

Altered response of the anterolateral abdominal muscles to simulated weight-bearing in subjects with low back pain

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Abstract An important aspect of neuromuscular control at the lumbo-pelvic region is stabilization. Subjects with low back pain (LBP) have been shown to exhibit impairments in motor control of key muscles which contribute to stabilization of the lumbo-pelvic region. However, a test of automatic recruitment that relates to function has been lacking. A previous study used ultrasound imaging to show that healthy subjects automatically recruited the transversus abdominis (TrA) and internal oblique (IO) muscles in response to a simulated weight-bearing task. This task has not been investigated in subjects with LBP. The aim of this study was to compare the automatic recruitment of the abdominal muscles among subjects with and without LBP in response to the simulated weight-bearing task. Twenty subjects with and without LBP were tested. Real-time ultrasound imaging was used to assess changes in thickness of the TrA and internal oblique IO muscles as well as lateral movement (“slide”) of the anterior fascial insertion

of the TrA muscle. Results showed that subjects with LBP showed significantly less shortening of the TrA muscle ($P < 0.0001$) and greater increases in thickness of the IO muscle ($P = 0.002$) with the simulated weight-bearing task. There was no significant difference between groups for changes in TrA muscle thickness ($P = 0.055$). This study provides evidence of changes in motor control of the abdominal muscles in subjects with LBP. This test may provide a functionally relevant and non-invasive method to investigate the automatic recruitment of the abdominal muscles in people with and without LBP.

Keywords Low back pain · Ultrasound imaging · Motor control · Weight-bearing · Functional testing · Transversus abdominis muscle

Introduction

Motor control of the trunk muscles is an area that has been researched extensively. A number of changes in motor control of trunk muscles have been reported in subjects with low back pain (LBP). There is evidence of delayed activation [22, 24, 25] of the transversus abdominis (TrA) muscle in clinical and experimental LBP, alterations in recruitment of the multifidus muscles [21] and a number of studies have demonstrated increased activity of the superficial muscles of the lumbo-pelvic region [6, 8, 9, 22, 28, 32, 37, 43] in association with LBP. One explanation for the findings of overactivity is that the changes represent “splinting” of the lumbo-sacral spine by the central nervous system [21]. It has been proposed that the documented motor control changes, such as dysfunction of the TrA muscle [31], are associated with higher long-term incidence of LBP. Based on changes seen in subjects with

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LBP, rehabilitation programs have been developed to address the demonstrated impairments in motor control [12] and RCTs have shown these approaches to be effective [7, 33, 41].

Various methods of assessment have been employed to assess motor control of the abdominal muscles in the clinical situation. Most tests have been performed during the clinical muscle test for the TrA muscle, which consists of observation of the abdominal wall during a cognitive “drawing-in” of the abdominal wall [36]. During performance of the muscle test, clinicians have palpated the abdominal wall [14] and used a cuff placed under the abdomen (in a prone position) to assess the abdominal muscles [12]. More recently, real-time ultrasound imaging has been used to observe and measure the abdominal muscles at rest and on contraction [3, 10, 26, 29, 30, 40, 42]. Studies using ultrasound imaging have found that thickness of the TrA can be reliably measured [3, 30]. Furthermore, in initial validation studies, measures of TrA muscle contraction [29], IO muscle contraction, and length changes of the TrA muscle obtained using real-time ultrasound correlated with measures obtained by fine-wire electromyography (EMG) [23] and magnetic resonance imaging (MRI) [11].

While assessments of abdominal muscle function have traditionally focused on voluntary activation of the deep abdominal muscles, more recently investigators have attempted measurement of activity in automatic tasks. This approach is of potential value because voluntary activation is affected by factors such as motivation. Ferreira et al. [4] used both ultrasound imaging and fine-wire EMG to compare the recruitment of the abdominal muscles in response to an isometric low load task involving the lower limb in subjects with and without LBP. Results showed that subjects with LBP had significantly less increases in thickness (or less contraction) of the TrA muscle as seen on ultrasound imaging in response to the task, which was isometric flexion and extension of the knee. Recently, Hides et al. [16] used a different task, which involved simulated weight-bearing, in a study using ultrasound imaging conducted on healthy subjects. A weight-bearing task was selected as it was considered to represent a functional and relevant task, as in everyday life, the lumbopelvic region must manage axial gravitational loading [35]. Subjects were examined in supine lying, without the extraneous influence of postural control. Results showed increases in the thickness of TrA and the internal oblique (IO) muscles in response to simulated weight-bearing. Also, the anterior fascial insertion of the TrA muscle was observed to “slide” laterally, indicating concentric shortening of this transversely oriented muscle [11]. The response of subjects with LBP to the same simulated weight-bearing stimulus has not been studied.

The aim of the present study was to compare the recruitment of the abdominal muscles (measured as a change in thickness of the TrA and IO muscles, and shortening of the TrA muscle on ultrasound imaging) during a modified weight-bearing task in subjects with and without LBP.

Materials and methods

Participants

Twenty healthy volunteers (14 females, six males) and 20 volunteers (12 males and eight females) with a history of LBP were recruited into the study. Subjects were included in the LBP group if they reported a history of LBP (scoring three or greater on a Visual Analogue Scale), that occurred daily or was of at least 3 months duration and with or without referral into the lower limbs. Exclusion criteria for the healthy group included reported previous history of LBP, lumbar injury or surgery, a known history of inflammatory disease affecting the spine, obvious spinal abnormality, reported neuromuscular disease, pregnancy, involvement in competitive sports greater than three times a week, and involvement in specific training of the TrA muscles in the previous 3 months. One subject (female subject from the LBP group) could not be included in the final sample due to equipment failure at the time of testing. The final study sample therefore comprised a healthy group of 20 subjects and a LBP group of 19 subjects. This study was approved by the institutional ethics committee. Informed consent was obtained and the rights of human subjects were protected.

Apparatus and assessment task

The experimental task has been presented in detail elsewhere [16], but in brief, the subject was positioned in supine lying on a near-frictionless surface (a platform on wheels), with the heel of the test limb resting on a foot plate (Fig. 1). A brace, attached to the foot plate via a strain gauge (Amalgamated Instruments Bridge Amplifier Model AST-500 Australia with a Picolog ADC-16 DAQ converter) was placed over the participant’s shoulders to prevent cephalad sliding of the subject during the experimental task. The strain gauge measured the subject’s force output during the experimental task. A computer monitor was placed above the participant, directly in their line of sight for the purpose of feedback.

The testing position was standardised by aligning the ankle, knee and hip in the sagittal plane. A goniometer was used to ensure the participant’s knee was positioned at 60 ° of flexion. In addition, prior to the beginning of the task,

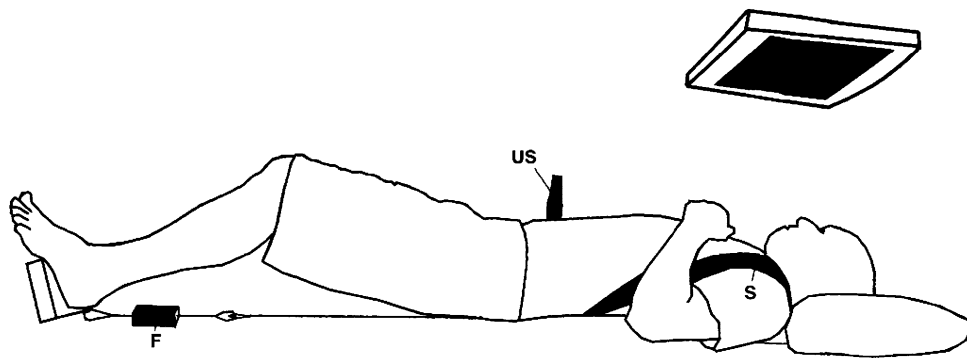


Fig. 1 Experimental setup: the subject was positioned in a supine position on a near-frictionless surface with the foot supported at the heel. A monitor (M) was placed in the subject's field of view to provide feedback on force output as the subject pressed through their heel. Shoulder straps, which restrained cephalad motion, connected to

the foot support via a strain gauge (S) which measured loading levels. Ultrasound imaging (US) was used to measure thickness of the transversus abdominis (TrA) and internal oblique (IO) muscles, and slide of the anterior abdominal fascia

the participant's pelvic position was standardised so that their anterior superior iliac spine (ASIS) and posterior superior iliac spine (PSIS) were aligned vertically. To aid isolation of weight-bearing during the unilateral task to the leg being tested, the contralateral leg was supported by pillows in a position similar range of hip and knee flexion.

The experimental task aimed to simulate axial gravitational loading through the spine, pelvis and lower limb being tested. Participants were required to perform a unilateral isometric contraction of the muscles of the lower limb, similar to a leg press activity. During this activity, the restraining brace acted to limit cephalad movement of the body, generating a longitudinal compressive force from the shoulders to the weight-bearing limb, thus creating axial loading through the spine (similar to gravitation).

Custom software (LabVIEW 7.1 environment, National Instruments, Texas) displayed feedback to the participant on their target and actual weight-bearing force output. The target was displayed to the subjects as a moving coloured line on the monitor. As the subject pressed through their heel on the footplate, a different coloured line representing their effort was also displayed on the monitor. The subject's aim was to match their line to the target line. Due to the close functional association between the TrA muscle and the diaphragm [19], the subject was required to pause breathing at the end of a normal respiratory cycle for the duration of the experimental task (approximately 10 s). Standardised instructions of "take a relaxed breath in and out, pause your breathing and wait for the line on the screen" were used. Once the display of force feedback was seen by the subject on the monitor above, the subject commenced the leg press activity by placing pressure through their heel. As prior work indicated only low force levels are necessary to elicit activation of the deep abdominal musculature [16] and differentiate between LBP and healthy subjects [4], the maximal force allowed was

50% of the subjects' body weight, which was reached over a continuous 10-s ramp period (unpublished data from our laboratory suggests that 50% of body weight corresponds to approximately 15% of maximal voluntary leg press force). During the continuous ramp manoeuvre the custom-written software produced audible "time stamps" at 25 and 45% of subject's body weight. These time stamps were produced to enable synchronisation of the ultrasound (video) and force (electrical signal) data. Prior work [16] showed that 25% of the subject's body weight is sufficient to elicit deep abdominal muscle activation.

The University of Queensland (Australia) holds a Provisional Patent on the measurement apparatus used in this investigation.

Assessment of the deep abdominal muscles using real-time ultrasound

A real-time ultrasound imaging apparatus (GE-Diasonics Synergy, Japan) equipped with a 5-MHz curvilinear transducer was used to obtain images of the anterolateral abdominal wall. A transverse image was obtained along a line midway between the inferior angle of the rib cage and the iliac crest for left and right sides [4, 16]. The ultrasound transducer was aligned perpendicular to the anterolateral abdominal muscles. In order to standardise the location of the ultrasound transducer for each participant, the anterior fascial insertion of the TrA muscle was positioned approximately 2 cm from the medial edge of the ultrasound image when the subject was relaxed [4, 16]. Ultrasound images of the anterolateral abdominal musculature were captured as a continuous video file with the audible time stamps outputted by the custom-written software (see above) at 25 and 45% of subject body weight. This assessment was performed on both sides of the abdominal wall (ipsilateral and contralateral to weight-bearing leg).

Testing protocol

Initially, participants completed a survey regarding demographic information and the Habitual Activity Questionnaire [1]. Subjects with LBP also completed the Roland Morris Disability Questionnaire. Anthropometric variables of height (cm), weight (kg) and body mass index (BMI) were recorded (Table 1). The participant's weight was entered into the custom-written computer software program (in the Labview 7.1 environment, National Instruments, Texas) to standardise lower limb force requirements during the simulated weight-bearing task.

Participants were positioned in the testing apparatus and instructed on its use. Participants were allowed three practice attempts at the simulated weight-bearing task in order to familiarise them with the procedure. Following this, they performed six weight-bearing trials on each leg. Each side of the abdomen was imaged three times per leg. The order of testing for weight-bearing leg side (right vs. left leg) and side of the abdomen measured by real-time ultrasound (ipsilateral versus contralateral) was randomised. A short break (30 s to 1 min) was allowed between each repetition. The ultrasound video files were stored for offline analysis.

Data processing and image analysis

Still ultrasound images were extracted offline, at rest, 25 and 45% of body weight force levels. ImageJ (version 1.36b, <http://rsb.info.nih.gov/ij/>) was used for image visualisation and measurement. Participant identifying information was removed from all ultrasound images and images from each trial were assigned a random number to ensure operator blinding. All measurements were recorded in millimetres. As changes in external oblique muscle thickness have been shown to be poorly correlated with electromyographic activity [23], only the IO and TrA muscles were assessed on the ultrasound image. The following measurements were undertaken:

- Thickness of IO and TrA muscles at 0% (rest), 25 and 45% of body weight force levels.
- Lateral movement (slide) of the anterior abdominal fascia at 25% (relative to position at rest) and 45%

(relative to position at 25%) of body weight force levels.

Linear measurements of muscle thickness for the TrA and IO muscles were measured as the distance between the superior and inferior hyperechoic muscle fascias, at approximately the middle of the image [16]. Thickness measurements were perpendicular to the direction of the muscle fibres. Measurements of slide of the anterior abdominal fascia (representing shortening of the TrA muscle on contraction) were conducted by locating the position of the fascial tip of the TrA muscle in the relaxed image and superimposing it on the contracted image, then measuring the distance to the fascial tip on the contracted image using a horizontal line. The intra-rater reliability of these measurements was high (three repeated measurements on 1 trial selected at random from ten subjects; intraclass correlation coefficient (ICC)_{1,3}; range 0.93–0.99). The inter-session reliability of the measures, in the weight-bearing task (ICC_{3,2}; separation of 3–7 days between two testing sessions in 20 subjects; three measurements per session) ranged from 0.81 to 0.94 for IO thickness, from 0.50 to 0.81 for TrA thickness and from 0.87 to 0.91 for TrA slide.

Further data processing and statistical analysis

Group differences (LBP or non-LBP) in baseline anthropometric variables were tested with independent sample *t* tests. Analysis of variance (ANOVA) evaluated the influence of subject-group and ultrasound-side on resting IO and TrA muscle thickness (0% of body weight force).

Data were further processed to evaluate the response to the weight-bearing stimulus: IO and TrA muscle thickness measures were converted to percentage change in thickness from 0 to 25 and 25 to 45% force output levels. Similarly, the lateral “slide” of the anterior fascial insertion of the TrA muscle between 0–25 and 25–45% of body weight force was evaluated during statistical analysis. Average values of the three trials [40] on each leg/ultrasound-side were taken. In the subsequent ANOVA, effects of ‘group’ (healthy and LBP), ‘force-level’ (0–25 and 25–45%), ‘ultrasound-side’ (ipsilateral and contralateral), ‘weight-bearing-leg’ (left and right) and up to a four-way interaction among these

Table 1 Subject anthropometric characteristics

Subject-group	Age (years)	Height (cm)	Weight (kg)	BMI (kg/m ²)
Healthy	24.4 (5.7)	170.3 (8.8)	66.3 (10.2)	22.8 (2.7)
Low back pain (LBP)	28.1 (10.3)	173.2 (9.2)	73.5 (16.2)	24.3 (4.0)

BMI body mass index

Values are mean (SD). No significant differences existed between groups (*P* all >0.1)

variables were evaluated. Anthropometric variables (age, height, weight, BMI) and gender were included as covariates. Where necessary, allowances were made for heterogeneity of variance due to force level, ultrasound-side and/or subject-group. Linear-mixed effects models [34] with the “nlme” package in the “R” statistical environment (version 2.0.1, <http://www.r-project.org>) were used to implement all analyses.

Results

Baseline characteristics

No significant differences in age, height, weight or BMI existed between subjects with and without LBP (P all >0.1 , Table 1). Subjects with LBP had a mean (SD) visual analogue scale score of 3.44(2.85)mm and a Roland Morris Disability questionnaire score of 8.22(1.69). Mean (SD) resting thickness of the TrA and IO muscles were 3.9(0.7) and 8.4(2.0) mm, respectively. No group or side of abdomen differences existed for thickness of the TrA and IO muscles at rest (F all <1.28 , P all >0.269). Table 2 gives the descriptive statistics for ultrasound measures of the anterolateral abdominal muscles during simulated weight-bearing.

Shortening of the transversus abdominis muscle (slide) in response to the weight-bearing task

The amount of lateral slide of the anterior fascial insertion of the TrA muscle varied between the two groups (group: $F = 10.78$, $P = 0.002$; force-level \times group: $F = 20.93$, $P < 0.0001$; Fig. 2). In healthy subjects, as force output

increased, significant lateral slide of the TrA muscle fascial insertion occurred at both the 25% force levels ($t = 7.72$, $P < 0.001$) with further slide from 25 to 45% of body weight force ($t = 14.84$, $p < 0.001$; Figure 2). In LBP subjects, significant slide of the TrA muscle occurred up to 25% of body weight force ($t = 3.97$, $P < 0.001$; Fig. 2), but this was less than in that healthy subjects ($t = -2.26$, $P = 0.025$). Between 25 and 45% of body weight force, no further slide of the TrA muscle occurred in the LBP subjects ($t = 1.65$, $P = 0.101$). The magnitude of slide from 25 to 45% of body weight force was also significantly less than that of healthy subjects ($t = -4.27$, $P < 0.001$). Ultrasound-side and weight-bearing-leg were non-significant (F all <2.08 , P all >0.151), indicating symmetrical slide of the TrA muscle in both groups and no influence of testing on the left or right leg.

Changes in thickness of the transversus abdominis muscle in response to the weight-bearing task

In the healthy subjects, significant increases in thickness of the TrA muscle occurred with force (0–25%: $t = 4.99$, $P < 0.001$; 25–45%: $t = 3.82$, $P = 0.001$; Fig. 3). Similarly, in the subjects with LBP, increases in the thickness of the TrA muscle occurred with force (0–25%: $t = 5.84$, $P < 0.001$; 25–45%: $t = 6.26$, $P < 0.001$). No strong effects for differences between LBP and healthy subjects existed (group: $F = 3.93$, $P = 0.055$; force-level \times group: $F = 2.49$, $P = 0.117$). Between 0 and 25% of body weight

Table 2 Descriptive statistics of ultrasound measures of the anterolateral abdominal muscles during simulated weight-bearing

Subject-group	Force-level		
	0%	25%	45%
TrA muscle slide			
Healthy	–	4.3(1.4)	6.7(1.9)
Low back pain	–	2.4(3.1)	3.6(3.6)
TrA muscle thickness			
Healthy	3.8(0.7)	4.2(0.8)	4.4(0.9)
Low back pain	4.0(0.8)	4.5(1.1)	4.9(1.3)
IO muscle thickness			
Healthy	8.3(1.9)	9.2(2.3)	9.5(2.6)
Low back pain	8.6(2.2)	9.5(2.9)	10.4(3.3)

TrA transversus abdominis, IO internal oblique

All values are mean (SD) in millimetres. Force-level represents percentage of subject’s body weight (0% = rest). For the significance of the differences between force-levels and groups, please see text and Fig. 2

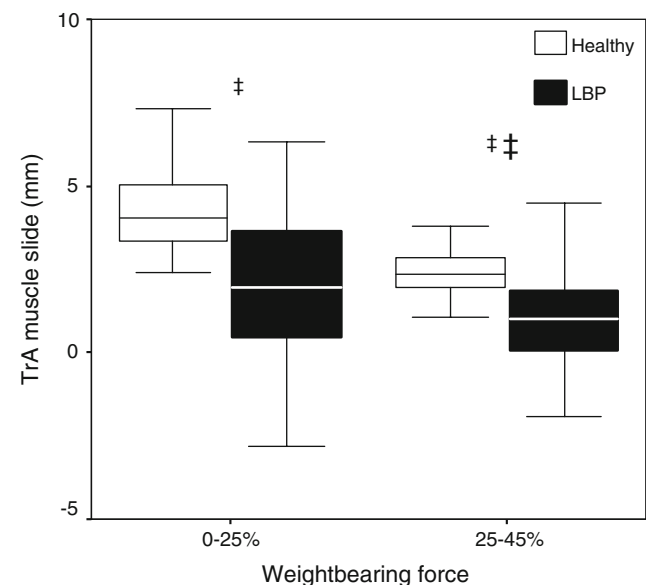


Fig. 2 Box plots of transversus abdominis muscle slide in each subject group. ‡ Indicates significant ($P < 0.001$) difference between groups. The median (central line), interquartile range (box) and extreme values excluding outliers (whiskers) are displayed. For significance of changes with weight-bearing force, see text

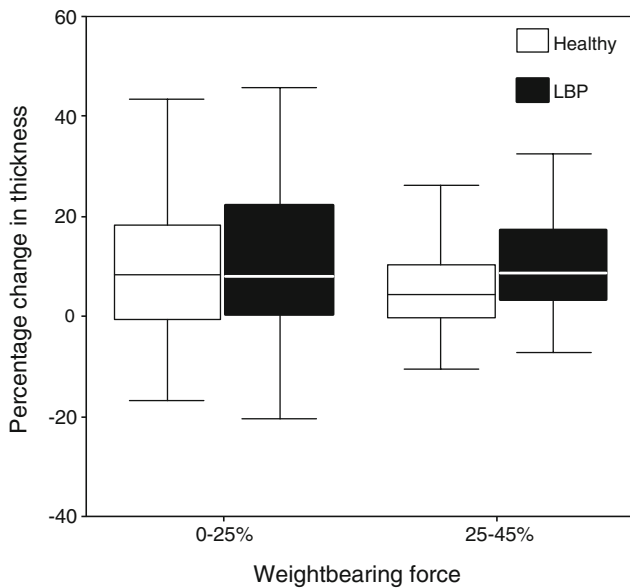


Fig. 3 Box plots of transversus abdominis muscle thickness change in each subject group. A trend ($P = 0.052$) existed for difference between groups at the 25–45% force-level. The median (central line), interquartile range (box) and extreme values excluding outliers (whiskers) are displayed. For significance of changes with weight-bearing force, see text

force, both subjects with and without LBP showed similar increases in the thickness of the TrA muscle ($t = 0.14$, $P = 0.885$; Fig. 3), though from 25 to 45% of body weight force the LBP subjects showed a marginally greater but non-significant increase in thickness ($t = 1.96$, $P = 0.052$; Fig. 3).

Ultrasound-side and weight-bearing-leg were non-significant (F all < 2.23 , P all > 0.139), indicating symmetrical changes in thickness of the TrA muscle in both groups and no influence of the leg tested (left vs. right).

Changes in thickness of the internal oblique muscle in response to the weight-bearing task

The amount of change in thickness of the IO muscle varied between the two groups (force-level \times group: $F = 9.84$, $P = 0.002$; Fig. 4). From 0 to 25% of body weight force, similar thickness increases occurred in both groups (healthy: $t = 7.23$, $P < 0.001$; LBP: $t = 7.03$, $P < 0.001$; LBP vs. healthy: $t = 0.45$, $P = 0.655$). With further increases in body weight force to 45%, significant increases in IO muscle thickness occurred in both groups (healthy $t = 3.98$, $P < 0.001$; LBP $t = 7.74$, $P < 0.001$), but the LBP subjects showed significantly greater IO muscle thickness increase (LBP vs. healthy: $t = 4.20$, $P < 0.001$). The changes in thickness of the IO muscle were, however, asymmetrical, with greater increases measured on the contralateral (non-weight-bearing) side (ultrasound-side \times force-level: $F = 7.01$, $P = 0.009$;

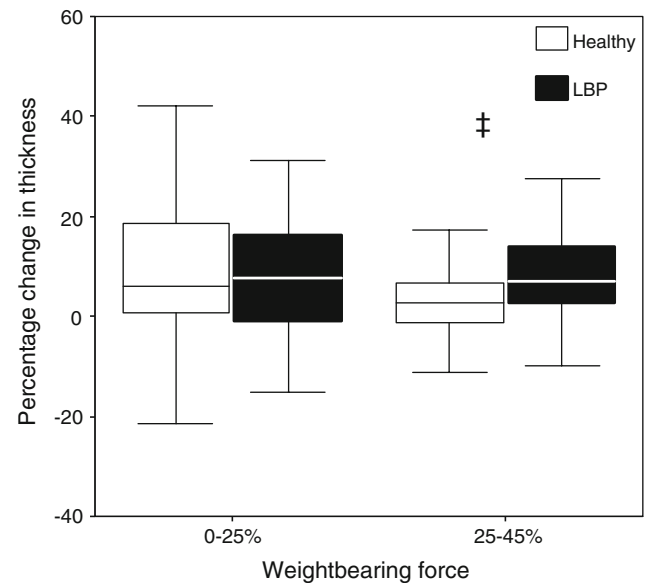


Fig. 4 Box plots of internal oblique thickness change in each subject group. ‡ Indicates significant ($P < 0.001$) difference between groups. The median (central line), interquartile range (box) and extreme values excluding outliers (whiskers) are displayed. For significance of changes with weight-bearing force, see text

0–25%: $t = 3.78$, $P < 0.001$; 25–45%: $t = 2.11$, $P = 0.037$; Fig. 5). Although the LBP subjects showed more increases in the thickness of the IO muscle overall, both groups showed a similar pattern of asymmetrical changes in thickness of the IO muscle (ultrasound-side \times force-level \times group: $F = 0.03$, $P = 0.861$). The weight-bearing-leg (left vs. right) was not significant in all comparisons (F all < 1.52 , P all > 0.225).

Discussion

The results of the present study support the findings of previous studies which have indicated that the automatic recruitment of the abdominal muscles is modified in subjects with LBP [4, 24, 25]. Furthermore, the study showed that abdominal muscle recruitment can be measured using ultrasound imaging during an isometric simulated weight-bearing leg task which was performed at low effort. This test may provide a functionally relevant and non-invasive method to investigate the automatic recruitment of the abdominal muscles in people with and without LBP.

Trunk muscle recruitment with isometric leg simulated weight-bearing tasks

Automatic recruitment of the TrA muscle during a standardised limb load has been used previously to assess the

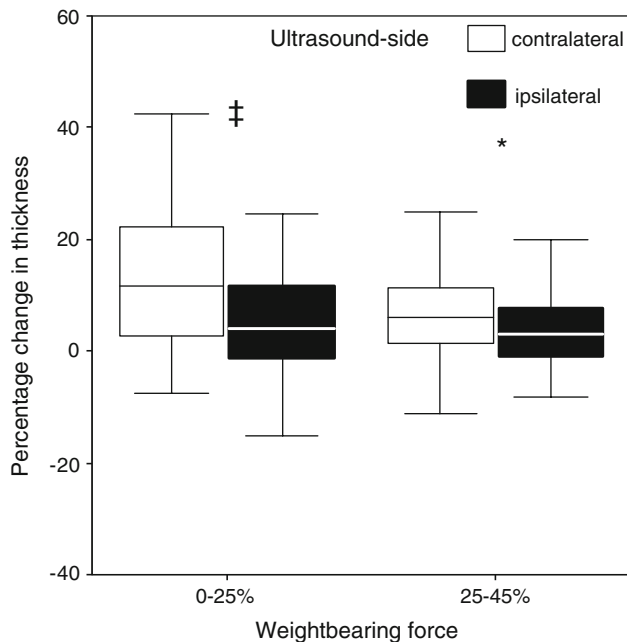


Fig. 5 Box plots of asymmetrical thickness increase of the internal oblique muscle on the contra- and ipsilateral (to weight-bearing) sides of abdomen. Contralateral = side of abdomen contralateral to weight-bearing leg * $P < 0.05$; ‡ $P < 0.001$. The median (*central line*), interquartile range (*box*) and extreme values excluding outliers (*whiskers*) are displayed

motor control characteristics and function of the TrA muscle [4, 13]. The study of Ferreira et al. [4] used a non weight-bearing task, whereas the present study and a previous study [16] used a weight-bearing task with the load passing axially through the trunk and lower limb to the heel. Results of the current study showed that not only did the TrA muscle respond to simulated gravitational loading as predicted [38, 39], but in healthy subjects without LBP it continued to respond at higher levels of loading. In healthy subjects the contraction of TrA muscle was symmetrical. This is in line with an animal study, which showed that TrA muscle is only effective in its stabilising role in when it contracted symmetrically on both sides of the trunk [17]. In contrast, the contraction of the IO muscle was asymmetrical in healthy subjects. A possible explanation is that the IO muscle was activated asymmetrically to control the position of the pelvis during the unilateral task [16].

Discrimination between subjects with and without LBP

The main finding of this study was that subjects with LBP used a different strategy of trunk muscle recruitment during a simulated weight-bearing lower limb task when compared with healthy subjects. Ferreira et al. [4] also found a difference between these groups, but they instead studied responses to isometric knee flexion and extension with the knee suspended in springs. Their results showed smaller

increases in the thickness of the TrA muscle in response to their chosen task, but there was no difference between groups for the IO muscle. The results of the current study showed less shortening of the TrA muscle in subjects with LBP for both levels of force measured, and subjects with LBP showed no further response between 25 and 45% of body weight force. These results are in line with those of Ferreira et al. [4]. Interestingly, inspection of the TrA slide data suggests that the subjects with LBP in the current study appeared to show much more variability. Further studies could investigate whether variability of motor control is greater in subjects with LBP. However, in contrast to the findings of Ferreira et al. [4], there were no significant differences between groups for changes in muscle thickness of the TrA muscle, with a trend towards more (rather than less) thickness change of the TrA muscle from 25 to 45% of the weight-bearing force in the subjects with LBP. While it is possible that the two tasks may recruit muscles differently, consideration of the results for the IO muscle in the two studies may offer a possible explanation for this finding.

The subjects with LBP in the current study showed greater increases in the thickness of the IO muscle than the healthy subjects at 25–45% of the weight-bearing force, whereas Ferreira et al. did not find a difference between groups. In subjects with LBP, overactivity of the superficial (global [2]) lumbo-pelvic muscles is commonly observed [6, 8, 9, 22, 28, 32, 37, 43]. This may represent an attempt by subjects to provide generalised stiffness [5] to the vertebral column or to increase intra-abdominal pressure, which can also provide generalised stiffening of the spine [17, 18]. If the subjects with LBP in this study used a more general strategy of “bracing” their abdominal muscles to increase intra-abdominal pressure, this may explain why the IO and TrA muscles increased in thickness (contracted against the resistance of the increased intra-abdominal pressure) in subjects with LBP, but the TrA muscle did not shorten to the same extent as seen in the subjects without LBP.

There are some limitations on the current study. Other abdominal muscles, such as the external oblique muscles and rectus abdominis, were not measured and may well also contribute to in the task. Also, the erector spinae muscle group was not assessed. The lumbar multifidus muscle is known to be an important contributor to lumbar intervertebral stiffness [27, 44] and known to also be affected in LBP [13, 15, 20]. Although assessment of the multifidus muscle in the current protocol may require implementation of more invasive techniques such as fine wire electromyography, assessment of the multifidus muscle and the erector spinae muscles during a simulated weight-bearing task may provide further insight into the changes in motor control evident in subjects with LBP. Another consideration is that while we have simulated

weight-bearing in a supine position (to focus solely on the effect of axial loading on the spine) it is unclear whether the muscle activation patterns would be exactly the same in the upright position.

Conclusion

In conclusion, in this study, subjects with and without LBP performed a unilateral simulated weight-bearing task while ultrasound imaging was used to monitor the TrA and IO muscles. Subjects with LBP showed significantly less shortening of the TrA muscle and greater increases in the thickness of the IO muscle during the simulated weight-bearing task, but there was no significant difference between groups for changes in TrA muscle thickness. The advantages of this test over voluntary tests of abdominal muscle activation are that it is unlikely to be affected by motivation and learning, and it provides a way to assess the automatic strategy used by the central nervous system to control the trunk muscles. An additional advantage is that the test is functional in nature and aims to simulate forces through the trunk that are experienced in everyday life. Further work will be required to establish the reliability, sensitivity and specificity of the test.

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