

Factors Associated With the Ultrasound Characteristics of the Lumbar Multifidus: A Systematic Review

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

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21

22 **Abstract**

23 *Objective*

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

29 *Type*

30 Systematic review.

31 *Literature Survey*

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

33 *Methodology*

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

40 *Synthesis*

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

46 *Conclusions*

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

52 *Level of evidence*

53 I

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

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58 **Introduction**

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

76

77 Previous studies indicated that ultrasonography (US) is a reliable and valid technique for the
78 evaluation of CSA, thickness and linear dimensions (depth and length) of the LM.^{20,21} Echo
79 intensity (EI) refers to the ability to reflect or transmit ultrasound waves in the context of
80 surrounding tissue, whereby the structure can be characterized as hyper-echoic or hypo-
81 echoic, representing lighter or darker pixels on the screen, respectively.²² Echo intensity is

82 considered to be an indicator of the ratio of adipose and connective tissue to muscle,²³⁻²⁵ as
83 a higher EI is highly correlated with a higher level of adipose tissue using a muscle biopsy²⁴ as
84 well as with a higher intramuscular fat content using MRI.²⁵ Ultrasonography is noninvasive,
85 radiation free, widely available and inexpensive. Moreover, real time imaging allows a
86 dynamic evaluation which is a unique advantage compared to other imaging techniques.
87 Because of these features, the use of US in musculoskeletal conditions has significantly
88 increased over the last years.^{26,27} To optimize the applicability of US for the evaluation of LM
89 structural characteristics, it is essential to understand the factors associated with these
90 measurements. Sex differences may play a role, as global skeletal muscle mass is greater in
91 men than women.²⁸ Independent of sex, global skeletal muscle mass decreases with age,
92 especially above the age of 50 years and with an increasing rate above 65 years.^{29,30}
93 Weight^{31,32} and physical activity^{33,34} have an influence on abdominal muscle size; hence, an
94 impact on lumbar muscle size might be presumed. The influence of posture should also be
95 taken into account. Only investigating lumbar muscle characteristics in a recumbent position
96 might not be sufficient to distinguish between subjects with and without LBP.^{35,36}
97 Additionally, cadaver studies by Macintosh et al.⁷ and Amonoo-Kuofi et al.³⁷ suggest a
98 lumbar muscle size difference related to spinal level. Lastly, symmetry of lumbar muscle
99 structure might be of relevance. For example, localized muscle atrophy has been
100 demonstrated in the presence of disc or nerve root injury,^{38,39} as well as in acute/subacute
101 unilateral LBP.⁴⁰

102

103 Therefore, the first objective of this study was to provide a literature overview of the
104 association between age, sex, height, weight, physical activity level, posture, lumbar level,

105 and body side, and the intrinsic structural characteristics (CSA, thickness, linear dimensions
106 and EI) of the LM measured by US. Secondly, differences between healthy subjects and
107 patients with chronic low back pain (CLBP) were summarized.

108

109

110 **Methods**

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

122

123 After removal of duplicates, assessment for eligibility was performed independently by two
124 reviewers (S.R. and E.R). Disagreements were resolved by consensus or by consulting a third
125 reviewer (A.D.G.). Using a basic spreadsheet, data was extracted by one reviewer (S.R.) and
126 checked by a second reviewer (E.R.): author, publication year, population characteristics
127 (number of subjects, age, sex, anthropometric parameters and LBP-related characteristics),
128 measurement position, frequency and shape of the US probe, assessed lumbar level,
129 structural characteristics of the LM assessed by US (thickness (mm), CSA (cm²), EI (grey level
130 intensity on an arbitrary units scale)), and outcome measures (measure of association or
131 comparison between control and CLBP group). Risk of bias was assessed by two reviewers
132 (S.R. and E.R.) by using an adapted version of the Downs and Black checklist (Appendix).⁴²

133 This tool was identified as one of the two most useful instruments for the assessment of
134 non-randomized studies⁴³ and is recommended by the Cochrane collaboration for this
135 purpose.⁴⁴ The original tool was adapted for non-interventional studies, and has been used
136 before.^{45,46} Related questions (items 4, 8, 9, 13, 14, 17, 19, 23, 24 and 26) were omitted.
137 Case-series studies and case studies were not assessed on items related to a control group
138 (items 21 and 22). We maintained item 15 related to blinding of the observer measuring the
139 outcomes, as this was possible when different subject groups were investigated. Item 27
140 concerning the power of the study was adapted to: “Was a sample size calculation done?
141 (yes = 1, no = 0)”. Consequently, the number of questions varied between study designs and
142 the results on risk of bias were presented as a percentage score (Table 2). Inter-rater
143 agreement for risk of bias assessment was measured by calculating the Kappa statistic using
144 IBM SPSS Statistics Version 25. The following classification was used to interpret this
145 agreement: poor (0.00), slight (0.01–0.20), fair (0.21–0.40), moderate (0.41–0.60),
146 substantial (0.61–0.80) and almost perfect (0.81–1.00).⁴⁷ No articles were excluded based on
147 bias assessment. Interpretation of the strength of reported correlations was done following
148 the rule of thumb of Hinkle et al.: little if any (0.00-0.30), low (0.30-0.50), moderate (0.5-
149 0.70), high (0.70-0.90) and very high (0.90-1.00).⁴⁸

150

151

152 **Results**

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

160

161 *Age*

162 Five studies included age in their analysis.^{49–53} No significant association was found between
163 age and **CSA** of the LM at L4,⁵⁰ L5⁵⁰ nor at L2 to L5⁴⁹ in healthy subjects nor patients with
164 CLBP. Stokes et al. reported a smaller shape ratio, which is a ratio of linear measurements
165 (anteroposterior divided by lateral dimensions), at L5 in younger compared to older healthy
166 persons.⁵⁰ No difference in symmetry was seen between age groups.⁵⁰ For **thickness** at rest,
167 no association with age was reported for the LM at L4 in women without LBP.^{51,52} Two
168 studies analyzed the relation between **EI** of the LM and age in healthy subjects, one showing
169 a moderate positive correlation,⁵³ the other showing no significant association.⁵²

170

171 *Sex*

172 Associations with sex were investigated in eight studies.^{49,50,53–58} Four studies found a
173 significantly larger **CSA** of the LM in males compared to females at L2,^{49,57} L3,^{49,57} L4^{49,50} and
174 L5^{50,58} in subjects with and without CLBP, although two of these studies could not confirm
175 these findings for certain lumbar levels.^{49,57} No significant difference in symmetry of CSA was

176 observed between sexes in an asymptomatic population⁵⁰ nor in patients with CLBP.⁴⁹ In
177 healthy subjects, Stokes et al. reported a smaller shape ratio in females compared to
178 males.⁵⁰ A larger muscle **thickness** in males compared to females was demonstrated in
179 healthy subjects at L4-5 at rest^{53,56} and during contraction⁵⁶, as well as in patients with CLBP
180 at L5 at rest.⁵⁴ Two studies did not show a sex effect on thickness change during contraction
181 of the LM at L2 to L5 in subjects with and without CLBP⁵⁷ or at L4-5 in healthy subjects.⁵⁶ Cai
182 et al. found a smaller thickness change in male runners with CLBP compared to healthy
183 subjects, but not in females.⁵⁵ Importantly, when taking into account anthropometric
184 parameters, the sex difference in CSA was no longer significant in the study of Stokes et al.⁵⁰
185 but remained significant in two other studies on CSA⁵⁸ and thickness.⁵⁶ Yoshiko et al.
186 reported a lower **EI** of the LM in healthy males compared to females.⁵³

187

188 *Anthropometric parameters*

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

199

200 *Physical activity level*

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

210

211 *Posture*

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

217

218 *Lumbar level*

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

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

226

227 *Symmetry*

228 Fifteen studies investigated the difference between left and right side of the
229 body.^{20,48,49,53,55-58,63-69} Several studies found a high correlation between left and right **CSA** of
230 the LM in healthy subjects at L5,^{58,65} L2 to L5,⁴⁹ S1⁶⁸ and L2 to S1,²⁰ and in patients with CLBP
231 at L5,⁶⁵ with side-to-side differences smaller than 5%. However, in two studies a larger
232 asymmetry in CSA was observed in healthy subjects at L4 and L5.^{50,67} No influence of sex, age
233 or vertebral level on symmetry of the CSA was reported by Stokes et al.⁵⁰ Side-to-side
234 differences larger than 10% were also seen by Hides et al. in subjects with unilateral CLBP at
235 L4 and L5 but not at L2 and L3.⁴⁹ Side-to-side differences in patients with central or bilateral
236 pain were lower.⁴⁹ Smaller asymmetry was found in CSA than in shape.^{50,59} For **thickness** at
237 rest, side-to-side differences were reported to be around 5% in healthy subjects⁵⁶ and
238 around 10% in patients with CLBP.⁵⁴ There was no significant asymmetry in resting thickness
239 in subjects with unilateral CLBP in prone or standing at L4-5 and L5-S1,⁷⁰ nor in subjects with
240 and without CLBP at L4-5.⁶⁹ Dar et al. described a significant side-to-side difference in
241 thickness change during contraction at L5-S1, but not at L4-5, in a subgroup of healthy
242 subjects.⁶⁴ A small but significant asymmetry in thickness change was observed by Wallwork
243 et al. from L2 to L5 in subjects with and without CLBP.⁵⁷ This asymmetry was not confirmed
244 by Sweeney et al. in subjects with CLBP at L4-5 or L5-S1.⁷⁰

245

246 *Chronic low back pain*

247 In fourteen studies, the influence of CLBP was analyzed.^{49,55,71–74,57,61,63,65–67,69,70}

248 Asymptomatic subjects had a larger **CSA** of the LM compared with subjects with CLBP at L4

249 and L5,^{49,57,61,63,72,73} although findings were not significant for all levels⁵⁷ or in all positions.⁶³

250 In unilateral CLBP, a significant asymmetry in CSA was noted at L4 and L5,⁴⁹ as well as a

251 strong relation between pain scores and the ratio of the CSA of the unaffected and affected

252 side at L5.⁶⁶ However, Zhang et al. did not report a difference in CSA of the LM between

253 unaffected and affected sides,⁷³ nor was a difference in CSA confirmed between subjects

254 with and without CLBP at L2,⁴⁹ L3⁴⁹ or L5.⁶⁵ At L2, Wallwork et al. even observed a slightly

255 larger CSA in subjects with CLBP compared to healthy controls.⁵⁷ Lee et al. reported a

256 different change in CSA of the LM at L4 and L5 in different postures in patients with CLBP

257 compared to healthy controls.⁶³ The largest CSA was observed in upright standing in healthy

258 subjects, while in patients with CLBP the maximal CSA occurred at 25° forward stooping.⁶³

259 Yet, this group difference was not confirmed by Chan et al.⁶¹ In the study of Rostami et al.,

260 the difference between contracted and resting CSA of the right LM at L4 was significantly

261 smaller in patients with CLBP compared to controls.⁷² Wallwork et al. confirmed this finding

262 at L5, but not at L2, L3 and L4.⁵⁷ Regarding **thickness** of the LM, four studies showed no

263 significant differences between subjects with and without CLBP at rest at L4,^{67,74} L4-5,^{68,69}

264 L5⁶⁷ or L5-S1⁷⁰, nor at L4-5 during maximal contraction lifting the head, upper trunk and

265 contralateral arm against static resistance.⁶⁹ Zhang et al. reported a smaller thickness at rest

266 and during contraction in subjects with CLBP compared with healthy controls.⁷³ A smaller

267 thickness change during contraction of the LM was found in subjects with CLBP compared

268 with healthy controls at L4⁷³ and L4-5.^{55,69,71} On the other hand, Sweeney et al. found a

269 larger thickness change at L5-S1 (not at L4-5) in subjects with CLBP during a contralateral

270 arm lift in standing, but not in prone position.⁷⁰ The **fat area** at L4 was higher in subjects with

271 CLBP in the study of Chan et al.⁶¹

272

273

274 **Discussion**

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

278

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

293

294 Ultrasound-assessed thickness and CSA of the LM were found to be larger in males than
295 females.^{49,50,54,56-58} There may be a more ovoid LM muscle shape in females than males.^{50,59}
296 However, few studies took into account weight, percent body fat or BMI as covariates for
297 sex-related differences.^{50,56,58} Although none of the included studies could confirm a

298 relationship between CSA of the LM and BMI,^{50,59} there were moderate to strong positive
299 correlations with weight.^{50,59,60} By contrast, Watson et al. found a moderate negative
300 correlation between percent body fat and CSA of the LM at L5.⁵⁸ They hypothesized that a
301 sedentary lifestyle might lead to an increase in body fat deposition and muscle fat
302 infiltration, as well as disuse atrophy of the LM.⁵⁸ On MRI, Crawford et al. reported a higher
303 fat infiltration in paravertebral muscles including the LM in women compared to men, after
304 controlling for BMI.⁸⁶ Correspondingly, in the current review, a higher EI was reported in
305 women than in men.⁵³

306

307 Furthermore, the influence of physical activity level on weight and body fat should not be
308 overlooked. A direct relationship between physical activity level and CSA and thickness of
309 the LM was reported in two studies, although both had a high risk of bias (Table 2).^{51,57}
310 Ikezoe et al. suggested that the muscle mass of the LM might be maintained by small muscle
311 contraction during daily physical activities, given the fact that independent elderly women
312 had a larger LM thickness compared to chronically bedridden women.⁵¹ This statement is
313 supported by Cholewicki et al. who previously documented electromyographically that only
314 1-3% of the maximum voluntary contraction of the LM is needed to maintain segmental
315 stability around a neutral spine position.⁸⁸ On MRI, Hides et al. noted a decrease in CSA of
316 the LM after eight weeks of bed rest, most likely because of removal of normal axial
317 gravitational loading as a stimulus for muscle activity.⁸⁹ Moreover, it is possible that specific
318 sport-related physical demands lead to hypertrophy of the LM as seen in elite athletes
319 (weightlifters⁹⁰ and rowers⁹¹) compared to normal healthy controls, even in the presence of
320 LBP. Important to note is that analyses were mostly based on self-reported physical activity,

321 which tends to overestimate the activity level. In addition, patients with LBP are even more
322 likely to underestimate sedentary time.⁹²

323

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

332

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

338

339 Correlation between left and right side CSA and thickness of the LM is high in healthy
340 subjects at L2 to S1.^{20,49,58,65,68} Side-to-side differences in shape of the LM were larger
341 compared to side-to-side differences in CSA in healthy subjects,^{50,59} suggesting that shape
342 might be a less sensitive parameter to investigate asymmetry. Most studies on healthy
343 subjects reported approximately 5% asymmetry in CSA and thickness of the LM.^{49,58,59,68}

344 Based on previous studies, an asymmetry in CSA of > 10% was suggested as potentially

345 abnormal.⁴⁹ But this criterion of 10% asymmetry in CSA might not be applicable for all
346 populations, as asymmetry up to 40% has been reported in healthy subjects, based on
347 US^{59,67} and MRI images.⁹³ Moreover, asymmetry may be normal in some groups, for example
348 because of predominant unilateral use of muscles in sports.⁵⁹ Other factors (e.g.
349 handedness, physical activity) influencing asymmetry were investigated, but results were
350 inconsistent.⁹⁴ On the contrary, some studies indicate that LM asymmetry may be related to
351 occurrence of injuries in cricket⁹⁵ and football.⁹⁶
352
353 Subjects with CLBP have a smaller CSA of the LM on US, as demonstrated in several studies
354 included in this review,^{49,57,61,63,72} and confirmed in studies using CT and MRI.^{97,98} However,
355 this difference between subjects with and without CLBP might not be present at the upper
356 lumbar levels^{49,57} or in specific populations such as elite athletes.⁶⁵ In subjects with CLBP,
357 asymmetry in CSA of the LM seems to be more pronounced compared to healthy
358 subjects.^{49,63} Asymmetry of the LM was also seen on MRI in patients with chronic unilateral
359 LBP.⁹⁹ On the other hand, Fortin et al. found no association between LBP history and LM
360 asymmetry on MRI.⁹⁴ Muscle atrophy in subjects with CLBP might be the result of inhibition
361 of muscle activity because of perceived pain or because of the incapacity of a muscle or
362 ligament to recover to its initial resting length due to long-lasting strain.⁶¹ But curiously, no
363 significant differences in LM thickness in rest were found between subjects with and without
364 CLBP.^{67,69,70,74} Thus, thickness measures of the LM might be insufficient to detect size
365 differences as they do not account for medial to lateral expansion. A larger fat area of the
366 LM was reported in subjects with CLBP compared to asymptomatic controls, however, only
367 the L4 level was investigated.⁶¹ This implicates a larger proportion of noncontractile tissue in

368 the LM and possibly a reduction in muscle quality which could contribute to differences in
369 muscle function.

370

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

380

381 *Methodological considerations and implications for future research*

382 This systematic review has several limitations. No inter-rater agreement was calculated for
383 data extraction. Because of the heterogeneity of the included studies, the results were
384 summarized qualitatively. Across the included studies, several factors increasing the risk of
385 bias were present (Table 2). First, study populations were sometimes small, and clear
386 definitions of the patient and control groups were frequently not available. Definition and
387 aspects (duration, intensity, location) of LBP differed between studies or were not
388 mentioned. Information about participant recruitment was mostly insufficient, making it
389 more difficult to compare results. In most studies the investigator was not blinded for LBP
390 status of the study participant, possibly increasing the risk of bias. Moreover, potential
391 confounding factors such as age, BMI or activity level were often not taken into account. Sex

392 differences should be related to weight and other anthropometric parameters for a correct
393 interpretation of findings. More research is needed to determine the association between
394 anthropometric parameters and the structural characteristics of the LM, especially in
395 populations with a higher BMI. The role of physical activity level in the structure and
396 function of the LM is still unclear and should be further investigated using objective
397 measurements of physical activity. Furthermore, US protocols varied between studies, with
398 some investigating left and right sides separately, and some pooling the results for both
399 sides. However, side-to-side differences of the LM may be present in case of unilateral
400 LBP,^{40,99} which implies both sides should be examined separately. Several studies
401 investigated only one lumbar level, which limits interpretation of the findings. As
402 characteristics of the LM differ between lumbar levels, investigating more than one level is
403 recommended to be able to understand the differences related to LBP. Most studies analyze
404 CSA or thickness to assess muscle size or symmetry, but do not determine EI as a reflection
405 of fatty infiltration. However, greater infiltration with fatty or fibrous tissue can influence
406 muscle quality without altering muscle size. Further investigating the change of EI in subjects
407 with CLBP versus healthy subjects can provide more insight in the structural muscle
408 alterations in CLBP.

409

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

416 **Conclusion**

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

427

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430

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751 **Table 1. Inclusion and exclusion criteria.**

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	Inclusion	Exclusion
Population	<ul style="list-style-type: none"> - Humans > 18 years old - Patients with nonspecific CLBP (duration > 3 months) or healthy, pain-free subjects 	<ul style="list-style-type: none"> - Animals - Patients with other disorders (neurological, deformation, etc.) or CLBP due to a specific cause
Instrument and site	<ul style="list-style-type: none"> - Ultrasonography of the lumbar multifidus 	<ul style="list-style-type: none"> - Only non-ultrasound imaging method - Only non-multifidus muscles
Outcome	<p>Structural characteristics of the lumbar multifidus (CSA, thickness, anteroposterior/lateral dimensions, echo intensity)</p> <ul style="list-style-type: none"> • Association with one of the influencing factors (age, sex, anthropometric parameters, physical activity level, posture, lumbar level, body side) <p>AND/OR</p> <ul style="list-style-type: none"> • Comparison between CLBP and control group 	<ul style="list-style-type: none"> - Effect of intervention (treatment including surgery, application of load or resistance)[‡] - Relation with prognostic factors
Type of report	<ul style="list-style-type: none"> - Clinical report - Full-text - In English, Dutch or French[†] 	<ul style="list-style-type: none"> - Systematic review, meta-analysis, letter to editor - No full text available, abstract only - Other languages

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

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

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

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

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Item	Aboufazel ⁷¹	Berglund ⁵⁴	Cai ⁵⁵	Chan ⁶¹	Coldron ⁶²	Dar ⁶⁴	Djordjevic ⁶⁹	Hides (1992) ⁵⁹	Hides (1995) ²⁰	Hides (2008) ⁴⁹	Huang ⁶⁶	Ikezo 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	2	1	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

760

761 NA: not applicable

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765 **Table 3. Results of the included studies**

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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/m ² VAS ≥ 5 LBP duration > 3 months	30 F – 36.7±6.7y BMI: 23.6±3.3kg/m ²	- 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/m ² VAS: 38.8±22.8 37 F – 40.6±10.1y BMI: 25.3±3.6kg/m ² 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/m ² NPS of last week: 2.3±1.0 9 F – 26.0±2.6y BMI: 22.0±2.1kg/m ² 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/m ² 9 F – 23.6±2.5y BMI: 21.1±2.1kg/m ² 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/m ² ODI: 22±3% LBP duration: not reported	12 M – 25.2±1.1y BMI: 21.8±0.8kg/m ²	- 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±0.09cm ² to 7.16±0.10cm ² ; p<0.025), decrease from standing to 25° stooping (in control group at L side: 7.16±0.10cm ² to 5.51±0.13cm ² ; p<0.025), no difference between 25° and 45° stooping (in control group at L side: 5.51±0.13cm ² to 5.71±0.36cm ² ; 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±0.07cm ² to 6.58±0.20cm ² vs. 5.51±0.13cm ² to 7.16±0.10cm ² and R side: 4.81±0.13cm ² to 6.61±0.21cm ² vs. 5.55±0.13cm ² to 7.06±0.08cm ² ; p<0.001) - larger fat area in all positions in CLBP vs. control group (L side: 0.90±0.09cm ² to 1.08±0.23cm ² vs. 0.56±0.10cm ² to 0.71±0.10cm ² and R side: 0.88±0.13cm ² to 1.13±0.23cm ² vs. 0.60±0.09cm ² to 0.73±0.11cm ² ; 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±1.02cm ² vs. 5.39±1.02cm ² ; r=0.90 and R side: 5.48±1.22cm ² vs. 5.44±1.22cm ² ; 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 <i>17 M</i> <i>11 F</i> intervention group: 32.2±6.4y BMI: 22.4±0.8kg/m ² control group: 31.9±2.9y BMI: 24.1±2.4kg/m ²	- 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/m ² 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/m ²	- 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/m ² ; in F: 21.4±2.7kg/m ²	- 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±0.63cm ² , L3: 3.18±0.92cm ² , 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±1.32cm ² , L5: 7.14±0.66cm ² , S1: 6.50±0.81cm ² ; 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±1.13cm ² vs. 2.01±1.37cm ² , L3: 3.85±1.36cm ² vs. 3.02±1.40cm ² , L4: 4.79±1.70cm ² vs. 3.80±1.74cm ² ; p=0.001), not significant at L5 (p=0.22) - no association between sex and asymmetry (p>0.1) <i>In control group:</i> - increase in CSA to caudal levels	- smaller CSA in CLBP vs. control group at L4 (4.07±1.88cm ² vs. 5.42±1.88cm ² ; p=0.001) and L5 (3.78±1.73cm ² vs. 6.48±1.72cm ² ; 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±2.1cm ² vs. affected side: 7.61±1.96cm ²	NA
Ikezoe et al. ⁵¹ (2012)		74 healthy - 33 young F – 20.0±0.8y BMI: 22.1±2.3kg/m ² - 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/m ² 13 dependent: 87.8±6.3y BMI: 16.6±2.1kg/m ²				- 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	<i>In control group:</i> - 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±1.94cm ² vs. 7.44±1.17cm ² ; p=0.032) - L4 R side: larger CSA in standing vs. prone (9.19±1.76cm ² vs. 7.68±1.29cm ² ; p=0.019), standing vs. 25° stooping (9.19±1.76cm ² vs. 7.84±1.66cm ² ; p=0.043) and standing vs. 45° stooping (9.19±1.76cm ² vs. 7.11±1.45cm ² ; p=0.001) (not significant at L5) <i>In CLBP group:</i> - 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±1.17cm ² vs. 7.20±0.94cm ² ; p=0.006) and 25° vs. 45° stooping (8.50±1.17cm ² vs. 7.28±1.17cm ² ; p=0.011)	- smaller CSA at L4 in standing in CLBP vs. control group (L side: 7.55±1.45cm ² vs. 8.92±1.94cm ² ; p=0.02 and R side: 8.10±0.97cm ² vs. 9.19±1.76cm ² ; 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/m ² 7 F - 25,1±3,6y BMI: 24.4±4.0kg/m ² 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/m ²	- prone - 5-10MHz linear probe	- CSA - S1 bilateral	side	- L side > R side (4.18±0.55cm ² vs. 4.11±0.57cm ² ; 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/m ² VAS: 1.6±2.0 LBP duration > 12 months competitive off-road cyclists	24 M – 27.8±5.3y BMI: 24.9±3.5kg/m ² competitive off-road cyclists	- prone/ on bike in 4 positions - 5MHz curved probe	- CSA at rest and contraction (CAL+ipsilateral leg lift) - L4 bilateral		NA	<i>CLBP vs. control group:</i> - smaller CSA at rest in prone at L side (5.67±0.52cm ² vs. 6.17±0.59cm ² ; p=0.014) - smaller CSA in contraction in prone at R side (6.47±0.94cm ² vs. 7.30±0.87cm ² ; p=0.01) - smaller CSA change during contraction in prone at R side (0.88±0.45cm ² vs. 1.28±0.41cm ² ; p=0.009) - smaller CSA in 4 positions on bike at L side (4.77±0.59cm ² to 4.84±0.54cm ² vs. 5.31±0.73cm ² to 5.51±0.76cm ² ; p<0.05) and R side (4.85±0.50cm ² to 4.91±0.55cm ² vs. 5.39±0.71cm ² to 5.58±0.71cm ² ; p<0.05)
Scott et al. ⁶⁵ (2015)	20 CLBP <i>14 M</i> <i>6 F</i> 31.9±7.2y BMI: 24.0±2.2kg/m ² VAS: 5.3±1.9	20 healthy <i>14 M</i> <i>6 F</i> 31.3±7.6y BMI: 22.3±3.0kg/m ²	- prone/ sitting - curvilinear 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)		<p>120 healthy</p> <p>52 M – 40.1±13.0y BMI: 25.8±3.2kg/m²</p> <p>68 F – 34.2±12.8y BMI: 23.0±3.1kg/m²</p>	<ul style="list-style-type: none"> - prone - 5MHz convex probe 	<ul style="list-style-type: none"> - CSA, AP and lateral dimensions - L4 + L5 bilateral 	<ul style="list-style-type: none"> - age - sex - antrop. factors - level - side 	<ul style="list-style-type: none"> - 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) <i>4M</i> <i>6F</i> 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 <i>6M</i> <i>4F</i> 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 <i>244M</i> – 21.8±3.9y BMI: 25.0±2.8kg/m ² <i>96F</i> – 22.3±5.0y BMI: 24.5±2.9kg/m ² 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 <i>8M</i> <i>9F</i> 41.9±13.7y H: 174.2±10.3cm W: 76.1±16.7kg VAS ≥ 3	17 healthy <i>8M</i> <i>9F</i> 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 0.15cm ² ; p<0.05) and L3 (difference of 0.9cm ² ; 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±1.2cm ² vs. 5.56±1.1cm ² ; F=29.1; p=0.001) - larger CSA in CLBP vs. control group at L2 (2.40±0.9cm ² vs. 1.94±0.9cm ² ; 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 0.17cm ²) 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/m ² 17F – 32.8±13.6y BMI: 23.9±4.3kg/m ²	- prone - 3.5-5MHz convex probe	- CSA - L5 bilateral	- sex - anthrop. factors - side	- larger CSA in M vs. F (7.58±1.51cm ² vs. 6.01±0.70cm ² ; 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±1.32cm ² vs. R side: 6.48±1.39cm ² ; 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/m ² 14F - 82±7y BMI: 22±4kg/m ²	- 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/m ² ODI: 32.8±20.1% VAS: 4.0±1.0	26 healthy – 32.4±7.2y 13M 13F BMI: 21.0±2.0kg/m ²	- 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±0.74cm ² vs. 4.36±0.58cm ² ; 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)

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

773

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

775

776 **Figure 1. PRISMA flow chart of study selection process.**

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

779 **Appendix 2 – List of abbreviations**

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

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