

# Shear wave elastography investigation of multifidus stiffness in individuals with low back pain

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DOI:

[10.1016/j.jelekin.2019.05.004](https://doi.org/10.1016/j.jelekin.2019.05.004)

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*Document Version*

Peer reviewed version

*Citation for published version (Harvard):*

Murillo, C, Falla, D, Rushton, A, Sanderson, A & Heneghan, NR 2019, 'Shear wave elastography investigation of multifidus stiffness in individuals with low back pain', *Journal of electromyography and kinesiology : official journal of the International Society of Electrophysiological Kinesiology*, vol. 47, pp. 19-24.  
<https://doi.org/10.1016/j.jelekin.2019.05.004>

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Checked for eligibility: 29/05/2019

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**SHEAR WAVE ELASTOGRAPHY INVESTIGATION OF MULTIFIDUS STIFFNESS  
IN INDIVIDUALS WITH LOW BACK PAIN**

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This study was approved by the University of Birmingham ethics committee and the  
procedures were conducted in agreement with the Declaration of Helsinki (ERN\_17-  
0782).

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**Key words:** Low back pain; muscular stiffness, lumbar multifidus; shear wave  
elastography

## 30 **Abstract**

31 The purpose of this study was to investigate differences in passive muscular  
32 stiffness between the superficial multifidus (SM) and deep multifidus (DM), and to  
33 compare their passive and active stiffness in individuals with low back pain (LBP)  
34 and asymptomatic individuals. Fifteen LBP individuals and 15 asymptomatic  
35 individuals were recruited. Passive stiffness of the SM and DM was measured  
36 bilaterally using shear wave elastography (SWE) with participants lying prone. Active  
37 stiffness was measured for the SM during trunk extension, and the contraction ratio  
38 was calculated. DM displayed higher passive muscular stiffness than SM in both the  
39 asymptomatic and LBP groups ( $14.41 \pm 2.62$  and  $15.40 \pm 2.77$  kPa respectively;  
40  $p < 0.001$ ). Individuals with LBP exhibited higher passive muscular stiffness of SM  
41 (LBP:  $10.15 \pm 4.21$ , asymptomatic:  $6.84 \pm 1.69$  kPa;  $p < 0.005$ ) and a lower contraction  
42 ratio (LBP:  $1.54 \pm 0.47$ , asymptomatic:  $2.65 \pm 1.36$  kPa;  $p < 0.003$ ) compared to the  
43 asymptomatic group. The findings support a differentiation in passive muscular  
44 stiffness between SM and DM and provide evidence for an alteration in muscular  
45 stiffness at rest in individuals with LBP. The lower increase of muscular stiffness with  
46 contraction observed for those with LBP may reflect a deficit in activation of the  
47 multifidus.

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## 53 **Introduction**

54           Research in the field of electromyography (EMG) has supported differences in  
55 function between the superficial (SM) and deep fibers of the multifidus (DM) and in  
56 addition, impaired function of this muscle in people with low back pain (LBP)  
57 [MacDonald et al., 2006]. EMG research has supported first, differences in function  
58 between the superficial (SM) and deep fibers of the multifidus (DM) and second,  
59 impaired function of this muscle in people with LBP [Danneels et al., 2002; Moseley  
60 et al., 2002; MacDonald et al., 2009]. It has been theorized that both, the differences  
61 in function between multifidus fibers and the functional impairment observed in  
62 people with LBP, may be related to the muscle structure, but research in this vein is  
63 inconclusive [Porterfield and DeRosa, 1998; Cagnie et al., 2015]. However,  
64 investigating the mechanical properties of muscle, such as muscular stiffness, may  
65 offer a better understanding of variation within the multifidus fibers and the  
66 relationship between muscle structure and normal/altered function [Brandenburg et  
67 al., 2014; Roberts, 2016].

68           Shear wave elastography (SWE) provides a non-invasive quantitative  
69 measure of muscular stiffness (measured in shear elastic modulus) at rest (passive)  
70 and during a contraction (active), which has shown to be positively related to the  
71 level of muscular activity and muscle force [Nordez and Hug, 2010; Brandenburg et  
72 al., 2014; Yoshitake et al., 2014; Ateş et al., 2015]. SWE has previously been used  
73 to investigate the stiffness of the lumbar multifidus of asymptomatic individuals at  
74 rest and during contraction with good to excellent reliability (intra class correlation  
75 coefficients (ICC) values of between 0.77 to 0.94) [Moreau et al., 2016; Creze et al.,  
76 2017; Koppenhaver et al., 2018]. However, no study has investigated whether or not  
77 differences in muscular stiffness exist between the SM and DM. Furthermore, only

78 two studies have investigated passive muscular stiffness of multifidus in people with  
79 LBP, but the results are conflicting [Chan et al., 2012; Masaki et al., 2017].

80

81 In this study, we investigate (1) whether differences in muscular stiffness at  
82 rest exist between the SM and DM in asymptomatic and LBP individuals and (2) if  
83 differences in muscular stiffness at rest and with contraction exist in individuals with  
84 LBP compared to asymptomatic individuals. This study stands to provide novel  
85 insights into the normal mechanical properties of the multifidus muscle and how this  
86 is modified in individuals with LBP.

87 **Methods**

88 **Participants**

89           Fifteen individuals with LBP and 15 asymptomatic were recruited from staff  
90 and student communities at the University of Birmingham. All participants were  
91 eligible for this study if they were aged between 20-55 years, with 55 chosen as the  
92 maximum age to reduce the effect of age-related adipose infiltration within the  
93 muscle [Marcus et al., 2010]. The LBP group included participants who had reported  
94 continuous LBP for more than 3 months or non-continuous pain for greater than 6  
95 months with pain on at least half of the days [Krismer and Van Tulder, 2007]. The  
96 asymptomatic group included participants without history of LBP. Exclusion criteria  
97 for both groups included neurological or respiratory disorders, pregnancy or previous  
98 spinal surgery. Individuals with LBP must not have been receiving treatment from a  
99 health care professional at the time of recruitment. Additional exclusion criteria for  
100 the LBP group included no known underlying pathology such as spinal stenosis,  
101 vertebral fracture, disc herniation, radicular low back pain with neurological deficit  
102 suggesting nerve root compression and/or ankylosing spondylitis [Krismer and Van  
103 Tulder, 2007]. Ethical approval was granted by the University of Birmingham ethics  
104 committee (ERN\_17-0782) and the procedures were conducted in agreement with  
105 the Declaration of Helsinki. Informed written consent was obtained from all  
106 participants.

107

108 **Questionnaires**

109           Participants with LBP completed the Numerical Rating Scale (NRS) to assess  
110 their pain intensity on the day of the measurement session and were also asked to  
111 rate their usual level of pain during the previous week. Additionally, the Oswestry

112 Disability Index (ODI) and Tampa Scale for Kinesiophobia (TSK) were used to  
113 assess perceived disability and fear-avoidance behavior respectively [Vlaeyen et al.,  
114 1995; Fairbank and Pynsent, 2000].

115

## 116 **Procedure**

117 Stiffness of the SM and DM was measured bilaterally using an ultrasound  
118 imaging device with SWE (LOGIQ S8 GE Healthcare, Chicago USA) and a 9-linear  
119 array probe. All measurements were performed by the same experienced examiner  
120 trained in SWE measures. Participants were positioned in prone with a rolled towel  
121 placed under their abdomen to minimize the lumbar lordosis [Stokes et al., 2007].  
122 The ultrasound probe was placed 2cm lateral to the level of the third lumbar spinous  
123 process (L3), which corresponds with the space between transverse process of L3  
124 and L4; confirmed by the ultrasound image. The probe was placed on the skin with  
125 minimal pressure across all participants [Cortez et al., 2016]. As muscle tissue is  
126 anisotropic, the ultrasound B-mode was used to identify the parallel orientation to the  
127 muscle fibers of SM; so the probe was positioned rotated towards the midline  
128 approximately 10° and also tilted approximately 10° from the sagittal plane [Cortez et  
129 al., 2016]. Once the orientation of the muscle fibers was identified, the outline of the  
130 probe was marked on the participant's skin to ensure consistency in placement  
131 across measures. For the DM, it was not possible to identify the orientation of the  
132 fibers. The multifidus muscle was divided in two equal region of interest (ROI), which  
133 were located under the thoracolumbar fascia (TLF) (without including it) for the SM,  
134 and just below this position and above the articular processes of the vertebrae for  
135 the DM (figure 1). As the ROIs were defined to include the larger SM and DM area  
136 possible, these were different across participants.

137 To measure passive muscular stiffness of the SM and DM, participants  
138 remained five minutes lying down on the plinth before starting the acquisition to  
139 ensure that the muscle was at rest [Creze et al., 2017]. The probe was placed on the  
140 area marked previously and was kept motionless for five seconds to obtain a well-  
141 defined elastography frame [Koo et al., 2013]. Then, two acquisitions on each side  
142 allowed recording of nine continuous elastograms for SM and DM. Active muscular  
143 stiffness measures of the SM were acquired during an isometric trunk extension akin  
144 to Ito test [1996], (~15° of trunk extension). The examiner visually monitored that  
145 participants did not drop the trunk extension position during the performance of the  
146 task [Ito et al., 1996]. The SWE acquisition commenced when the participant  
147 reached a steady trunk extension position, and nine elastograms were acquired  
148 twice on each side with a 10-second rest between repetitions.

149

### 150 **Image processing**

151 After the SWE acquisition, an area was circled over the ROI for all saved  
152 elastograms. The few elastograms with artefacts caused by an attenuation effect  
153 were eliminated for the analysis to avoid under- or over-estimation of shear elastic  
154 values [MacDonald et al., 2016]. Shear elastic modulus ( $\mu$ ) within each ROI were  
155 automatically calculated by the SWE software following the formula  $\mu = \rho v^2$ , where  $\rho$   
156 is the density of the muscle tissue (assumed to be 1000 kg/m<sup>3</sup>) and  $v$  is the shear  
157 wave propagation velocity [Gennisson et al., 2013]. The mean of the two acquisitions  
158 was calculated to obtain representative values for each measure [Masaki et al.,  
159 2017]. To quantify the increase of shear elastic modulus with contraction, the  
160 contraction ratio [Botanlioglu et al., 2013] was calculated for the SM by dividing  
161 shear modulus at rest from the mean of shear modulus with contraction (absolute  
162 values).



163

## 164 **Statistical analysis**

165 Descriptive statistics were used to analyze demographic data with inferential  
166 analysis including parametric and non-parametric tests used to compare groups. The  
167 Shapiro-Wilk normality test did not reveal significant deviation from normality for the  
168 measures of passive muscular stiffness and contraction ratio and paired-samples t-  
169 tests revealed no differences between sides for all measures, so the mean of the  
170 right and the left side was calculated for further analysis.

171 A two-way repeated measures analysis of variance (ANOVA) (with group as  
172 the between-subject independent variable and muscle fibers as within-subject factor)  
173 was performed to investigate if differences in shear elastic modulus at rest (passive  
174 muscular stiffness) of the SM and DM existed within and between groups. Pairwise  
175 comparisons with Bonferroni adjustment were used to determine significant  
176 differences. Independent samples t-tests were performed to compare the contraction  
177 ratio of the SM between groups. The intra-rater reliability of the SWE acquisitions  
178 (mean of 9 elastograms, right side asymptomatic group) was examined using two-  
179 way mixed-effects model [ICC (3.1)].

180

## 181 **Results**

182

### 183 **Population Characteristics**

184 The characteristics of both groups are presented in Table 1. Both groups were  
185 comparable in age, gender, and BMI, with no significant differences seen between  
186 groups. The LBP group showed low disability and pain, with an average reported  
187 pain level at the time of data collection of  $2.27 \pm 1.62$  out of 10.

188

## 189 **Muscular Stiffness**

190        Figures 2 and 3 show representative elastograms to determine passive  
191 muscular stiffness of the SM and DM, and active muscular stiffness of the SM for an  
192 asymptomatic individual and an individual with LBP. There was a significant  
193 difference between the shear elastic modulus at rest of the SM and DM as  
194 determined by the repeated measures ANOVA with Greenhouse-Geisser correction  
195 ( $F(1,29) = 65.05, p < 0.001$ ). Post hoc comparisons revealed that shear elastic  
196 modulus at rest were higher in the DM than the SM in both groups ( $p < 0.001$ ) (Table  
197 2, Figure 4). Moreover, shear elastic modulus of the SM at rest were greater for the  
198 LBP group relative to the asymptomatic group ( $p = 0.005$ ). However, no significant  
199 differences in shear elastic modulus of the DM were found between groups  
200 ( $p = 0.181$ ). An independent samples t-test revealed a lower contraction ratio of the  
201 SM for the LBP group compared to the asymptomatic controls ( $1.54 \pm 0.47$  and  
202  $2.65 \pm 1.36, p < 0.003$ ) (Figure 5). The ICC values (95% confidence interval) were 0.92  
203 (0.79-0.97) and 0.90 (0.72-0.97) for shear elastic modulus at rest of the SM and DM  
204 respectively; and 0.81 (0.51-0.94) for shear elastic modulus of the SM with  
205 contraction.

206

## 207 **Discussion**

208

209        This is the first study to investigate whether differences in passive muscular  
210 stiffness exist between the DM and SM both in asymptomatic participants and in  
211 people with LBP. The findings illustrate a difference in muscular stiffness between  
212 the SM and DM, supporting the existence of differences between the deep and  
213 superficial fibers of the multifidus [MacDonald et al., 2009; Moseley et al., 2002]. In

214 addition, individuals with LBP exhibited increased muscular stiffness of the SM at  
215 rest, and a reduced ability to stiffen this muscle with isometric trunk extension  
216 compared to asymptomatic individuals.

217

### 218 **Passive muscular stiffness of SM and DM**

219 Shear elastic modulus values at rest differed between the fibers of the  
220 multifidus, with the DM displaying greater shear elastic modulus values. Previous  
221 studies have evaluated stiffness of the multifidus but without differentiation between  
222 the DM and the SM or they have only examined the SM [Chan et al., 2012; Moreau  
223 et al., 2016; Masaki et al., 2017]. In line with the current findings, higher shear elastic  
224 values at rest have been observed for the deep posterior cervical muscles relative to  
225 the superficial muscles using SWE [Dieterich et al., 2017].

226 In vitro animal studies have showed that type I fibers are stiffer than type II  
227 [Goubel and Marini, 1987; Petit et al., 1990]; and therefore, the current findings may  
228 reflect differences in fiber type distribution between SM and DM. Histological  
229 research is inconclusive due to sample bias; but functional MRI have revealed  
230 differences in the relaxation time between SM and DM, suggesting that the DM has a  
231 higher percentage of type I fibers compared to the SM [Dickx et al., 2010; Cagnie et  
232 al., 2015]. Type I fibers are more fatigue resistant than type I; and so, ideally suited  
233 to hold low load tonic activity contributing to the postural control [Porterfield and  
234 DeRosa, 1998]. Thus, together with previous research, the current findings lend  
235 support to the existence of a structural differences between the SM and DM; which  
236 may have a functional implication in which the DM may provide spinal support  
237 [MacDonald et al., 2006].

238

## 239 **Differences in multifidus stiffness in individuals with LBP**

240 Greater shear elastic modulus values of the SM at rest were found for the LBP  
241 group when compared to asymptomatic participants. Masaki et al [2017] previously  
242 reported significantly greater shear elastic modulus of multifidus at rest (measured at  
243 the level of L4) in individuals with LBP; however, Chan et al [2012] did not observe  
244 group differences even if multifidus was examined at the same spinal level. In both  
245 studies, the ROI covered both the SM and DM and therefore, any potential  
246 differences between groups for SM muscular stiffness may have been concealed by  
247 the DM values. Furthermore, Chan et al [2012] utilized strain elastography, which is  
248 more operator dependent, potentially influencing their results [Brandenburg et al.,  
249 2014].

250 The differences in shear elastic modulus between LBP and asymptomatic  
251 individuals may reflect differences in muscle composition since passive stiffness is  
252 not only attributed to the contractile tissue within the muscle [Gillies and Lieber,  
253 2011]. Interestingly, Brown et al [2011] induced lumbar disc degeneration in rabbits  
254 and found that, though the individual paravertebral muscle fibers became stiffer, the  
255 fiber bundles (composed of both muscle fibers and connective tissue) displayed a  
256 greater increase in stiffness. Thus, the increase of connective tissue due to a fibrotic  
257 proliferation may increase the shear elastic modulus values in LBP individuals  
258 [Brown et al., 2018], explaining the current findings and those reported by Masaki et  
259 al [2017].

260 By contrast, the opposite findings reported by Chan et al [2012] may be  
261 explained because of the higher adipose tissue infiltration found in their LBP group,  
262 which may have decreased the shear elastic modulus values and concealed the  
263 between group differences [Roskopf et al., 2015]. It has been found that the fat

264 infiltration within multifidus may be caused by aging rather than by presence of pain  
265 [Lee et al., 2017]. This may explain the higher adipose tissue infiltration reported by  
266 Chan et al [2012] in the LBP group, which was older than the control group. In the  
267 same manner, the current findings of higher muscular stiffness may be result of a  
268 low level of adipose tissue infiltration in our LBP group, which was relatively young.  
269 In addition, though all participants had LBP for longer than 6 months, nearly all of  
270 them had non-continuous LBP and, therefore, may also exhibit a low amount of  
271 adipose tissue infiltration [Goubert et al., 2017].

272

### 273 **Differences in Contraction Ratio**

274 The participants with LBP presented a significantly lower contraction ratio;  
275 reflective of a smaller increase of muscular stiffness with contraction. The contraction  
276 ratio has previously been used to compare the increase of muscular stiffness with  
277 contraction between different conditions (pain/no pain) or between different  
278 muscles/muscle layers [Botanlioglu et al., 2013; Dieterich et al., 2017]. As a  
279 normalized measurement for each participant, where muscular stiffness at rest  
280 differs between conditions, the contraction ratio allows for a more accurate  
281 estimation of differences in stiffness with contraction and force generation  
282 [Botanlioglu et al., 2013; Dieterich et al., 2017]. Similar to the current findings, lower  
283 normalized active muscular stiffness was found in the deeper posterior neck muscles  
284 during isometric neck extension in individuals with neck pain [Dieterich et al., 2018].

285 As previous research has shown a positive linear relationship between shear  
286 elastic modulus, contraction and the level of muscular activity and muscle force, the  
287 current results may be compared in some extent to findings from EMG studies that  
288 investigated the activation of the SM during isometric contractions [Nordez and Hug,

289 2010; Yoshitake et al., 2014; Ateş et al., 2015]. In agreement with the current  
290 findings, reduced activation of the multifidus has been observed during trunk  
291 extension in a prone position in individuals with acute and experimental LBP  
292 [Danneels et al., 2002; Dickx et al., 2008]. It is speculated that this deficit in  
293 contraction found in individuals with LBP (reflected by a lower increase of muscular  
294 stiffness), may be explained in part by the proliferation of collagen  
295 content/connective tissue hypothesized above based on the finding of higher  
296 muscular stiffness at rest. These changes within the muscle would result in a  
297 decrease in the amount of contractile tissue and subsequently reduced ability to  
298 perform an efficient contraction [Goubert et al., 2017].

299

### 300 **Methodological Considerations**

301 A limitation of SWE is the large inter-individual variability. Given that the SWE  
302 acquisitions were performed at a specific vertebral level and at a standardized  
303 distance from the spinous process, intra-muscular variations and regional differences  
304 likely explain a small extent of the variability with in the current data [Cortez et al.,  
305 2016; Stokes et al., 2007]. The higher variability in shear modulus of the SM at rest  
306 in the LBP group likely reflects the large variability of individual neuromuscular  
307 adaptations due to LBP and/or an increase of the amount of non-contractile tissue  
308 [Hodges et al., 2013; Brown et al., 2018]. Although elastograms with artefacts were  
309 removed from the analysis, the attenuation effect of the ultrasound push beam can  
310 be greater in the deep lumbar region due to the TLF, and might have generated  
311 artificial areas of very low/high stiffness, altering the muscular stiffness measurement  
312 and concealing the detection of significant differences between groups for the DM  
313 [MacDonald et al., 2016]. Also, the assessment of the muscular stiffness of the DM

314 with contraction was not included in the present study due to the poor-quality signal  
315 observed during the pilot sessions. Previous studies have reported poor quality  
316 signal during the evaluation of the deep abdominal muscles during contractions  
317 [MacDonald et al., 2016]. Also, as trunk position was controlled visually as Ito et al  
318 [1996] originally described, we cannot exclude small differences in trunk angle  
319 between groups, which could have affected measurements with contraction.  
320 Additionally, as LBP participants were not under treatment, the levels of pain and  
321 disability were fairly low; and so, different results may be obtained for individuals with  
322 more severe symptoms.

323

324 In conclusion, the present study provides new insights into the mechanical  
325 properties of the lumbar muscles. Specifically, the study demonstrates a difference in  
326 muscular stiffness between the DM and SM, with a greater shear elastic modulus  
327 values observed for the DM in both asymptomatic and LBP individuals. Greater  
328 shear elastic modulus values at rest of the SM was found in individuals with LBP.  
329 Finally, a deficit in the contraction of the SM during an isometric trunk extension task  
330 was observed for those with LBP, reflected by a lower increase of muscular stiffness  
331 with contraction.

332

333 **Financial Disclosure and Conflict of Interest:** This research did not receive any  
334 specific grant. The authors declare no conflict of interest.

335

336

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