The relationship between EMG and change in thickness of transversus abdominis

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Abstract

Objective. To investigate the relationship between changes in thickness and EMG activity in the transversus abdominis muscle of healthy subjects and the reliability of ultrasound measurements using different modes and transducers.

Design. Convenience sampling.

Background. Chronic low back pain is associated with transversus abdominis dysfunction but EMG studies of this muscle are restricted to invasive techniques. Since the thickness of transversus abdominis changes with activity, such changes measured from ultrasound images might provide insight into this muscle’s function non-invasively. In addition, little is known about the comparability of ultrasound measurements from different modes and transducers, nor the reliability of transversus abdominis measurements.

Methods. In 9 healthy subjects (aged 29–52 years, four male) transversus abdominis was studied at rest and during activity (5–80% max) with simultaneous EMG and ultrasound (M mode, 5 MHz curvilinear transducer) measurements. Intra-rater reliability for thickness measurements was studied on 13 subjects using 7.5 MHz linear and 5 MHz curvilinear transducers in B and M modes.

Results. Muscle thickness changes correlated well with EMG activity (P < 0.001, R² = 0.87) and there were no significant differences between subjects (P > 0.05). Using 7.5 MHz head, the ICC for B mode was 0.989 and for M mode was 0.981 for between days reliability. The ICC for between transducer reliability was 0.817.

Conclusions. Changes in thickness of transversus abdominis can be used to indicate changes in the electrical activity in this muscle.

Relevance Ultrasound scanning can be used in the clinical setting to provide objective information about transversus abdominis function.

Keywords: Electromyography; Ultrasound; Transversus abdominis; Human muscle

1. Introduction

Chronic low back pain (CLBP) accounts for significant and increasing societal costs (Rosen, 1993a,b). Whilst the exact underlying mechanisms remain unclear, alteration in the function of the trunk muscles, particularly transversus abdominis, is now considered important (Hodges and Richardson, 1996, 1998). In asymptomatic individuals the deeper trunk muscles, including transversus abdominis, assist in stabilising the spine (Bergmark, 1989; Cholewicki et al., 1997; Hodges and Richardson, 1996; Panjabi, 1992) and changes in transversus abdominis activation patterns are associated with CLBP (Hodges and Richardson, 1996, 1998). The anatomical position of transversus abdominis means that studies of its function have usually employed invasive techniques involving fine wire or needle electrodes that are unsuited to a therapeutic setting. Valid, reliable and non-invasive tools for measuring transversus abdominis would be useful in CLBP research and clinical management (Cairns et al., 2000; Critchley, 2002; Critchley and Coutts, 2002).
‘Lower abdominal hollowing’ is produced by activation of transversus abdominis (Critchley and Coutts, 2002; Richardson et al., 1999) and this manoeuvre is now commonly used to assess and rehabilitate this muscle in patients with CLBP (Richardson et al., 1999; Richardson and Jull, 1995). During lower abdominal hollowing, transversus abdominis has been observed to increase in thickness and this thickness increase has been measured using real-time ultrasound scanning (Critchley, 2002; Critchley and Coutts, 2002). These authors proposed that this thickness increase is an indication of muscle activity, but further investigation is required to validate the relationship between thickness change and muscle activity.

Ultrasound transducers of higher frequencies produce images of greater clarity but less depth. As transversus abdominis is deeply situated, it is sometimes necessary to use a lower frequency transducer to image this muscle. However, differences, if any, between thickness measurements obtained with the commonly used 5 and 7.5 MHz transducers are unknown. B (brightness) mode and M (motion) mode ultrasound images can be used depending on whether a ‘snap shot’ or a moving image is required. However, any differences between measurements from images generated in these modes are also unknown. Similarly, the intra-rater reliability of thickness measurements of the transversus abdominis requires further investigation.

The aims of this study were therefore to: (1) investigate the relationship between electromyographic (EMG) activity and transversus abdominis thickness at rest and during various levels of maximum voluntary contraction (MVC) measured simultaneously by needle electrode and real time ultrasound and (2) determine the repeatability of intra-rater measurement of transversus abdominis thickness as measured by real time US in B (brightness) and M (motion) mode and by 7.5 MHz linear or 5 MHz curvilinear transducers.

2. Method

2.1. Subjects

Thirteen healthy subjects (six males) gave written, informed consent and participated in the study. Subjects with conditions which prevented them undertaking the test procedure such as low back pain preventing them from lying still, neurological or musculoskeletal conditions affecting the trunk, pregnancy or stress incontinence were excluded from the study. The study had the approval of the local Research Ethics Committee.

All subjects participated in the reliability studies and had a mean age of 39.7 (SEM 2.3) years, body height 1.72 (SEM 0.24) m, body mass 71.5 (SEM 3.5) kg, and body mass index (BMI) 23.9 (SEM 0.8) kg m\(^{-2}\). Three females had previously been pregnant and two subjects had previously experienced back pain, but were currently pain free.

Nine subjects (four male) aged 40.7 (SEM 2.7) years, height 1.73 (SEM 0.31) m, body mass 71.2 (SEM 15.2) kg, and BMI 23.6 (SEM 1.0 8) kg m\(^{-2}\) participated in the investigation of the relationship of transversus abdominis activity and thickness. They included those with previous back pain.

For all experiments, subjects were requested to void urine prior to participation in the study and then were positioned in relaxed supine lying on a plinth with a pillow under the head and the knees bent to approximately 20° over two pillows.

2.2. Ultrasound measurement

Ultrasound images of the antero-lateral abdominal wall were obtained using an Aloka SSD-900 (Aloka Co Ltd, Tokyo, Japan) with 7.5 MHz linear and 5 MHz curvilinear array transducers. Gel was interposed between the transducer and the skin and the transducer was positioned adjacent and perpendicular to the abdominal wall, 25 mm antero-medial to the midpoint between the ribs and ilium on the mid-axillary line and parallel to the muscle fibres of transversus abdominis (Critchley, 2002; Critchley and Coutts, 2002; Misuri et al., 1997). The image gain and contrast were adjusted to produce the best contrast between the tissues. In B mode a static cross-sectional image is seen from the entire length of the transducer. In M mode, data is collected from the midpoint of the transducer and presented as a continuous image of the preceding 5 s. The tram line effect created represents the connective tissue boundaries between muscles (Fig. 1).

![Fig. 1. Representative US image in B (left) and M mode (right) displayed in Scion image. EO = external oblique muscle, IO = external oblique muscle, TA = transversus abdominis muscle. The double headed arrows show the measuring sites for TA thickness within the connective tissue planes.](image-url)
US images were recorded on videotape (super HGVHS, Konica Corporation, Tokyo, Japan) for subsequent analysis. After analogue to digital conversion with a resolution of 1024 × 768 pixels (Wincast TV32 V 4.6, Hauppauge Computer Works Inc. Hauppauge, NY, USA) they were measured using Scion Image (Scion Corp. Frederick, MD, USA). All thickness measurements were of muscle only, that is, between muscle-fascia boundaries. Measurements were made in pixels and individually calibrated to the cm scale on each ultrasound image. Measurements were taken whilst the operator was blind to the level of EMG activity.

To determine reliability between days and between B and M mode, a single operator performed scans on two days, approximately one week apart. Images in B and M mode were displayed side by side. Measurements of B and M mode images were made at different times and the image not being measured was masked to avoid bias. Measurements were compared and their reliability assessed. Between transducer reliability was established by comparing M mode measures of the two transducers in a similar fashion. M mode images were used for the comparison with EMG activity as the fascial planes were more easily identifiable. The 3 MHz transducer was used as the curved head allowed imaging of the muscle at the needle EMG recording site. Measurements of US images were made whilst blind to EMG values.

2.3. EMG measurement

The EMG data were obtained using a bipolar needle electrode (50 mm length, 0.46 mm diameter) with a recording area of 0.07 mm² (Medelec, Oxford Instruments, Oxford, UK). After skin preparation with alcohol swabs the needle was inserted with ultrasound guidance (De Troyer et al., 1990). An oblique insertion was used so that the needle tip was in transversus abdominis approximately 25 mm antero-medial to the left mid-axillary line, midway between the ribs and iliac crest. This allowed the scanner to image the portion of muscle containing the needle tip. Further confirmation of correct needle position was provided as penetration of fascial layers was observed as an indentation in the fascia followed by sudden release and restoration of normal contiguity. In most situations this was associated with a distinct reduction in resistance. The correct position was confirmed by gently moving the needle so that the tip was identified on the ultrasound image. Once in situ, the needle was taped to the skin to maintain its position. Imaging at the end of each experiment confirmed the needle position.

The EMG signal was preamplified (NL824, Digitimer, Welwyn Garden City, UK), isolated and amplified (NL820) and filtered between 30 and 3000 Hz (NL125). The raw and root mean square integrated (RMS) signals (NL705), were converted from analogue to digital (Micro 1401, Cambridge Electronic Design, UK) then displayed and recorded (Signal v1.8, Cambridge Electronic Design, UK). All data were sampled at 500 Hz in 180 s sweeps and stored for subsequent analysis. Root mean square (RMS) amplitude was measured as the mean over a 0.5 s window at baseline and at the relevant %MVC.

2.4. Procedure

Subjects were taught the low abdominal hollowing manoeuvre (Richardson and Jull, 1995) and Valsalva manoeuvre by an experienced clinician. The EMG needle was then introduced and the ultrasound head positioned on the antero-lateral abdominal wall, as described above. EMG signal and M mode US images of muscle thickness were recorded simultaneously and were synchronised by tapping the abdomen as this left a visible record in both data sets.

Resting muscle thickness was measured at the end of quiet inspiration when there was no detectable EMG activity (Abe et al., 1996) whilst thickness measurement of contracted muscle were not referenced to any particular phase of respiration. Three Valsalva manoeuvres and three low abdominal hollowing maximum voluntary contractions (MVC) were performed for 2–3 s. The largest RMS EMG value obtained was used to set targets of 5%, 10%, 15%, 20%, 30%, 40%, 60% and 80% of MVC. Subjects then performed a series of 5 s low abdominal hollowing manoeuvres in random order attempting to match RMS EMG activity with each of these targets. Three minute rests were taken between manoeuvres to minimise fatigue. Single 2–3 s MVCs of Valsalva and low abdominal hollowing manoeuvres were performed at the end of the procedure to determine whether the protocol had any marked effect on muscle activity. The EMG needle electrode was then removed and MVCs were repeated with thickness measured to investigate the effect of the in situ needle on thickness change during muscle contraction.

2.5. Data analysis

All EMG data were normalised by expressing measures as a percentage of the largest EMG signal detected any time in the testing procedure. US thickness data were normalised by calculating increase in thickness from resting thickness and expressing this as a percentage of thickness increase at maximum EMG.

To investigate reliability, thickness measurements were analysed using Bland and Altman plots and confidence intervals (Bland and Altman, 1986; Brennan and Silman, 1992; Rankin and Stokes, 1998). Repeated measures ANOVA was performed to determine variability between trials. From the ANOVAs, intraclass correlations.
(ICC) (average measure) and 95% confidence intervals (CI) were calculated. To examine the relationship between EMG and thickness the Analysis of Covariance (ANCOVA) (General Linear Model Minitab) was employed. Two tailed paired t tests were used to compare the levels of EMG during maximal effort at the beginning and end of the experiment and the TA thickness immediately preceding and after needle removal. Unless stated otherwise data are presented as mean (SD). Statistical significance was set at the 5% probability level.

3. Results

3.1. Relationship between US and EMG

All subjects demonstrated a significant relationship between increases in transversus abdominis thickness and EMG activity ($P < 0.0005; R^2 = 0.87$, Fig. 2). There was no significant difference in the relationship between transversus abdominis thickness and EMG activity, between individual subjects ($P > 0.05$).

3.2. Effect of protocol on muscle activity and effect of in situ needle

There was no significant difference in EMG activity during MVCs at the beginning [0.217 (SD 0.096 mV)] and end [0.208 (SD 0.099 mV)] of the protocol ($P > 0.05$), suggesting the repeated muscle contractions demanded by the protocol did not greatly affect muscle performance. Similarly there was no significant difference in transversus abdominis thickness during an MVC with [7.2 (SD 0.2 mm)] and without [7.0 (SD 0.3 mm)] the needle in situ ($P > 0.05$).

3.3. Reliability of B and M mode and 5 and 7.5 MHz transducers

Intra-rater reliability for resting muscle thickness on two days was good for both B and M mode ultrasound. In B mode values of 3.0 (SD 0.5) mm and 3.0 (SD 0.5) mm were obtained. Values using M mode were 3.0 (SD 0.5) mm and 3.0 (SD 0.5) mm. Between days repeatability was high for both B and M mode scans performed with the 7.5 MHz linear transducer (ICCs = 0.989 for B and 0.981 for M mode, Table 1). Bland and Altman plots of the mean difference between measures on day one and two against the mean of days one and two indicated a maximum difference between measures of 0.2 mm for both modes. In both cases the differences were distributed around zero and there was no systematic bias (Fig. 3). A two tailed paired t test showed no significant difference between days for B or M mode. There were no significant differences between the measurements made with the two transducers (Table 1).

4. Discussion

These results indicate a linear relationship between electrical activity and thickness increase in transversus abdominis during low abdominal hollowing at all levels of contraction. This relationship between thickness increase and EMG activity showed no significant individual variation. In addition we have demonstrated that transversus abdominis thickness at rest can be measured reliably using real time ultrasound at two different scanning frequencies, in both M and B modes and that results from different modes and different scanning frequencies are comparable.

Fig. 2. Relationship of EMG activity and thickness change. Both values normalised as the percentage of value at maximum EMG activity.
These results are similar to those of Hodges et al. (2003) at lower levels of effort but contrast with the non-linear relationship they reported at higher levels of MVC. One possible explanation for these divergent results is that the tasks employed in the two studies may differ. The abdominal hollowing action utilised in the present study could result in greater muscle shortening and increase in thickness at higher levels of MVC than the isometric contraction employed by Hodges et al. (2003). Alternatively, the greater numbers in the present study may be a better representation of the relationship between electrical activity and change in muscle thickness.

The validity of using US measurements of transversus abdominis thickness as an indication of muscle activity warrants further consideration. As a single muscle fibre contracts it increases in cross-sectional area, the change in cross-section is proportional to the change in length (Boyett et al., 1991) and the increase in cross-section is proportional to tension developed (Takemori, 1990). As a flat muscle with fibres oriented parallel to the direction of pull, contraction of transversus abdominis is likely to show a similar relationship between tension and cross-sectional change. As change in width is constrained by the ribs and iliac crest, increase in cross-section will largely be expressed as increase in thickness. In the similarly structured masseter muscle, change in thickness measured with ultrasound correlated with EMG activity (Bakke et al., 1992) supporting the use of thickness change as a measure of activity in this type of muscle. Overall the results of this study support the practice of using ultrasound both as a biofeedback device in the teaching of transversus abdominis exercises (Stokes et al., 1997) and as a research tool to study transversus abdominis activity in asymptomatic (Misuri et al., 1997; Bunce et al., 2002; Critchley, 2002) and symptomatic groups (Critchley and Coutts, 2002; Critchley and Hurley, 2003).

Our data support previous findings that transversus abdominis thickness can be imaged and reliably measured by one operator at this site (Bunce et al., 2002; Critchley and Coutts, 2002; Misuri et al., 1997). We observed minimal individual variation in thickness between trials in this region. Reliable measurements of transversus abdominis were made with both 7.5 MHz linear and 5 MHz curvilinear transducers and in B and M mode. There were no significant differences between measurements using the different transducers or modes.

### Table 1

Intra-rater reliability between US scanning modes (B and M), between days and between US transducers (M mode) showing good agreement in all cases

<table>
<thead>
<tr>
<th>Intra-class correlation coefficient (average measure)</th>
<th>Bland and Altman tests</th>
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<tr>
<td>ICC</td>
<td>95% CI</td>
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<tr>
<td>Between days linear transducer B mode</td>
<td>0.989</td>
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<tr>
<td>Between days linear transducer M mode</td>
<td>0.981</td>
</tr>
<tr>
<td>Between linear and curvilinear transducers M mode</td>
<td>0.817</td>
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$d$ = mean difference, SE of $d$ = standard error of the mean difference, $d \pm 2SD_{diff}$ = 95% limits of agreement.

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Fig. 3. Bland and Altman plots for between scans repeatability on two days for US B (left) and M mode (right). For both modes there was good agreement on both testing days.
thus results from different modes and transducers may be compared.

Previous studies have generally used on-line measurement which adds considerably to their duration. This also requires an arbitrary decision to be made about when to stop imaging and perform the measurement. Recording continuous data on video for subsequent analysis eliminates interruptions of the activity in question and also enables a more considered decision about which particular ‘snap shot’ to measure.

5. Conclusions

This study has demonstrated a good correlation between EMG activity and thickness change in transversus abdominis measured using ultrasound scanning. Measures of thickness change may therefore be used as biofeedback or as a tool to investigate the function of this muscle. These results also indicate that real time ultrasound can be used in either B or M mode and with either 5 or 7.5 MHz frequency transducers to reliably measure transversus abdominis thickness from recorded images.

References


