Assessment of Abdominal Muscle Function During a Simulated Unilateral Weight-Bearing Task Using Ultrasound Imaging

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s part of normal function, the lumbopelvic region of the human body must manage axial gravitational loading.\(^9\) This demands central nervous system coordination of muscle function for weight bearing, load transfer from the upper to lower body, movement, locomotion, breathing, and stabilization.\(^1,7,12,15,26\)

The lumbopelvic musculature, therefore, takes on multiple roles.\(^3\) With regard to stabilization of the lumbopelvic region, Snijders et al.\(^21\) proposed a biomechanical model that predicted the action of transversely oriented muscles, such as the transversus abdominis (TrA), internal oblique (IO), piriformis, and coccygeus, could stabilize or stiffen the sacroiliac joints and other joints of the pelvis for weight bearing. Evidence supporting this model was provided in an in vivo investigation where subjects voluntarily activated their TrA muscles through an abdominal drawing-in maneuver, resulting in increased stiffness of the sacroiliac joints.\(^21\) It has been proposed that the TrA muscle may contribute to stability of the lumbopelvic region via its effects on intra-abdominal pressure and by affecting fascial tension.\(^2,10,11\)

Based on its ability to provide visualization of the deep muscles of the anterolateral abdominal wall, real-time ultrasound imaging has been used to objectively measure abdominal muscle function. Researchers using ultrasound imaging (in both brightness mode or motion mode) have determined that thickness of the TrA can be reliably measured.\(^4,20,24,25\) Furthermore, a validation study comparing measures obtained by ultrasound imaging and fine-wire elec-

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1. Senior Lecturer, Division of Physiotherapy, School of Health and Rehabilitation Sciences, The University of Queensland, Brisbane, Australia; Clinical Director, UQ/Mater Back Stability Clinic, Mater Health Services, South Brisbane, Australia.
2. Physiotherapist and medical student, The University of Queensland, Brisbane, Australia.
3. Senior Lecturer, School of IT and Electrical Engineering, The University of Queensland, Brisbane, Queensland, Australia.
4. Study Coordinator, Second Berlin Bedrest Study, Berlin, Germany.
5. Reader, Division of Physiotherapy, School of Health and Rehabilitation Sciences, The University of Queensland, Brisbane, Australia. This study was approved by the Medical Research Ethics Committee at The University of Queensland, Australia. The University of Queensland (Australia) holds an Australian Provisional Patent entitled “Assessment of Weight-Bearing Status” that is related to the measurement apparatus used in this manuscript. Address correspondence to J.A. Hides, Division of Physiotherapy, School of Health and Rehabilitation Sciences, The University of Queensland, Brisbane Queensland 4072, Australia. E-mail: j.hides@shrs.uq.edu.au

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**STUDY DESIGN:** Cross-sectional study.

**OBJECTIVE:** To investigate the function of the transversus abdominis (TrA) and internal oblique (IO) muscles bilaterally during a simulated weight-bearing task using ultrasound imaging.

**BACKGROUND:** An important aspect of neuromuscular control at the lumbopelvic region is stabilization. Biomechanical models have predicted that activation of transversely oriented muscles, such as the TrA and IO muscles, can stiffen the sacroiliac joints and actively stabilize the pelvis for weight bearing.

**METHODS AND MEASURES:** Nineteen healthy subjects were positioned in supine lying with their right heel against a footplate linked to a force transducer. Each subject performed a static simulated weight-bearing task of the right lower extremity. Ultrasound imaging was used to assess resultant changes in thickness of the IO and TrA muscles, as well as the lateral slide of the anterior abdominal fascia on each side of the abdomen alternately. Muscle thickness and slide of the fascia were assessed at standardized force levels (0% and 25% of body weight).

**RESULTS:** Substantial increases \((P<.0001)\) in mean \((\pm \text{SD})\) thickness of the IO \((18.5\% \pm 9.7\%)\) and TrA \((24.7\% \pm 17.5\%)\) muscles during the weight-bearing task were measured. Lateral movement (slide) of the anterior abdominal fascia of the TrA muscle also occurred \((\text{mean} \pm \text{SD}, 1.3 \pm 2.0 \text{mm}; P = .014)\) with weight bearing. Changes in muscle thickness and amount of slide were similar for the left and right side of the abdomen \((P>.11)\).


**KEY WORDS:** Internal oblique muscle, lumbar stabilization, real-time ultrasound imaging, sonography, transversus abdominis muscle...
tromyography (EMG) showed consistent, clear changes in sonographic parameters with incremental muscle activation in effort levels of less than 20% of maximal voluntary contraction (MVC) for the TrA and IO muscle thickness and shortening of the TrA (as visualized by a “slide” of the anterior abdominal fascia). Another study also showed a strong association between measures obtained by ultrasound imaging and fine-wire EMG for the TrA muscle ($R^2 = 0.87$). Measurements obtained using ultrasound imaging during the drawing-in maneuver of the abdominal wall have also correlated well with measurements obtained using MRI (intraclass correlation coefficients [ICCs] ranging from 0.78 to 0.95). An advantage of using MRI (with a larger field of view) was that it allowed measurements of the whole cross-sectional area of the muscles of the trunk, or the “corset,” which is not possible with ultrasound imaging. The TrA muscles were seen to shorten bilaterally (represented by the amount of lateral slide of the anterior abdominal fascia) and the cross-sectional area of the whole trunk decreased. The amount of slide of the anterior abdominal fascia correlated well with the decrease in the cross-sectional area of the trunk ($r = 0.78$), suggesting that measurement of the slide of the anterior abdominal fascia measured on ultrasound may be useful as a reflection of the abdominal corset, despite the narrow field of view. Ultrasound imaging was deemed to be an appropriate modality to depict the action of the deep myofascial corset of muscles.

While the abdominal drawing-in maneuver has successfully been used to voluntarily activate the TrA muscle, another approach that has been used to examine the stabilizing role of the TrA and IO muscles is to study their automatic recruitment in response to a limb task. Ferreira et al. used both ultrasound imaging and fine-wire EMG to compare the recruitment of the abdominal muscles in response to a non-weight-bearing, isometric, knee flexion and extension task in subjects with and without low back pain (LBP). They reported that, compared to those without LBP, 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. These results were verified using fine-wire EMG, and the study presented a novel test of automatic recruitment of the abdominal muscles in response to a low-load task involving the lower limb.

The aim of this pilot study was to assess recruitment of the anterolateral abdominal muscles during a low-load simulated unilateral weight-bearing task involving the lower limb. Ultrasound imaging was used to assess changes in thickness of the TrA and IO muscles, and slide of the anterior abdominal fascia bilaterally.

**METHODS**

**Subjects**

**N**ineteen healthy subjects (11 female, 8 male) participated in the study. The mean ($\pm$SD) age, height, and body mass of the subjects was 20.3 $\pm$ 5.0 years, 172 $\pm$ 9.8 cm, and 64.5 $\pm$ 11.4 kg, respectively. Exclusion criteria included a history of LBP, previous lumbar surgery, known neuromuscular or joint disease, significant spinal abnormality (eg, scoliosis), participation in competitive sports more than 3 times a week, pregnancy, and familiarity with the testing procedure. This study was approved by the Medical Research Ethics Committee at The University of Queensland. Informed consent was obtained and the rights of human subjects were protected. The University of Queensland (Australia) holds a provisional patent on the measurement apparatus used in this investigation.

**Procedure**

Testing was conducted in a supine position to avoid the confounding variables of balance control, which would be present in the standing position. Subjects were positioned on a near-frictionless surface (a platform on wheels) with a restraining brace passing over their shoulders and connected to a strain gauge bridge amplifier model AST-500 (Amalgamated Instruments Co Pty Ltd, Hornsby, Australia), and with a Picolog ADC-16 analog-digital converter (Amalgamated Instruments Co Pty Ltd) attached to a footplate. The right foot was positioned on the footplate, with the knee in 60° of flexion and the ankle in a plantargrade position (90°). A video monitor was positioned in the subject’s field of view for feedback on force output (FIGURE 1).

Custom software in LabVIEW Version 7.1 (National Instruments Corporation, Austin, TX) was used to display current and target force output to the subject. The subject was required to in-

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**FIGURE 1.** Experimental setup: the subject was positioned in a supine position on a near-frictionless surface, with the foot supported at the heel (H). 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.

**FIGURE 2.** Sample display of target force ramp (thin line) and actual force ramp achieved (thicker line) as a subject increased force output by pressing through the heel to 50% of body weight over the 10-second ramp period. Note that it was difficult for subjects to maintain a steady force output at the beginning and end of the force ramping.
crease force output by pressing through the heel up to 50% of body weight over a 10-second ramp period. (A sample output is shown in Figure 2.) Subjects were required to go up to 50% of their body weight to allow accurate assessment at 25% of body weight, which was the target force level used in the study. It was necessary to exceed the target force level, as it was difficult for subjects to maintain a steady force output at the beginning and end of the force ramping (Figure 2). A target of 25% of body weight (low load) was selected, as ultrasound imaging can only reliably measure muscle activity at less than 30% of MVC. Subjects were required to cease respiration (at the end of expiration) for the duration of the 10-second ramp period. Instructions were to “take a relaxed breath in, breathe out, and pause your breathing. Wait for the line on the screen and then press through your heel to match the target line.” These instructions allowed establishment of a baseline for measures before the subjects pressed through their heels. Subjects were directed to focus their attention on maintaining their force output with the ramp target. To ensure assessment of automatic recruitment patterns, no instruction regarding abdominal muscle activation was given.

A Synergy ultrasound apparatus (GE Diasonics, San Jose, CA), equipped with a 5-MHz curvilinear transducer, was used to assess the muscles of both sides of the anterolateral abdominal wall during the unilateral task, which was performed only with the right lower extremity. A transverse image of the anterolateral abdominal wall was obtained along a line midway between the inferior angle of the rib cage and the iliac crest for left and right sides (as per Ferreira et al and Hides et al). The ultrasound transducer was aligned perpendicular to the anterolateral abdominal muscles. To standardize the position of the transducer, 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. Subjects performed 6 trials in total, with the right (ipsilateral) and left (contralateral) sides of the abdomen imaged 3 times each. Ultrasound images were recorded as a video file and stored for offline analysis. This video file was time-stamped during acquisition by the LabVIEW force acquisition software at the beginning of the task (rest), at 25% of body weight force, and at the end of the task.

Data Processing and Image Analysis Still ultrasound images were extracted offline at rest and at 25% of body weight force levels. Image visualization and measurement were conducted using a software package (ImageJ, Version 1.36b; National Institutes of Health, Bethesda, MD). Ultrasound images were all deidentified and placed in a random order for measurement. The thickness of the TrA and IO muscles was measured as the distance between the superior and inferior hyper-echoic muscle fascias, at approximately the middle of the image (Figure 3). For slide of the anterior abdominal fascia, the distance from the medial edge of the TrA muscle to the medial edge of the ultrasound image was measured at rest (as per Hodges et al). This starting position was then superimposed on the contracted image, and the distance from this point to the medial edge of the contracted TrA muscle was measured (Figure 3). Muscle thickness at rest and at 25% body weight was then converted to a percentage change in muscle thickness to enable comparison of TrA and IO muscle thickness changes due to weight bearing.

Statistical Analysis Two separate analyses of variances (ANOVAs) were performed. In both analyses subject height, body mass, age, and gender were included as covariates, and the F statistic for the intercept term was used to indicate an overall effect due to percent change in muscle thickness or slide of the anterior abdominal fascia. The first ANOVA examined percentage change in IO and TrA muscle thickness: factors of muscle (TrA and IO), side of abdomen (contralateral and ipsilateral to weight-bearing lower extremity), and a 2-way interaction between these variables. Muscle was included as a repeated-measures factor in this case, because both the TrA and IO muscles are thought to contribute synergistically to force closure of the pelvis. The second ANOVA evaluated the slide of the anterior abdominal fascia: a side-of-abdomen factor, along with subject

![FIGURE 3.](image-url) (A) Ultrasound image of the right anterolateral abdominal wall at rest (no body weight application) showing 3 muscle layers and the measurements conducted. The most superficial layer is the external oblique (EO) muscle, the middle layer is the internal oblique (IO) muscle, and the deepest layer is the transversus abdominis (TrA) muscle. The fascial tip of the TrA muscle is represented by a circle and the distance from the medial edge of the TrA muscle to the medial edge of the ultrasound image was measured. Thickness measurements of the TrA and IO muscles were performed perpendicular to the muscle fascias approximately half way along the muscle belly seen on the ultrasound image. (B) Ultrasound image of right anterolateral abdominal wall at 25% of body weight force application, showing 3 muscle layers and the measurements conducted. The most superficial layer is the external oblique (EO) muscle, the middle layer is the internal oblique (IO) muscle, and the deepest layer is the transversus abdominis (TrA) muscle. Measurements of the thickness of the TrA and IO muscles and slide of the anterior abdominal fascia are shown. For slide of the anterior abdominal fascia, the starting position (from the relaxed image with no body weight application [represented by a circle]) was superimposed on the image obtained from 25% body weight application, and the distance between the original and new position of the fascia, seen as a second circle, was measured. Note the lateral pull of the TrA muscle.
Anthropometric covariates were included in this analysis. In these analyses the intercept term was used to make inference about the percentage change in muscle thickness from rest to application of 25% body weight (significant deviation from zero). These analyses were implemented using linear mixed-effects models in the R statistical environment. For all comparisons, an alpha value of less than .05 was accepted as statistically significant.

**RESULTS**

The mean (SD) thicknesses of the TrA and IO muscles at rest were 3.6 (0.9) and 7.0 (1.6) mm, respectively. The Table provides descriptive statistics of the recruitment of the anterolateral abdominal musculature during the simulated weight-bearing task.

The results of the first ANOVA showed that the average percentage change in IO and TrA muscle thickness was nonzero (intercept $F_{1,325} = 63.4, P < .0001$), suggesting that changes in muscle thickness from rest to 25% of body weight force application occurred (Table). There was a greater increase in the thickness of the TrA muscle than the IO muscle ($F_{1,325} = 4.63, P = .045$; mean [SEM] difference $= 6.2$ [2.9%]). There was no significant difference between sides of abdomen in percentage thickness change ($F_{1,325} = 0.007, P = .93$) and no interaction between side of abdomen and muscle ($F_{1,36} = 0.10, P = .75$). These results suggest that changes in TrA and IO muscle thickness were symmetrical for the ipsilateral and contralateral sides of abdomen during the unilateral weight-bearing task.

The results of the second ANOVA showed that the average slide of the anterolateral abdominal fascia was also nonzero (intercept $F_{1,121} = 6.17, P = .014$) (Table), suggesting that lateral slide occurred from rest to 25% of body weight force application. Importantly, no difference existed between ipsilateral and contralateral sides of abdomen for this variable ($F_{1,115} = 2.75, P = .11$), further suggesting that activation of the TrA muscle was symmetrical during the simulated weight-bearing task.

**DISCUSSION**

Ultrasound imaging has been used for both assessing abdominal muscle function and providing feedback of muscle contraction in rehabilitation. Assessment of the TrA muscle has been most commonly performed while subjects actively draw in the anterior abdominal wall and focus on the muscle action. Tasks such as simulated weight bearing that automatically recruit the TrA muscle could provide a useful measure of abdominal muscle function. A benefit of a simulated weight-bearing task as an assessment is that potential learning effects and the effect of the participants’ motivational level during testing would be minimized. In addition, a task that results in automatic recruitment of the abdominal muscles provides a measure that is independent of the rehabilitation strategy, which commonly involves actively drawing in the abdominal wall.

Results of this pilot study provide some initial evidence that the lumbar corset is automatically formed during a standardized unilateral simulated weight-bearing task using a low level of body weight in the supine position. The weight-bearing task resulted in an automatic bilateral and symmetrical increase in TA and IO muscle thickness and tensioned the anterior attachments of the muscles’ bellies, resulting in a sliding motion of the fascias, even though a unilateral task was performed. This may be of importance as the mechanical effect of the TrA muscle contraction on spinal stiffness was shown only to occur with bilateral contraction of the muscle. The pattern of abdominal muscle contraction seen in response to the unilateral simulated weight-bearing task was comparable to that seen during the voluntary drawing-in maneuver, which included increased thickness of the TrA and IO muscles and lateral slide of the anterior abdominal fascia bilaterally.

Both the TrA and the IO muscles increased in thickness in response to the unilateral weight-bearing task. This result has been also demonstrated in studies that have investigated voluntary activation of the TrA muscle by drawing in the abdominal wall. The IO muscle is a multifunctional muscle with some distinct horizontal fibers that contribute, with the TrA muscle, to the force closure pattern of abdominal muscle contraction. Both muscles contracted during this task, which supports the biomechanical models that have predicted that these muscles play an important role in functional stabilization of the lumbo-pelvic region during weight bearing.

Automatic recruitment of the TrA muscle during a standardized limb load has been used previously to assess the motor control characteristics and function of the TrA muscle. However, the study of Ferreira et al. used a non–weight-bearing task, whereas the present study used a weight-bearing task with the load passing axially through the trunk and lower limb to the heel. A weight-bearing task was chosen for this study based on biomechanical models predicting that...
such a task would result in automatic recruitment of the TrA muscle in a corset role to stabilize the lumbopelvic region for weight bearing. Although previous studies have not measured slide of the anterior abdominal fascia during a standardized weight-bearing task, this may be an effective way to independently assess the formation of the lumbopelvic corset.

One limitation of this study is that the testing procedure (simulated weight bearing) was artificial in nature. To allow accurate measurements, subjects were asked to pause their breathing during the test, and testing was conducted in the supine position to avoid the confounding variables of balance control, which would be present in the standing position. Another limitation of this pilot study was that lumbopelvic position was not measured. In future research using this standardized weight-bearing task, the amount of pelvic rotation in both the sagittal and transverse planes should be monitored, as changes in postural position may influence the recruitment patterns of the TrA muscle. Future studies could also compare the abdominal muscle responses of different patient groups (eg, subjects with LBP) to the simulated weight-bearing task. It may also be important to study the relationship between the voluntary draw-in test and the response to simulated weight bearing, to determine if differences exist between voluntary and automatic patterns of muscle recruitment.

CONCLUSION

DURING A SIMULATED UNILATERAL weight-bearing task, healthy subjects showed a bilateral and symmetrical increase in thickness of the TrA and IO muscles and a lateral displacement of the anterior abdominal fascia. This pattern of recruitment is in line with the hypothesized stabilization role of the deep lumbopelvic muscles. The simulated unilateral weight-bearing task may present a useful standardized assessment on which to base preventative and rehabilitative exercise.

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