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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

Abstract

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

Introduction

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

Shear wave elastography (SWE) provides a non-invasive quantitative measure of muscular stiffness (measured in shear elastic modulus) at rest (passive) and during a contraction (active), which has shown to be positively related to the level of muscular activity and muscle force [Nordez and Hug, 2010; Brandenburg et al., 2014; Yoshitake et al., 2014; Ateş et al., 2015]. SWE has previously been used to investigate the stiffness of the lumbar multifidus of asymptomatic individuals at rest and during contraction with good to excellent reliability (intra class correlation coefficients (ICC) values of between 0.77 to 0.94) [Moreau et al., 2016; Creze et al., 2017; Koppenhaver et al., 2018]. However, no study has investigated whether or not differences in muscular stiffness exist between the SM and DM. Furthermore, only two studies have investigated passive muscular stiffness of multifidus in people with LBP, but the results are conflicting [Chan et al., 2012; Masaki et al., 2017].

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

Methods

Participants

Fifteen individuals with LBP and 15 asymptomatic were recruited from staff and student communities at the University of Birmingham. All participants were eligible for this study if they were aged between 20-55 years, with 55 chosen as the maximum age to reduce the effect of age-related adipose infiltration within the muscle [Marcus et al., 2010]. The LBP group included participants who had reported continuous LBP for more than 3 months or non-continuous pain for greater than 6 months with pain on at least half of the days [Krismer and Van Tulder, 2007]. The asymptomatic group included participants without history of LBP. Exclusion criteria for both groups included neurological or respiratory disorders, pregnancy or previous spinal surgery. Individuals with LBP must not have been receiving treatment from a health care professional at the time of recruitment. Additional exclusion criteria for the LBP group included no known underlying pathology such as spinal stenosis, vertebral fracture, disc herniation, radicular low back pain with neurological deficit suggesting nerve root compression and/or ankylosing spondylitis [Krismer and Van Tulder, 2007]. Ethical approval was granted by the University of Birmingham ethics committee (ERN_17-0782) and the procedures were conducted in agreement with the Declaration of Helsinki. Informed written consent was obtained from all participants.

Questionnaires

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

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

Procedure

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

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

Image processing

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

Statistical analysis

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

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

Results

Population Characteristics

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

Muscular Stiffness

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

Discussion

This is the first study to investigate whether differences in passive muscular stiffness exist between the DM and SM both in asymptomatic participants and in people with LBP. The findings illustrate a difference in muscular stiffness between the SM and DM, supporting the existence of differences between the deep and superficial fibers of the multifidus [MacDonald et al., 2009; Moseley et al., 2002]. In addition, individuals with LBP exhibited increased muscular stiffness of the SM at rest, and a reduced ability to stiffen this muscle with isometric trunk extension compared to asymptomatic individuals.

Passive muscular stiffness of SM and DM

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

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

Differences in multifidus stiffness in individuals with LBP

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

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

By contrast, the opposite findings reported by Chan et al [2012] may be explained because of the higher adipose tissue infiltration found in their LBP group, which may have decreased the shear elastic modulus values and concealed the between group differences [Rosskopf et al., 2015]. It has been found that the fat infiltration within multifidus may be caused by aging rather than by presence of pain [Lee et al., 2017]. This may explain the higher adipose tissue infiltration reported by Chan et al [2012] in the LBP group, which was older than the control group. In the same manner, the current findings of higher muscular stiffness may be result of a low level of adipose tissue infiltration in our LBP group, which was relatively young. In addition, though all participants had LBP for longer than 6 months, nearly all of them had non-continuous LBP and, therefore, may also exhibit a low amount of adipose tissue infiltration [Goubert et al., 2017].

Differences in Contraction Ratio

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

As previous research has shown a positive linear relationship between shear elastic modulus, contraction and the level of muscular activity and muscle force, the current results may be compared in some extent to findings from EMG studies that investigated the activation of the SM during isometric contractions [Nordez and Hug, 2010; Yoshitake et al., 2014; Ateş et al., 2015]. In agreement with the current findings, reduced activation of the multifidus has been observed during trunk extension in a prone position in individuals with acute and experimental LBP [Danneels et al., 2002; Dickx et al., 2008]. It is speculated that this deficit in contraction found in individuals with LBP (reflected by a lower increase of muscular stiffness), may be explained in part by the proliferation of collagen content/connective tissue hypothesized above based on the finding of higher muscular stiffness at rest. These changes within the muscle would result in a decrease in the amount of contractile tissue and subsequently reduced ability to perform an efficient contraction [Goubert et al., 2017].

Methodological Considerations

A limitation of SWE is the large inter-individual variability. Given that the SWE acquisitions were performed at a specific vertebral level and at a standardized distance from the spinous process, intra-muscular variations and regional differences likely explain a small extent of the variability with in the current data [Cortez et al., 2016; Stokes et al., 2007]. The higher variability in shear modulus of the SM at rest in the LBP group likely reflects the large variability of individual neuromuscular adaptations due to LBP and/or an increase of the amount of non-contractile tissue [Hodges et al., 2013; Brown et al., 2018]. Although elastograms with artefacts were removed from the analysis, the attenuation effect of the ultrasound push beam can be greater in the deep lumbar region due to the TLF, and might have generated artificial areas of very low/high stiffness, altering the muscular stiffness measurement and concealing the detection of significant differences between groups for the DM [MacDonald et al., 2016]. Also, the assessment of the muscular stiffness of the DM with contraction was not included in the present study due to the poor-quality signal observed during the pilot sessions. Previous studies have reported poor quality signal during the evaluation of the deep abdominal muscles during contractions [MacDonald et al., 2016]. Also, as trunk position was controlled visually as Ito et al [1996] originally described, we cannot exclude small differences in trunk angle between groups, which could have affected measurements with contraction. Additionally, as LBP participants were not under treatment, the levels of pain and disability were fairly low; and so, different results may be obtained for individuals with more severe symptoms.

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

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