Technical and measurement report

Ultrasound transducer shape has no effect on measurements of lumbar multifidus muscle size

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ABSTRACT

Objective: Evidence is currently lacking for guidance on ultrasound transducer configuration (shape) when imaging muscle to measure its size. This study compared measurements made of lumbar multifidus on images obtained using curvilinear and linear transducers.

Method: Fifteen asymptomatic males (aged 21–32 years) had their right lumbar multifidus imaged at L3. Two transverse images were taken with two transducers (5 MHz curvilinear and 6 MHz linear), and linear and cross-sectional area (CSA) measurements were made off-line. Reliability of image interpretation was shown using intra-class correlation coefficients (0.78–0.99). Muscle measurements were compared between transducers using Bland and Altman plots and paired t-tests. Relationships between CSA and linear measurements were examined using Pearson’s Correlation Coefficients.

Results: There were no significant differences (p > 0.05) in the measurements of the two transducers. Thickness and CSA measurements had small differences between transducers, with mean differences of 0.01 cm (SDdiff = 0.21 cm) and 0.03 cm² (SDdiff = 0.58 cm²) respectively. Width measures had a mean difference of 0.14 cm, with the linear transducer giving larger measures. Significant correlations (p < 0.001) were found between all linear measures and CSA, with both transducers (r = 0.78–0.89).

Conclusion: Measurements of multifidus at L3 were not influenced by the configuration of transducers of similar frequency. For the purposes of image interpretation, the curvilinear transducer produced better definition of the lateral muscle border, suggesting it as the preferable transducer for imaging lumbar multifidus.

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1. Introduction

In recent years ultrasound technology has found widespread application, both in diagnostic use and rehabilitation (Whittaker et al., 2007). Rehabilitative ultrasound imaging (RUSI) can offer a safe, objective and relatively inexpensive means of evaluating muscle and related soft tissue morphology, and can provide visual feedback to aid interventions in research and clinical practice (Whittaker et al., 2007). The RUSI technique has undergone extensive reliability studies, showing high reliability for both taking and interpreting images (Kiesel et al., 2007; Wallwork et al., 2007; Koppenhaver et al., 2009). The validity of RUSI against the gold standard of magnetic resonance imaging (MRI) has also been established for several muscles (Hides et al., 1995, 1996; Lee et al., 2006; O’Sullivan et al., 2009). An area that has received relatively little attention is determining appropriate scanner specifications for imaging muscles and the present study addresses the topic of transducer shape (or configuration).

A curvilinear transducer with an approximate frequency of 5 MHz is commonly used to image lumbar multifidus (Hides et al., 1992; Stokes et al., 2005; Lee et al., 2006; Kiesel et al., 2007), with no justification of transducer choice given. Some guidance based on anecdotal evidence suggested that more sound waves would reach the lateral border of multifidus with a curvilinear transducer (Stokes et al., 2007). It is unknown, however, if the shape of the transducer affects measurements of muscle dimensions. In a recent study, phantom objects were imaged using both curvilinear and linear transducers (Warner et al., 2008). Small differences were found between the two transducer configurations when measuring simulated muscle cross-sectional dimensions using a semi-solid phantom, although these differences were not clinically significant (Warner et al., 2008).

The present study aimed to determine whether there was a difference between measurements made from images of lumbar multifidus muscle obtained using linear and curvilinear transducers. The null hypothesis was that there would be no difference between measurements from images using the two transducers.
2. Methods

2.1. Participants

Fifteen males (aged 21–32 years; mean height 180 cm, weight 81.7 kg and body mass index, BMI, 25.5) were recruited from staff and students at the University of Southampton. Exclusion criteria were: extended history of severe lower back pain, any wound or skin condition in the region to be scanned, any previous spinal or pelvic fractures that may interfere with positioning or any known spinal abnormality (such as scoliosis). Ethical approval for the project was obtained from the School of Health Professions & Rehabilitation Sciences Ethics Committee and all participants gave their written informed consent prior to participation.

2.2. Ultrasound imaging technique

Participants lay prone on a plinth, with a pillow under the pelvis to reduce the lumbar lordosis. The third lumbar spinal process (L3) was identified by palpating cranially from L5, using the posterior superior iliac crests as a reference point for L5. L3 was marked with a water-soluble chinograph pencil. Images were obtained using an Esaote ‘Aquila’ ultrasound scanner (ESAOTE S.p.A. Genova, Italy), with a 6 MHz linear transducer (60 mm footprint) and 5 MHz curvilinear transducer (80 mm footprint). Imaging procedure was undertaken by an experienced operator (MS), as described by Stokes et al. (2005), where the transducer was first placed longitudinally over the midline of the lumbar spine at the allocated landmark over L3 to aid orientation (Fig. 1A). The transducer was then rotated 90° to produce a transverse image of the bilateral multifidus muscles (Fig. 1B).

The transducer was then moved to the left of the spinous process over multifidus and perpendicular to the lamina, and then angled to find the sharpest image of the muscle’s borders (Fig. 2). Contraction of multifidus was induced by the participant lifting the ipsilateral leg to confirm identification of the muscle borders. When multifidus was at rest and clearly defined, an image was taken and stored on a memory card. Images were then taken with the second ultrasound transducer and the order of transducers was randomised between participants.

Measurements were made off-line, using Image J software on a computer screen (http://rsbweb.nih.gov/ij/). Multifidus thickness was defined as the maximal distance from the lamina to the superficial fascia of the muscle belly. Width was defined from the lateral edge of the spinous process to the inside of the lateral fascial border, with the measurement taken at the mid-point of the thickness measurement (half way up the muscle belly). CSA was measured by tracing the inside fascial and the outer line of the spinous process. Interpretation of images was made by the same investigator (PW) twice on two separate days for the same images to assess between day intra-rater reliability. The mean of the measures taken from the first session were used in the main analysis.

2.3. Reliability of image interpretation

Reliability of image interpretation between days for one rater (PW) was assessed using intra-class correlation coefficients ICC (3,1) (Shrout and Fleiss, 1979). Reliability of measurements repeated on two days on the same images were good to excellent, with ICC (3,1) ranging from 0.78 to 0.99 (Table 1).

Linear measurements were the most reliable for both transducers with ICC (3,1) of >0.93 and >0.88 for thickness and width respectively. Reliability of CSA was good for the curved transducer (ICC = 0.89) but poor for the linear transducer (ICC = 0.78).

2.4. Data analysis

Measurements using the two transducers were compared using Bland and Altman plots and paired t-tests. Pearson’s correlation coefficients were calculated to examine the relationship between the linear measurements and CSA for both transducers. The linear measurements were squared for this analysis to give them comparable dimensions to CSA.

3. Results

3.1. Comparison of measurements from the linear and curvilinear transducers

The t-test analysis showed no significant differences between transducers (Table 2).

The Bland and Altman plots (Fig. 3) showed minimal between-transducer differences. Confidence intervals for the mean difference (d) between transducers were close to zero (Table 2). For thickness (Fig. 3a), d of 0.01cm showed a clear similarity between transducers. The width measurement (Fig. 3b) showed the largest mean difference (0.14 ± 0.3 cm), indicating a bias towards a larger measurement with the linear transducer. This highlighted the potential for error between transducers but did not reach significance on paired t-tests (Table 2). CSA showed a small mean difference (0.03 cm²), but the standard deviation in difference was large (0.6 cm²) (Table 2).

The shape ratio of linear dimensions (thickness/width) were similar for both transducers; linear ratio of 1.03 (SD = 0.13), curvilinear ratio of 1.09 (SD = 0.11).

Fig. 1. Ultrasound images taken with a 6 MHz linear transducer. (A) Sagittal image along the midline of the spine showing L3/L4 spinous processes (SP). (B) Bilateral transverse image at L3 showing the multifidus muscle (M), SP and lamina (L).
3.2. Correlation between linear and cross-sectional area measurements

The correlation between the linear dimensions and CSA were statistically significant for each transducer ($p < 0.001$). The strength of the relationships ($r$) varied, with a similar order of strength for both transducers; thickness$^2$ being weakest, then width$^2$, and thickness$^2$/width strongest (Table 3). Correlation coefficients ($r$) were identical for the two transducers, except for thickness$^2$/width, which was marginally higher for the curvilinear ($r = 0.89$) than the linear ($r = 0.85$) transducer.

4. Discussion

The main finding indicates that measurements of all three dimensions of multifidus muscle size (thickness, width and CSA) at L3 were not influenced by whether a linear or curvilinear transducer was used, therefore confirming the null hypothesis that measurements would not differ. Intra-rater reliability of measurements on the same images on different days were good to excellent. Linear measures were highly correlated with CSA but thickness, which is most commonly used in the literature, had the lowest correlation.

Studies in the literature report multifidus thickness more commonly than width or CSA (Hides et al., 2008; Wallwork et al., 2009) and thickness is more rapid and easy to use in clinical practice. The mean differences in muscle thickness between the two transducers (0.01 cm) was well with reported values for minimally detectable change from between-day reliability studies, e.g. 0.07 cm (Wallwork et al., 2007). Previous studies also showed significant differences in multifidus depth in low back pain patients compared to healthy individuals (Hides et al., 2008; Wallwork et al., 2009). These differences are well outside the range of uncertainty found in the present study between transducers. Multifidus is commonly imaged in the parasagittal plane with the transducer in a longitudinal orientation (Kiesel et al., 2007). Although the present findings on transverse images were not confirmed for longitudinal images, it is unlikely that thickness measurements would differ.

The present findings are consistent with previous research conducted on a semi-solid phantom object containing wires at known distances apart. Warner et al. (2008) found mean differences between linear and curvilinear transducers of 0.02 cm (SD = 0.04 cm) for thickness and −0.09 to 0.1 cm (SD = 0.03 cm) for width. They also found larger differences in CSA estimation between the transducers (−0.33 to 0.24 cm$^2$). These errors were larger than those in the present study, although Warner et al. (2008) measured much larger objects (13–18.86 cm$^2$). Only one previous study compared linear and curvilinear ultrasound transducers on muscle thickness and found no significant difference for the transversus abdominis (TrA) muscle (McMeeken et al., 2004), a relatively thin muscle compared with multifidus.

The present findings support the physical principles behind the two transducers. On some images it was difficult to determine the borders for measuring CSA, particularly with the linear transducer. Previous studies also showed significant differences in multifidus depth in low back pain patients compared to healthy individuals (Hides et al., 2008; Wallwork et al., 2009). These differences are well outside the range of uncertainty found in the present study between transducers. Multifidus is commonly imaged in the parasagittal plane with the transducer in a longitudinal orientation (Kiesel et al., 2007). Although the present findings on transverse images were not confirmed for longitudinal images, it is unlikely that thickness measurements would differ.

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The present findings support the physical principles behind the two transducers. On some images it was difficult to determine the borders for measuring CSA, particularly with the linear transducer. The anterior (superficial) and posterior borders are well defined by the fascia and echogenic lamina respectively. Fig. 2 illustrates how difficult it can be to identify the lateral border, particularly with the linear transducer. Poor clarity of the borders could lead to misinterpretation of linear and CSA measures. The curvilinear transducer has the advantage of exposing the lateral border to more sound waves and thus better reflection, than the linear transducer. This fact was reflected in the stronger relationship between linear and CSA measurements with the curvilinear transducer and higher reliability of CSA interpretation. Another consideration in the relationship between muscle dimensions is the irregular shape of

![Fig. 2. Ultrasound scans at L3 taken with different transducers and showing the multifidus muscle, spinous process (SP), lamina (L). (Left) Linear array image (Right) Curvilinear array image.](image-url)

Table 1

Intra-class correlation coefficient (ICC) analysis of between day interpretation of the same images taken with curvilinear and linear transducers.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Transducer</th>
<th>ICC(3,1)</th>
<th>95% Confidence interval</th>
<th>Lower bound</th>
<th>Upper bound</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Curvilinear</td>
<td>0.93</td>
<td>0.80 to 0.98</td>
<td>0.80</td>
<td>0.98</td>
</tr>
<tr>
<td>Thickness</td>
<td>Linear</td>
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<td>0.64 to 0.96</td>
<td>0.64</td>
<td>0.96</td>
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<tr>
<td>Width</td>
<td>Curvilinear</td>
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<td>0.68 to 0.96</td>
<td>0.68</td>
<td>0.96</td>
</tr>
<tr>
<td>Thickness</td>
<td>Linear</td>
<td>0.99</td>
<td>0.98 to 0.99</td>
<td>0.98</td>
<td>0.99</td>
</tr>
<tr>
<td>Width</td>
<td>Curvilinear</td>
<td>0.92</td>
<td>0.75 to 0.97</td>
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<td>0.97</td>
</tr>
<tr>
<td>CSA</td>
<td>Linear</td>
<td>0.78</td>
<td>0.35 to 0.93</td>
<td>0.35</td>
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</table>

CSA, cross-sectional area.

<table>
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<tr>
<th>Measure</th>
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</tr>
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<tr>
<td>Thickness</td>
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<td>0.93</td>
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Mean ± 1 standard deviation.
the multifidus in the present group, possibly due to hypertrophy. The present group tended to have a trapezoid or almost triangular multifidus shape, which would give poorer correlation values between linear and CSA measures compared to regular ovoid shaped muscles (Stokes et al., 2005). In a review of posterior paraspinal ultrasound imaging, multifidus at L3 was 4.9 cm² (Hides et al., 1995; Stokes et al., 2007), which is much smaller than the average of 6.89 cm² in the present study. The habitual activity levels of the multifidus muscle. Such as MRI, but this has been established previously for multifidus (Hides et al., 1995). The study on a phantom, however, used wires at known distances (Warner et al., 2008) and similar bias towards more accurate measures with the curvilinear transducer were found. Reliability testing was restricted to image interpretation and did not include reliability of the technique itself (within or between days), since the person performing imaging was experienced. There would still be a degree of error involved in using the different transducers but the similarity of findings with those from the study of a phantom (Warner et al., 2008) suggests that the differences could, at least in part, be explained by the transducers. Another limitation was the time lapse from image collection to interpretation. Immediate measurements after these observations may help make measurements more accurate than later interpretation of a still image. As well as image interpretation, the imaging technique itself can introduce errors. It was reported that a 30° angle variance in the transducer head relative to the skin could result in an error of 15% in non-tapering muscle (Dupont et al., 2001). However, changes below 10° did not result in significant changes in muscle dimensions (Whittaker et al., 2009). Finally, with the small sample of sporting males of a similar body type, the present findings cannot be generalised to sedentary healthy subjects or patients with smaller muscles.

4.2. Recommendations

On the basis of the present study showing that the curvilinear transducer produced the clearest images of the lateral border and more repeatable measures of CSA, a curvilinear transducer is therefore recommended for imaging lumbar multifidus. Accurate muscle thickness measurements can also be made with a linear transducer but width and CSA may be less accurate and less reliable for monitoring changes in multifidus over time.

5. Conclusions

Measurements of multifidus width, thickness and CSA made from images using linear and curvilinear transducers were not significantly different. However, the curvilinear transducer gave better clarity of the lateral muscle border and is therefore recommended as the transducer of choice for ease of interpreting images of the lumbar multifidus. This study highlights the need for research to determine appropriate scanner specifications for RUSI in different muscles and study populations.

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References


