthy controls at L4[73] and L4-5.[55,69,71] On the other hand, Sweeney et al. found a larger thickness change at L5-S1 (not at L4-5) in subjects with CLBP during a contralateral arm lift in standing, but not in prone position.[70] The **fat area** at L4 was higher in subjects with CLBP in the study of Chan et al.[61]

Discussion

The main objective of this systematic review was to provide an overview of the association of predefined factors with the intrinsic structural characteristics of the LM defined by US, in subjects with and without CLBP.

Ultrasound-assessed thickness and CSA of the LM did not correlate with age in subjects with nor without CLBP.[49–52] In terms of shape at L5, a more ovoid muscle in the anteroposterior direction was associated with older age.[50] Prior studies using magnetic resonance imaging (MRI) have reported inconsistent associations between LM size and age, probably due to methodological differences in outcomes (CSA versus volume), regions of interests, and study samples. Age-related muscle atrophy has been frequently demonstrated for upper and lower limbs,[28,75,76] as well as for superficial abdominal muscles.[51,77] In deep trunk muscles such as the LM or deep abdominal muscles, age-related atrophy is less obvious.[51,78] This might be explained by the fact that deep trunk muscles predominantly contain type I fibers,[79–81] in which less age-related atrophy occurs in comparison with type II muscle fibers.[82–84] Qualitative age-related differences such as increased fatty infiltration were previously reported in several studies using MRI[85,86] or computed tomography (CT).[87] By contrast, opposite findings regarding the association between age and EI were reported in the current review.[52,53]

Ultrasound-assessed thickness and CSA of the LM were found to be larger in males than females.[49,50,54,56–58] There may be a more ovoid LM muscle shape in females than males.[50,59] However, few studies took into account weight, percent body fat or BMI as covariates for sex-related differences.[50,56,58] Although none of the included studies could confirm a relationship between CSA of the LM and BMI,[50,59] there were moderate to strong positive correlations with weight.[50,59,60] By contrast, Watson et al. found a moderate negative correlation between percent body fat and CSA of the LM at L5.[58] They hypothesized that a sedentary lifestyle might lead to an increase in body fat deposition and muscle fat infiltration, as well as disuse atrophy of the LM.[58] On MRI, Crawford et al. reported a higher fat infiltration in paravertebral muscles including the LM in women compared to men, after controlling for BMI.[86] Correspondingly, in the current review, a higher EI was reported in women than in men.[53]

Furthermore, the influence of physical activity level on weight and body fat should not be overlooked. A direct relationship between physical activity level and CSA and thickness of the LM was reported in two studies, although both had a high risk of bias (Table 2).[51,57] Ikezoe et al. suggested that the muscle mass of the LM might be maintained by small muscle contraction during daily physical activities, given the fact that independent elderly women had a larger LM thickness compared to chronically bedridden women.[51] This statement is supported by Cholewicki et al. who previously documented electromyographically that only 1-3% of the maximum voluntary contraction of the LM is needed to maintain segmental stability around a neutral spine position.[88] On MRI, Hides et al. noted a decrease in CSA of the LM after eight weeks of bed rest, most likely because of removal of normal axial gravitational loading as a stimulus for muscle activity.[89] Moreover, it is possible that specific sport-related physical demands lead to hypertrophy of the LM as seen in elite athletes (weightlifters[90] and rowers[91]) compared to normal healthy controls, even in the presence of LBP. Important to note is that analyses were mostly based on self-reported physical activity, which tends to overestimate the activity level. In addition, patients with LBP are even more likely to underestimate sedentary time.[92]

Ultrasound measurement of the CSA of the LM can be performed in prone or side lying position, as no significant difference between either position was demonstrated.[62] Two studies investigated the CSA of the LM in four positions.[61,63] Even though the risk of bias was high in both studies (Table 2), they both reported an increase in CSA of the LM in standing compared to a prone lying position.[61,63] This increase in CSA might reflect the exerted force of the LM to stabilize the lumbar region in standing position.[63] The CSA of the LM decreased in a stooped position compared to standing,[61,63] which might be explained by an eccentric type of contraction in stooping.

For lumbar level, several studies reported an increasing CSA of the LM caudally from L2 to S1.[49,50,59] These findings are in line with the cadaver study of Amonoo-Kuofi in 1983, documenting a larger LM at caudal levels.[37] No difference in thickness change of the LM was observed between L4-5 and L5-S1,[64] but the risk of bias in this one study examining the association between lumbar level and thickness change was high (Table 2).

Correlation between left and right side CSA and thickness of the LM is high in healthy subjects at L2 to S1.[20,49,58,65,68] Side-to-side differences in shape of the LM were larger compared to side-to-side differences in CSA in healthy subjects,[50,59] suggesting that shape might be a less sensitive parameter to investigate asymmetry. Most studies on healthy subjects reported approximately 5% asymmetry in CSA and thickness of the LM.[49,58,59,68] Based on previous studies, an asymmetry in CSA of > 10% was suggested as potentially abnormal.[49] But this criterion of 10% asymmetry in CSA might not be applicable for all populations, as asymmetry up to 40% has been reported in healthy subjects, based on US[59,67] and MRI images.[93] Moreover, asymmetry may be normal in some groups, for example because of predominant unilateral use of muscles in sports.[59] Other factors (e.g. handedness, physical activity) influencing asymmetry were investigated, but results were inconsistent.[94] On the contrary, some studies indicate that LM asymmetry may be related to occurrence of injuries in cricket[95] and football.[96]

Subjects with CLBP have a smaller CSA of the LM on US, as demonstrated in several studies included in this review,[49,57,61,63,72] and confirmed in studies using CT and MRI.[97,98] However, this difference between subjects with and without CLBP might not be present at the upper lumbar levels[49,57] or in specific populations such as elite athletes.[65] In subjects with CLBP, asymmetry in CSA of the LM seems to be more pronounced compared to healthy subjects.[49,63] Asymmetry of the LM was also seen on MRI in patients with chronic unilateral LBP.[99] On the other hand, Fortin et al. found no association between LBP history and LM asymmetry on MRI.[94] Muscle atrophy in subjects with CLBP might be the result of inhibition of muscle activity because of perceived pain or because of the incapacity of a muscle or ligament to recover to its initial resting length due to long-lasting strain.[61] But curiously, no significant differences in LM thickness in rest were found between subjects with and without CLBP.[67,69,70,74] Thus, thickness measures of the LM might be insufficient to detect size differences as they do not account for medial to lateral expansion. A larger fat area of the LM was reported in subjects with CLBP compared to asymptomatic controls, however, only the L4 level was investigated.[61] This implicates a larger proportion of noncontractile tissue in the LM and possibly a reduction in muscle quality which could contribute to differences in muscle function.

It is suggested that subjects with LBP have altered neuromuscular control resulting in different muscle activation.[9,100,101] Several studies in this review confirmed lower activation ratios in subjects with CLBP.[55,57,69,71,72] On the contrary, Sweeney at al. reported a larger thickness change in subjects with CLBP, however, only during a contralateral arm lift in standing.[70] Moreover, Lee et al. hypothesized that the LM is not able to respond to the postural demand in subjects with CLBP, particularly in upright positions, as they found an altered LM CSA in standing and stooping positions in subjects with CLBP compared to those without.[63] However, this group difference in change in CSA of the LM in different positions was not confirmed in the study of Chan et al.[61]

Methodological considerations and implications for future research

This systematic review has several limitations. No inter-rater agreement was calculated for data extraction. Because of the heterogeneity of the included studies, the results were summarized qualitatively. Across the included studies, several factors increasing the risk of bias were present (Table 2). First, study populations were sometimes small, and clear definitions of the patient and control groups were frequently not available. Definition and aspects (duration, intensity, location) of LBP differed between studies or were not mentioned. Information about participant recruitment was mostly insufficient, making it more difficult to compare results. In most studies the investigator was not blinded for LBP status of the study participant, possibly increasing the risk of bias. Moreover, potential confounding factors such as age, BMI or activity level were often not taken into account. Sex differences should be related to weight and other anthropometric parameters for a correct interpretation of findings. More research is needed to determine the association between anthropometric parameters and the structural characteristics of the LM, especially in populations with a higher BMI. The role of physical activity level in the structure and function of the LM is still unclear and should be further investigated using objective measurements of physical activity. Furthermore, US protocols varied between studies, with some investigating left and right sides separately, and some pooling the results for both sides. However, side-to-side differences of the LM may be present in case of unilateral LBP,[40,99] which implies both sides should be examined separately. Several studies investigated only one lumbar level, which limits interpretation of the findings. As characteristics of the LM differ between lumbar levels, investigating more than one level is recommended to be able to understand the differences related to LBP. Most studies analyze CSA or thickness to assess muscle size or symmetry, but do not determine EI as a reflection of fatty infiltration. However, greater infiltration with fatty or fibrous tissue can influence muscle quality without altering muscle size. Further investigating the change of EI in subjects with CLBP versus healthy subjects can provide more insight in the structural muscle alterations in CLBP.

The clinical relevance of LM shape has yet to be explored. Hypertrophy is only possible in the lateral or posterior direction because medial and anterior borders are defined by bony structures. Larger muscles thus tend to be more triangular, which cannot be deduced from the shape ratio. In patients with acute LBP, a rounder shape of the LM was seen at the affected level.[40] This might be caused by a change in muscle tone or presence of a muscle spasm.[40,50]

Conclusion

In this systematic review, several factors associated with the US characteristics of the LM are identified. A relation between age and LM size is not confirmed. Males have a larger thickness and CSA of the LM than females. The correlation between the left and right LM size is high in healthy subjects. More significant side-to-side differences are present in subjects with CLBP than in those without. An increase in LM size is seen from proximal to caudal lumbar levels. The presence of CLBP is associated with muscle size and function. The role of physical activity and body weight in characteristics of the LM is unclear. Muscle EI was not sufficiently investigated to reach any conclusions. The above-mentioned factors should be taken into account in future research on structural characteristics of the lumbar muscles, the relation with functional behavior or the effect of a targeted intervention.

Disclosure

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Table 1. Inclusion and exclusion criteria.

	Inclusion	Exclusion
Population	- Humans > 18 years old - Patients with nonspecific CLBP (duration > 3 months) or healthy, pain-free subjects	- Animals - Patients with other disorders (neurological, deformation, etc.) or CLBP due to a specific cause
Instrument and site	- Ultrasonography of the lumbar multifidus	- Only non-ultrasound imaging method - Only non-multifidus muscles
Outcome	Structural characteristics of the lumbar multifidus (CSA, thickness, anteroposterior/lateral dimensions, echo intensity) • Association with one of the influencing factors (age, sex, anthropometric parameters, physical activity level, posture, lumbar level, body side) AND/OR • Comparison between CLBP and control group	- Effect of intervention (treatment including surgery, application of load or resistance)‡ - Relation with prognostic factors
Type of report	- Clinical report - Full-text - In English, Dutch or French†	- Systematic review, meta-analysis, letter to editor - No full text available, abstract only - Other languages

CLBP: chronic low back pain, CSA: cross-sectional area

† No foreign language articles were included in the final analysis.

‡ Only baseline data of intervention studies was included, if a measure of association or comparison between CLBP and control group was present at this baseline assessment.

Table 2. Risk of bias in the included studies (adapted version of the Downs and Black checklist)

Item	Aboufazeli[71]	Berglund[54]	Cai[55]	Chan[61]	Coldron[62]	Dar[64]	Djordjevic[69]	Hides (1992)[59]	Hides (1995)[20]	Hides (2008)[49]	Huang[66]	Ikezoe[51]	Lee[63]	Masaki (2015)[52]	Masaki (2017)[74]	Nuzzo (2013)[60]	Nuzzo (2014)[67]	Pressler[68]	Rostami[72]	Scott[65]	Stokes[50]	Sweeney[70]	Teyhen[56]	Wallwork[57]	Watson[58]	Yoshiko[53]	Zhang[73]
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1
5	2	2	2	2	0	2	2	2	1	1	2	2	1	2	2	2	2	2	2	2	2	1	2	2	2	2	2
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	1	1	1	1	1	1	1	0	0	1	0	0	1	0	1	0	0	0	1	1	1	1	1	0	0	0	1
11	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	NA	0	0	NA	NA	0	0	0	0	NA	0	NA	NA	NA	1	0	NA	1	NA	1	NA	NA	0
16	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
18	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
20	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
21	0	1	0	1	NA	0	1	NA	NA	0	NA	0	1	NA	0	NA	NA	NA	0	0	NA	0	NA	0	NA	NA	0
22	0	1	0	0	NA	0	1	NA	NA	0	NA	0	0	NA	0	NA	NA	NA	0	0	NA	0	NA	0	NA	NA	0
25	1	0	1	0	0	0	1	0	0	1	0	0	0	0	1	0	0	0	1	1	1	1	1	1	1	1	1
27	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
total score (%)	67	78	67	67	53	56	78	67	60	61	63	56	56	67	67	67	67	67	72	72	80	67	80	61	73	73	67

NA: not applicable

Table 3. Results of the included studies

Author (year)	Patient characteristics (mean±SD)		Position + US probe	Structural characteristics of the LM + lumbar level	Associated factors	Measure of association (mean±SD)	CLBP vs. control group (mean±SD)
	CLBP group	Control group					
Aboufazeli et al.[71] (2018)	**30 F** – 34.6±6.2y BMI: 23.4±3.2kg/m² VAS ≥ 5 LBP duration > 3 months	**30 F** – 36.7±6.7y BMI: 23.6±3.3kg/m²	- prone - 7.5MHz convex probe	- thickness at rest and contraction (CAL+W) - L4/5 at most painful side or averaged L-R			smaller thickness change in CLBP vs. control group (3.21±0.09mm to 4.47±0.40mm vs. 2.88±0.37mm to 3.95±0.40mm; p=0.002)
Berglund et al.[54] (2017)	**65 CLBP** *28 M* – 45.6±9.2y BMI: 25.1±3.3kg/m² VAS: 38.8±22.8 *37 F* – 40.6±10.1y BMI: 25.3±3.6kg/m² VAS: 49.6±26.8 LBP duration > 3 months		- prone - 10-12 MHz linear probe	- thickness - L5 bilateral	- sex - side	- larger thickness in M vs. F on large side (2.78±0.43cm vs. 2.54±0.45cm; p=0.03) and on small side (2.52±0.45cm vs. 2.31±0.41cm; p=0.06) - significant side difference in M (9.3%) and F (8.8%) (p<0.001)	NA
Cai et al.[55] (2015)	**18 CLBP** *9 M* – 29.6±7.3y BMI: 21.5±2.4kg/m² NPS of last week: 2.3±1.0 *9 F* – 26.0±2.6y BMI: 22.0±2.1kg/m² NPS of last week: 2.4±0.9 LBP duration > 3/ < 36 months recreational runners	**18 healthy** *9 M* – 25.6±4.2y BMI: 21.7±2.0kg/m² *9 F* – 23.6±2.5y BMI: 21.1±2.1kg/m² recreational runners	prone	- thickness at rest and contraction (CAL+W) - L4/5 bilateral	sex	no significant difference in thickness change between M and F (p=0.092)	smaller thickness change in CLBP vs. control group in M only (0.33±0.11cm vs. 0.59±0.19cm; p<0.05)

Author (year)	Patient characteristics (mean±SD)		Position + US probe	Structural characteristics of the LM + lumbar level	Associated factors	Measure of association (mean±SD)	CLBP vs. control group (mean±SD)
	CLBP group	Control group					
Chan et al.[61] (2012)	**12 M** – 36.6±2.9y BMI: 22.0±0.5kg/m² ODI: 22±3% LBP duration: not reported	**12 M** – 25.2±1.1y BMI: 21.8±0.8kg/m²	- prone/ standing/ forward stooping 25°+ 45° - 5-12MHz probe	- CSA and fat area - L4 bilateral	posture	- increase in CSA from prone to standing (in control group at L side: 6.16±0.09cm² to 7.16±0.10cm²; p<0.025), decrease from standing to 25° stooping (in control group at L side: 7.16±0.10cm² to 5.51±0.13cm²; p<0.025), no difference between 25° and 45° stooping (in control group at L side: 5.51±0.13cm² to 5.71±0.36cm²; p=1) - no association between posture and fat area (p=0.978)	- smaller CSA in all positions in CLBP vs. control group (L side: 5.01±0.07cm² to 6.58±0.20cm² vs. 5.51±0.13cm² to 7.16±0.10cm² and R side: 4.81±0.13cm² to 6.61±0.21cm² vs. 5.55±0.13cm² to 7.06±0.08cm²; p<0.001) - larger fat area in all positions in CLBP vs. control group (L side: 0.90±0.09cm² to 1.08±0.23cm² vs. 0.56±0.10cm² to 0.71±0.10cm² and R side: 0.88±0.13cm² to 1.13±0.23cm² vs. 0.60±0.09cm² to 0.73±0.11cm²; p<0.001)
Coldron et al.[62] (2003)		**20 F** - 19-45y BMI: not reported	- prone/ left side lying - 5MHz curvilinear probe	- CSA - L5 bilateral	posture	- high correlation between prone and side lying (L side: 5.54±1.02cm² vs. 5.39±1.02cm²; r=0.90 and R side: 5.48±1.22cm² vs. 5.44±1.22cm²; r=0.91; p<0.001) - no significant difference in CSA between prone and side lying (L side: p=0.16 and R side: p=0.77)	NA
Dar et al.[64] (2016)		**28 healthy** *17 M* *11 F* intervention group: 32.2±6.4y BMI: 22.4±0.8kg/m² control group: 31.9±2.9y BMI: 24.1±2.4kg/m²	- prone - 6MHz convex probe	- thickness at rest and contraction (contralateral leg lift) - L4/5 + L5/S1 bilateral	- level - side	- larger thickness change at L5/S1 for L vs. R side (32.07±6.63% vs. 26.78±7.95%, p=0.02), only in intervention group (baseline data) - no significant side difference in thickness at rest and contraction at both levels nor in thickness change at L4/5 (p>0.05) - no significant difference in thickness or thickness change	NA

Author (year)	Patient characteristics (mean±SD)		Position + US probe	Structural characteristics of the LM + lumbar level	Associated factors	Measure of association (mean±SD)	CLBP vs. control group (mean±SD)
	CLBP group	Control group					
						between L4/5 and L5/S1 on same side ($p>0.05$)	
Djordjevic et al.[69] (2015)	**36 CLBP** *18 M* *18 F* 53.2±8.1y BMI: 27.4±4.6kg/m² ODI: 28.8±11.3% VAS in last 24h: 5.3±2.7 LBP duration: 18.2±3.8 weeks	**37 healthy** *15 M* *22 F* 52.6±9.5y BMI: 26.9±5.5kg/m²	- prone - 3-6MHz curvilinear probe	- thickness in rest and contraction (CAL +resistance) - L4/5 bilateral	side	- significant effect of side at rest and contraction due to significant difference between rest and contraction in both groups on both sides ($F_{3,108} = 302.15$; $p<0.0001$) - no significant effect of side or interaction group x side for relative thickness change ($F_{1,142} = 0.34$; $p=0.5608$)	- no significant difference for thickness at rest and maximal contraction between CLBP and control group ($F_{1,36} = 0.1635$; $p=0.688$) - smaller relative thickness change in CLBP vs. control group (0.3±0.2 vs. 0.4±0.2; $F_{1,142} = 36.01$; $p<0.0001$)
Hides et al.[59] (1992)		**48 healthy** *21 M* *27 F* 18-35y BMI in M: 22.3±2.7kg/m²; in F: 21.4±2.7kg/m²	- prone - 5MHz convex probe	- CSA, AP and lateral dimensions - L4 bilateral	- anthrop. factors - side	- no association between CSA and BMI ($p>0.1$) - in M: positive correlations between CSA and weight ($r=0.78$; $p<0.001$), CSA and height ($r=0.63$; $p<0.01$), CSA and weight x height ($r=0.79$; $p<0.01$) - in F: positive correlations between CSA and weight ($r=0.60$; $p<0.05$), CSA and height ($r=0.54$; $p<0.05$), CSA and weight x height ($r=0.65$; $p<0.05$) - no significant side difference for CSA ($p>0.1$), shape ratio ($p>0.1$) AP and lateral dimensions ($p>0.1$) - high correlation between CSA and linear dimensions (in M: $r=0.98$; $p<0.001$ and in F: $r=0.93$; $p<0.01$)	NA
Hides et al.[20] (1995)		**10 F** - 21-31y (mean 25.5y) BMI: not reported	- prone - 7.5MHz linear probe	- CSA - L2 -> S1 bilateral	- level - side	- no significant difference in CSA between L and R at any level ($F_{1,275}=0.01$; $p>0.05$) - significant difference in CSA between each level (L2: 1.95±0.63cm², L3: 3.18±0.92cm², L4:	NA

Author (year)	Patient characteristics (mean±SD)		Position + US probe	Structural characteristics of the LM + lumbar level	Associated factors	Measure of association (mean±SD)	CLBP vs. control group (mean±SD)
	CLBP group	Control group					
						4.74±1.32cm², L5: 7.14±0.66cm², S1: 6.50±0.81cm²; $F_{4.275} = 544.81$; p<0.0001)	
Hides et al.[49] (2008)	**42 CLBP** *21 M* *21 F* 46.8±13.2y BMI: not reported RMQ: 7.0±5.6 VAS: 4.4±2.7 LBP duration: 62.2±90.6 months	**40 healthy** *27 M* *13 F* 28.4±5.7y BMI: not reported	- prone - 5MHz convex probe	- CSA - L2 -> L5 bilateral	- age - sex - level - side	- no association between age and CSA (p>0.05) or asymmetry in CSA (p>0.1) - larger CSA at L2->L4 in M vs. F (L2: 2.78±1.13cm² vs. 2.01±1.37cm², L3: 3.85±1.36cm² vs. 3.02±1.40cm², L4: 4.79±1.70cm² vs. 3.80±1.74cm²; p=0.001), not significant at L5 (p=0.22) - no association between sex and asymmetry (p>0.1) *In control group:* - increase in CSA to caudal levels	- smaller CSA in CLBP vs. control group at L4 (4.07±1.88cm² vs. 5.42±1.88cm²; p=0.001) and L5 (3.78±1.73cm² vs. 6.48±1.72cm²; p=0.001); not at L2 and L3 - more asymmetry in unilateral CLBP vs. bilateral CLBP or control group at L4 (11.8±19.1% vs. 5.1±12.2% vs. 3.4±12.0%; p=0.004) and L5 (17.5±24.2% vs. 10.5±15.5% vs; 1.9±15.2%; p=0.016), not at L2 and L3
Huang et al.[66] (2014)	**24 CLBP** (unilateral) *10 M* *14 F* 23.8±5.2y H: 168.8±8.6cm W: 62.6±16.4kg VAS: 2.2±1.2 LBP duration > 6 months		- supine - 7.5MHz linear probe	- CSA - L5 bilateral	side	- positive correlation between VAS and ratio of CSA between unaffected and affected sides (r=0.72; p<0.01) - ratio un-/affected side: 1.16±0.1 - CSA of unaffected side: 8.79±2.1cm² vs. affected side: 7.61±1.96cm²	NA
Ikezoe et al.[51] (2012)		**74 healthy** - *33 young F* – 20.0±0.8y BMI: 22.1±2.3kg/m² - *41 older F*	- prone - 5-10MHz probe	- thickness - L4 right	- age - activity level	- no significant difference between independent elderly vs. young F (p>0.05) - smaller thickness in dependent elderly vs. young F (22.8±5.44mm vs. 26.7±7.62mm; p<0.01)	NA

Author (year)	Patient characteristics (mean±SD)		Position + US probe	Structural characteristics of the LM + lumbar level	Associated factors	Measure of association (mean±SD)	CLBP vs. control group (mean±SD)
	CLBP group	Control group					
		28 independent: 85.7±5.5y BMI: 20.5±3.2kg/m² 13 dependent: 87.8±6.3y BMI: 16.6±2.1kg/m²				- smaller thickness in dependent elderly vs. independent elderly F (22.8±5.44mm vs. 23.2±7.49mm; $p<0.05$)	
Lee et al.[63] (2006)	**16 M** - 34-47y (mean 39.9y) BMI: not reported LBP duration > 1y	**19 M** - 35-47y (mean 41.7y) BMI: not reported	- prone/ standing/ 25°-/45° stooping - 5MHz convex probe	- CSA - L4 + L5 bilateral	posture	*In control group:* - increase in CSA from prone to standing, decrease from 25° to 45° stooping at L4 - L4 L side: larger CSA in standing vs. 45° stooping (8.92±1.94cm² vs. 7.44±1.17cm²; p=0.032) - L4 R side: larger CSA in standing vs. prone (9.19±1.76cm² vs. 7.68±1.29cm²; p=0.019), standing vs. 25° stooping (9.19±1.76cm² vs. 7.84±1.66cm²; p=0.043) and standing vs. 45° stooping (9.19±1.76cm² vs. 7.11±1.45cm²; p=0.001) (not significant at L5) *In CLBP group:* - increase in CSA from prone to standing to 25° stooping, decrease in 45° stooping - L4 R side: larger CSA in 25° stooping vs. prone (8.50±1.17cm² vs.7.20±0.94cm²; p=0.006) and 25° vs. 45° stooping (8.50±1.17cm² vs. 7.28±1.17cm²; p=0.011)	- smaller CSA at L4 in standing in CLBP vs. control group (L side: 7.55±1.45cm² vs. 8.92±1.94cm²; p=0.02 and R side: 8.10±0.97cm² vs. 9.19±1.76cm²; p=0.03) (not significant at L5 or in other positions; p>0.05)
Masaki et al.[52] (2015)		**36 F** – 72.4±8.0y H: 150.2±4.5cm W: 48.8±7.7kg	- prone	- thickness and EI - L4 bilateral	age	-no significant association between age and thickness (r=-0.02; p>0.05) or EI (r=-0.21; p>0.05)	NA

Author (year)	Patient characteristics (mean±SD)		Position + US probe	Structural characteristics of the LM + lumbar level	Associated factors	Measure of association (mean±SD)	CLBP vs. control group (mean±SD)
	CLBP group	Control group					
			- 8MHz linear probe				
Masaki et al.[74] (2017)	**9 CLBP** *1 M* *8 F* 44.7±13.0y H: 157.4±6.6cm W: 52.1±9.4kg ODI: 19.6±7.8% NRS in static situations: 5.0±1.4 NRS in dynamic situations: 5.0±1.7 LBP duration: 98.0±73.1 months	**23 healthy** *8 M* *15 F* 34.7±10.2y H: 164.1±7.5cm W: 56.9±8.9kg	- prone - linear probe	- thickness - L4 bilateral		NA	no significant difference in thickness between CLBP and control group (p>0.05)
Nuzzo et al.[60] (2013)		**62 M** - 36.2±9.4y H: 178.5±8.2cm W: 88.6±15.3kg fire fighters	- prone - 5MHz curvilinear probe	- CSA and thickness - L4 + L5 R	anthrop. factors	positive correlations between weight and L4 CSA (r=0.49; p<0.001), L5 CSA (r=0.43; p<0.001), L4 thickness (r=0.40; p=0.001) and L5 thickness (r=0.45; p<0.001)	NA
Nuzzo et al.[67] (2014)		**69 healthy** *62 M* – 36.2±9.4y BMI: 27.7±3.7kg/m² *7 F* - 25,1±3,6y BMI: 24.4±4.0kg/m² 32% with history of self-reported LBP (not clinically meaningful), no current LBP	- prone - 5MHz curvilinear probe	CSA at L4 + L5 bilateral, thickness at L4 + L5 R	side	- asymmetry of ≥10% in - M: 34% at L4, 31% at L5 - F: 57% at L4, 14% at L5 - mean asymmetry in - M: 9.2±8.8% at L4, 9.8±15.1% at L5 - F: 13.7±8.6% at L4, 4.8±3.3% at L5	no significant difference in thickness or CSA between subjects with and without history of self-reported LBP (p>0.05)

Author (year)	Patient characteristics (mean±SD)		Position + US probe	Structural characteristics of the LM + lumbar level	Associated factors	Measure of association (mean±SD)	CLBP vs. control group (mean±SD)
	CLBP group	Control group					
		fire fighters					
Pressler et al.[68] (2006)		**30 F** - 23±2y BMI 23±2.5kg/m²	- prone - 5-10MHz linear probe	- CSA - S1 bilateral	side	- L side > R side (4.18±0.55cm² vs. 4.11±0.57cm²; $p<0.035$) - high correlation between CSA at L and R side ($r=0.94$; $p<0.001$) - asymmetry of 3.5±3.4%	NA
Rostami et al.[72] (2015)	**14 M** – 27.2±4.7y BMI: 24.0±4.1kg/m² VAS: 1.6±2.0 LBP duration > 12 months competitive off-road cyclists	**24 M** – 27.8±5.3y BMI: 24.9±3.5kg/m² competitive off-road cyclists	- prone/ on bike in 4 positions - 5MHz curved probe	- CSA atrest and contraction (CAL+ipsi-lateral leg lift) - L4 bilateral		NA	*CLBP vs. control group:* - smaller CSA at rest in prone at L side (5.67±0.52cm² vs. 6.17±0.59cm²; $p=0.014$) - smaller CSA in contraction in prone at R side (6.47±0.94cm² vs. 7.30±0.87cm²; $p=0.01$) - smaller CSA change during contraction in prone at R side (0.88±0.45cm² vs. 1.28±0.41cm²; $p=0.009$) - smaller CSA in 4 positions on bike at L side (4.77±0.59cm² to 4.84±0.54cm² vs. 5.31±0.73cm² to 5.51±0.76cm²; $p<0.05$) and R side (4.85±0.50cm² to 4.91±0.55cm² vs. 5.39±0.71cm² to 5.58±0.71cm²; $p<0.05$)
Scott et al.[65] (2015)	**20 CLBP** *14 M* *6 F* 31.9±7.2y BMI: 24.0±2.2kg/m² VAS: 5.3±1.9	**20 healthy** *14 M* *6 F* 31.3±7.6y BMI: 22.3±3.0kg/m²	- prone/ sitting - curvi-linear probe	- CSA - L5 bilateral	side	no significant difference L vs. R in prone nor sitting ($p>0.05$)	no significant difference between CLBP and control group in prone nor sitting ($p>0.05$)

Author (year)	Patient characteristics (mean±SD)		Position + US probe	Structural characteristics of the LM + lumbar level	Associated factors	Measure of association (mean±SD)	CLBP vs. control group (mean±SD)
	CLBP group	Control group					
	LBP duration > 3 months						
Stokes et al.[50] (2005)		**120 healthy** *52 M* – 40.1±13.0y BMI: 25.8±3.2kg/m² *68 F* – 34.2±12.8y BMI: 23.0±3.1kg/m²	- prone - 5MHz convex probe	- CSA, AP and lateral dimensions - L4 + L5 bilateral	- age - sex - antrop. factors - level - side	- no association between CSA and age (p>0.05) - no association between symmetry and age (p>0.05) - smaller shape ratio at younger age at L5 (p<0.001) - larger CSA in M vs. F at L4 (7.87±1.85cm² vs. 5.55±1.28cm²; p<0.001) and L5 (8.91±1.68cm² vs. 6.65±1.00cm²; p<0.001), but not significant when normalized for weight - no association between symmetry and sex (p>0.05) - smaller shape ratio in F vs. M (0.95±0.17 vs. 1.03±0.17; p=0.025) - no association between CSA and BMI (p>0.05) - larger CSA at L5 vs. L4 (in M: 8.89±1.69cm² vs. 7.97±1.80cm², in F: 6.64±1.01cm² vs. 5.55±0.99cm²; p<0.001) - high correlation between CSA at L4 and L5 (in M: r=0.82 and in F: r=0.80; p<0.001) - no association between symmetry and level (p>0.05)	NA

Author (year)	Patient characteristics (mean±SD)		Position + US probe	Structural characteristics of the LM + lumbar level	Associated factors	Measure of association (mean±SD)	CLBP vs. control group (mean±SD)
	CLBP group	Control group					
						- smaller shape ratio at L5 vs. L4 in F (0.95±0.17 vs. 1.02±0.17; p<0.001) - positive correlations between CSA and AP and lateral dimensions (r>0.6; p<0.0001)	
Sweeney et al.[70] (2014)	**10 CLBP** (unilateral) *4M* *6F* 36±12.2y H: 165.7±10.8cm W: not reported RMQ: 5.0±3.1 LBP duration: 28.2±22.0 months	**10 healthy** *6M* *4F* 31.8±5.5y H: 170.0±9.2cm W: not reported	- prone/ standing - 5MHz curved probe	- thickness at rest and contraction (CAL) - L4/5 + L5/S1 bilateral	side	no significant difference in thickness at rest or thickness change between painful and non-painful sides in LBP group in prone nor standing (p>0.05)	- no significant difference in thickness at rest between CLBP and control group in prone nor standing (p>0.05) - larger thickness change during CAL in standing at L5/S1 in CLBP vs. control group (9.97±10.84% vs. 2.29±3.43%; p=0.05) - no significant difference between CLBP and control group during CAL in prone (p>0.05)
Teyhen et al.[56] (2012)		**340 healthy** *244M* – 21.8±3.9y BMI: 25.0±2.8kg/m² *96F* – 22.3±5.0y BMI: 24.5±2.9kg/m² US army soldiers	- prone - 5MHz curvilinear probe	- thickness at rest and contraction (CAL+W) - L4/5 bilateral	- sex - side	- larger thickness in M vs. F at rest (3.11±0.45cm vs. 2.67±0.36cm; p<0.001) and during contraction (3.82±0.48cm vs. 3.26±0.40cm; p<0.001), also when corrected for height and weight (p<0.05) - no significant sex difference for %thickness change (p=0.79) -no significant sex difference for asymmetry at rest (p=0.98) or during contraction (p=0.68)	NA
Wallwork et al.[57] (2009)	**17 CLBP** *8M* *9F* 41.9±13.7y H: 174.2±10.3cm W: 76.1±16.7kg VAS ≥ 3	**17 healthy** *8M* *9F* 33.9±11.2y H: 176.6±10.3cm W: 81.2±12.5kg	- prone - 5MHz curvilinear probe	- CSA and thickness at rest and contraction (voluntary swelling) - L2 -> L5 bilateral	- sex - activity level - side	- larger CSA in M vs. F at L2 (difference of 0.15cm²; p<0.05) and L3 (difference of 0.9cm²; p<0.05) - no association between sex and thickness change (p>0.05) - positive association between activity level and CSA at L3 (F=5.9;	- smaller CSA in CLBP vs. control group at L5 (3.81±1.2cm² vs. 5.56±1.1cm²; F=29.1; p=0.001) - larger CSA in CLBP vs. control group at L2 (2.40±0.9cm² vs. 1.94±0.9cm²; F=5.8; p=0.047)

Author (year)	Patient characteristics (mean±SD)		Position + US probe	Structural characteristics of the LM + lumbar level	Associated factors	Measure of association (mean±SD)	CLBP vs. control group (mean±SD)
	CLBP group	Control group					
	LBP duration > 3 months					p=0.03), L4 (F=11.9; p=0.006) and L5 (F=5.4; p=0.04) - no association between activity level and thickness change (p>0.05) - significant asymmetry of CSA (mean difference of 0.17cm²) and thickness change (mean difference of 2.7%) at each level (p<0.05)	- smaller thickness change in CLBP vs. control group at L5 (3.05±7.2% vs. 6.29±6.5%; F=6.6; p=0.02) - no significant difference in asymmetry of CSA or asymmetry of thickness change between CLBP and control group (p>0.05)
Watson et al.[58] (2008)		**25 healthy** *8M*- 31.9±6.5y BMI: 24.8±2.5kg/m² *17F* – 32.8±13.6yBMI: 23.9±4.3kg/m²	- prone - 3.5-5MHz convex probe	- CSA - L5 bilateral	- sex - anthrop. factors - side	- larger CSA in M vs. F (7.58±1.51cm² vs. 6.01±0.70cm²; $F_{1.23}$=12.8; p=0.002), without effect for % body fat (p>0.05) - negative correlation between CSA and body fat (L side: r=-0.41 and R side: r=-0.44; p<0.05) - high correlation between sides (L side: 6.54±1.32cm² vs. R side: 6.48±1.39cm²; r=0.92; p<0.001) - mean asymmetry: 4.97% in M and 6.45% in F	NA
Yoshiko et al.[53] (2018)		**22 healthy** *8M* - 73±5y BMI: 23±3kg/m² *14F* - 82±7y BMI: 22±4kg/m²	- prone - 8-10MHz linear probe	- thickness and EI - L4/5 R	- age - sex	- positive correlation between age and EI (r=0.64; p<0.05) - larger thickness in M vs. F (2.99±0.47cm vs. 2.49±0.37cm; p<0.05) - lower EI in M vs. F (47.45±6.97a.u. vs. 60.65±9.61a.u.; p<0.05)	NA
Zhang et al.[73] (2018)	**24 CLBP** – 35.9±7.6y *11M* *13F* BMI: 21.8±2.1kg/m² ODI: 32.8±20.1% VAS: 4.0±1.0	**26 healthy** – 32.4±7.2y *13M* *13F* BMI: 21.0±2.0kg/m²	- prone - 6-13MHz probe	- CSA and thickness at rest and contraction (head, trunk, arms lifted)		- no significant difference between painful vs. nonpainful sides for CSA (p=0.69), thickness at rest (p=0.82), thickness during contraction (p=0.89) or thickness change (p=0.62)	- smaller CSA in CLBP vs. control group (2.83±0.74cm² vs. 4.36±0.58cm²; p<0.001) - smaller thickness in CLBP vs. control group at rest (1.66±0.21cm vs. 2.10±0.20cm; p<0.001) and during

Author (year)	Patient characteristics (mean±SD)		Position + US probe	Structural characteristics of the LM + lumbar level	Associated factors	Measure of association (mean±SD)	CLBP vs. control group (mean±SD)
	CLBP group	Control group					
	LBP duration: 6.8±6.1y			- L4 bilateral			contraction (2.17±0.34cm vs. 2.95±0.25cm; p<0.001) - smaller thickness change in CLBP vs. control group (29.69±8.62% vs. 40.43±5.83%; p<0.001)

AP: anteroposterior, a.u.: arbitrary units, BMI: body mass index, CAL: contralateral arm lift, CAL+W: contralateral arm lift with handheld weight, cm: centimeter, CSA: cross-sectional area, CLBP: chronic low back pain, EI: echo-intensity, F: female, H: height, kg: kilogram, L: left, LBP: low back pain, LM: lumbar multifidus, M: male, m: meter, MHz: megahertz, NA: not applicable, NPS: numeric pain score, ODI: Oswestry Disability Index, R: right, RMQ: Roland Morris Questionnaire, US: ultrasound, VAS: Visual Analog Scale, W: weight, y: year

If not specifically mentioned, structural characteristics were analyzed at rest.

Figure 1. PRISMA flow chart of study selection process.

Appendix 1 - Checklist for the assessment of the methodological quality: adapted version of the Downs and Black checklist

Appendix 2 – List of abbreviations

Appendix 3 - Reference list of articles excluded based on full text