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Original Article

Deep abdominal muscle thickness measured under sitting conditions during different stability tasks

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Abstract. [Purpose] This study was conducted to investigate ultrasonically determined changes in the thickness of the transversus abdominis and internal oblique muscles during different sitting conditions. [Subjects and Methods] Twenty healthy men volunteered to participate in this study. Four different sitting conditions including (A) sitting, (B) sitting with left hip flexion, (C) sitting with an abdominal hollowing maneuver (AHM), and (D) sitting with an AHM and left hip flexion, were used. Subjective exercise difficulty was evaluated. [Results] Transversus abdominis and internal oblique muscle thicknesses significantly differed between conditions, with significantly greater thickness between positions from (A) to (D). Stability of the surface when sitting had no effect on the muscle thickness of the transversus abdominis. By contrast, sitting on an unstable surface caused an increase in muscle thickness of the internal oblique in each condition. The subjects reported progressively increasing difficulty in performing each exercise in a stable position from (A) to (D), while the difficulty in an unstable position was significantly different between (A) and (B), and between (C) and (D). [Conclusion] Our findings suggest that task (B) on a stable surface should be chosen for maximal activation of transversus abdominis without inducing overactivation of the internal oblique muscle.

Key words: Deep abdominal muscles, Ultrasonography, Abdominal hollowing

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INTRODUCTION

The local muscle system consists of muscles with insertion in or origin from (or both) the lumbar vertebrae and includes the transversus abdominis (TrA) and multifidus muscles. The global muscle system comprises muscles with origin from the pelvis and insertion in the thoracic cage, and includes the rectus abdominis, internal oblique (IO) and external oblique (EO) muscles[1)]. These anatomical differences in muscle attachment influences the function of each muscle on the lumbar spine. In short, local muscles are believed to contribute to the stability of the lumbar spine, whereas global muscles contribute to gross movement of the lumbar spine[1, 2)].

The TrA muscle has been considered to have a protective role during activity that challenges the integrity of the lumbar spine[2–4)]. Many reports have suggested a preferential ability for the TrA muscle to increase spinal stability over other muscles[2, 4–7)]. In particular, it is suggested that the TrA muscle should be recruited while suppressing activity of the IO and EO muscles. Richardson et al. called this the ideal contraction pattern for abdominal muscle activation in terms of spinal stability[7)].

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Contraction of the TrA without increasing activation of other abdominal muscles is described as an abdominal hollowing maneuver (AHM)[7, 8]. The AHM is usually conducted in the supine position because a tester can easily observe and palpate the muscle activation. However, this position is not ideal, as it is not functional and the effect of an unstable surface such as a balance ball on muscle activation cannot be determined. By contrast, the sitting position is more functional than the supine position and provides the opportunity to introduce greater challenge to muscle activation such as that in unstable surfaces.

Validity studies have compared ultrasonographic measurements with those obtained by using magnetic resonance imaging and electromyographic activity to determine muscle activation in low-force contractions[9–11]. These findings support the use of ultrasonographic imaging as a reliable and noninvasive technique to measure abdominal muscle thickness[12]. Studies have measured TrA and IO muscle activation by using ultrasonography during hip flexion while sitting on a balance ball. Changes in muscle thickness were significantly greater in the sitting position than in the supine position[12, 13].

Evidence suggest that the AHM is effective for muscle activation and hence re-education of the TrA muscle[2, 8, 14, 15]. The TrA and IO muscles are also known to contract while sitting on a balance ball and increase in thickness with increasing levels of instability[12]. Given the above-mentioned findings, the purpose of this study was to investigate the changes in the thicknesses of the TrA and IO muscles during sitting on a stable surface or a balance disc during 4 different levels of trunk stability tasks accomplished by sitting, sitting with single hip flexion, an AHM, and an AHM with single hip flexion. The study hypothesis was that the thickness of the TrA muscle would increase with an AHM during sitting on an unstable surface.

SUBJECTS AND METHODS

Twenty healthy men (mean ± SD: age, 22.2 ± 2.7 years; height, 170.4 ± 5.6 cm; weight, 63.4 ± 6.3 kg) volunteered to participate in this study. This study was conducted in accordance with the Declaration of Helsinki and was approved by the ethics committee at the Saitama Medical University, Saitama, Japan (M-37). All the participants provided written informed consent before participation in this study.

Ultrasonographic imaging of the abdominal muscles was performed under 8 conditions as follows: (A) sitting, (B) sitting with left hip flexion, (C) sitting with an AHM, and (D) sitting with an AHM and left hip flexion, either with or without a balance disc (39209, Regent Far East, Co. Ltd.) on a stable chair (Fig. 1). During ultrasonographic measurements, the subjects were asked to hold the task position for 10 seconds. All the measurements were conducted in a predetermined randomly assigned order. The subjects sat with their arms folded across their chest and spine in neutral position while breathing normally. During hip flexion, the subjects held their left foot 10 cm above the floor for tasks (B) and (D). To establish intrarater reliability, the ultrasonographic measurements in all the positions were repeated with an interval of 1 to 2 weeks in the first 11 of the 20 subjects.

A diagnostic ultrasonographic imaging unit set in B-mode (Prosound 6, Aloka) with a 7.5-MHz linear head transducer was used to measure the thickness of the TrA and IO in all of the testing positions. All the measurements were performed on the right side of the abdominal wall. The ultrasound transducer was transversely placed across the abdominal wall over the anterior axillary line, midway between the 12th rib and the iliac crest, in order to obtain a clear image of the deep abdominal layers[12]. The image was frozen at the end of expiration, and a vertical straight line through the center of the ultrasonographic image was used to ensure standardized placement of the measurement line. By using the cursor points, muscle thickness

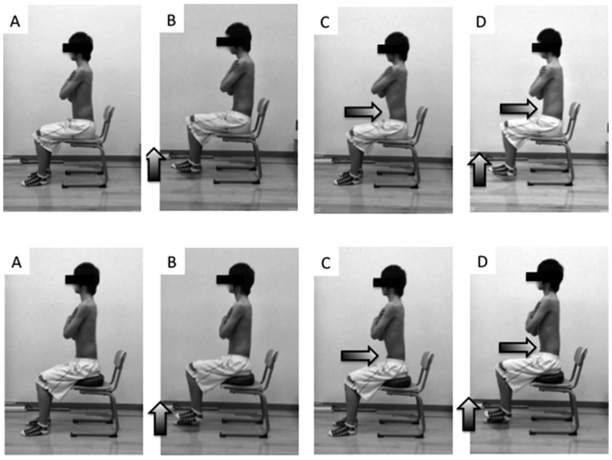

Fig. 1. The 8 testing positions (2 stability levels of sitting position and 4 tasks
The upper row shows tasks sitting on a chair, and the lower row shows tasks sitting on an unstable surface. From left to right: (A) sitting, (B) sitting with left hip flexion, (C) sitting with an abdominal hollowing maneuver (AHM), and (D) sitting with an AHM and left hip flexion)

was carefully measured between the inside edge of the fascial bands in millimeters (mm). The ultrasound transducer was not displaced during the testing procedure. The change in the thickness of each abdominal muscle under different sitting positions was normalized to actual muscle thickness at a resting position in the supine position. The visual analogue scale (VAS) was used to identify the perceived difficulty of the task in each testing position.

The SPSS statistical package was used for the statistical analysis. The Kolmogorov-Smirnov test was used to assess the normality of the distribution of the tested variables. The intraclass correlation coefficient (ICC) (1,1) was used to assess the intrarater reliability of the measurements of muscle thickness on two occasions. The ICC reflects the percentage of agreement between the values from two repetitions of the measurements. A 2-way mixed-design analysis of variance (ANOVA; 2 stability levels of sitting position × 4 tasks) for each muscle was used to test the main effects of stability of the sitting position, tasks, and their interactions on the thickness of the tested muscles. Statistical significance was set at $p < 0.05$. Significant main effects and interactions were further analyzed by using the post hoc (Bonferroni) multiple range test.

RESULTS

ICC(1,1) was greater than 0.76 for the repeated measurements of the thicknesses of the TrA ($\rho = 0.76–0.90$) and IO ($\rho = 0.84–0.91$) during all the test positions (Table 1). These results indicated high intrarater reliability for the measurements$^{16)}$.

The thicknesses of the TrA and IO in the supine position were 3.1 ± 0.7 and 9.3 ± 1.7 mm, respectively. The TrA thickness in sitting with an AHM on a balance disc significantly increased about twofold greater than that in sitting with an AHM. That in left hip flexion on a balance disc also significantly increased about 2.4 times greater than that in the supine position. Furthermore, the TrA thickness with an AHM and left hip flexion on a balance disc also increased significantly 2.6 times greater than that in the supine position (Table 2).

The results of the 2-way ANOVA revealed a significant difference in the main effects of the task ($F = 93.3$, $p < 0.01$) but no significant difference in those of the stability levels in the sitting position ($F = 2.82$, $p > 0.05$) on the relative changes in the thickness of the TrA muscle. The pairwise comparisons revealed that the relative thickness of the TrA significantly differed between the 4 tasks such that in task (A), the thickness was less than that in task (B), which was less than that in task (C), which was less than that in task (D) (Table 3).

In regard to the IO, the results of the 2-way ANOVA revealed a significant difference in the main effects of task ($F = 97.2$, $p < 0.01$) and a significant difference in those of stability levels ($F = 6.89$, $p < 0.01$) on the relative changes in muscle thickness. The pairwise comparisons revealed that the relative thickness of the IO significantly differed between the 2 stability levels. In short, that in sitting on a balance disc was greater than that in sitting on a chair. Furthermore, muscle thickness significantly differed among the 4 tasks such that muscle thickness in task (A) was less than that in task (B) and that in task (C), which was less than that in task (D). Additionally, we found no significant difference in the thickness of the IO between task (B) and task (C) (Table 3).

As for task difficulty scored by using the VAS, the results of the 2-way ANOVA revealed a significant difference in the interaction between task and stability levels in the sitting position ($F = 3.27$, $p < 0.05$) according to the relative change in muscle thickness. With respect to the effects of task and stability levels in the sitting positions, significant changes were observed for each task ($F = 43.5$, $p < 0.01$; $F = 76.7$, $p < 0.01$). The VAS score during sitting on an unstable surface was greater

Table 1. Intrarater reliability of the measurements of muscle thickness

	(A)*	(B)*	(C)*	(D)*	(A)$	(B)$	(C)$	(D)$
TrA	0.82	0.78	0.87	0.90	0.90	0.88	0.90	0.84
IO	0.85	0.90	0.84	0.87	0.86	0.90	0.91	0.88

TrA: transverse abdominis, IO: internal oblique. *Sitting on a chair; $sitting on an balance disc. One-way intraclass correlation coefficient (ICC) values: (A) sitting, (B) sitting with left hip flexion, (C) sitting with an abdominal hollowing maneuver (AHM), and (D) sitting with an AHM and left hip flexion

Table 2. Relative changes in abdominal muscle thickness during 2 levels of sitting stability challenge and 4 tasks in comparison with those in the supine position

Muscle	Stability	Supine	A	B	C	D
TrA	Stable*	1.0	1.2±0.2	1.6±0.2	2.1±0.5	2.4±0.4
	Unstable$		1.3±0.2	1.7±0.2	2.1±0.5	2.6±0.4
IO	Stable*	1.0	1.0±0.1	1.4±0.2	1.4±0.4	1.7±0.3
	Unstable$		1.1±0.1	1.6±0.2	1.4±0.4	1.9±0.2

TrA: transverse abdominis, IO: internal oblique. *Sitting on a chair; $sitting on a balance disc. (A) sitting, (B) sitting with left hip flexion, (C) sitting with an abdominal hollowing maneuver (AHM), and (D) sitting with an AHM and left hip flexion than that during sitting on a stable surface ($p < 0.01$). As for tasks, the multiple comparisons of the VAS scores between the 4 tasks in sitting on a chair showed significant differences in that the VAS score in (A) was less than that in (B), which was less than that in (C), which was less than that in (D). However, the VAS scores in the 4 tasks in sitting on an unstable surface showed that the score was less in (A), which was less than that in (B) and that in (C), which was less than that in (D).

DISCUSSION

The ultrasonographic measurement of the thicknesses of the TrA and IO muscles during single hip flexion on or off an unstable surface showed excellent intrarater reliability[15)]. More complex tasks, including an AHM, were also highly reliable[16)]. Reliability may have been enhanced by factors such as marking for the measurement point, picture capture at the same end point of expiration, and rigorously defined motor tasks.

No significant difference in TrA thickness was observed between the tasks performed in sitting on a stable or unstable surface. By contrast, IO thickness was greater when sitting on an unstable surface than when sitting on a more stable surface. These results indicate that stability levels did not affect the muscle activation of the local muscle (TrA). Hence, the study hypothesis was refuted. Global muscles such as the EO and IO are thought to be easily recruited and to often substitute for local muscles such as the TrA and multifidus. Based on the results of this study, it was postulated that TrA contraction was not enough to stabilize the trunk when sitting on an unstable surface and IO might therefore have been recruited. While the TrA muscle inserts on the costal process of the lumbar spine via the thoracolumbar fascia and acts to stabilize the spine, the middle and lower part of the TrA are known to be anatomically only 0.37 to 0.39 times thicker than the IO muscle[17)]. The study results taken together with these anatomical observations suggest that IO activation may reinforce TrA muscle activation under increasing levels of lumbar stability challenge. Finally, the results suggest that exercise performed while sitting on a chair leads to a more isolated TrA activation without IO activation than sitting on a balance disc, which might be preferential from the perspective of load on the lumbar spine.

Some other studies have measured the thicknesses of abdominal muscles under different conditions. One study showed that TrA muscle thickness with an AHM was almost equal to that during a 25% maximum voluntary contraction (MVC)[8)]. In addition, a study using wire electromyography showed that active straight-leg raising induced 5% of the MVC for the TrA muscle[18)]. Furthermore, a study that performed ultrasonographic measurement showed that TrA thickness with an AHM was twofold greater and that during active straight-leg raising was 1.25 times greater than that at rest[19)]. Based on the above-mentioned findings, AHM can be considered to have a much stronger effect on TrA activation than active straight-leg raising. When comparing between the abdominal muscles, the TrA was recruited more readily than the EO, IO, and rectus abdominis[20)]. The present results were obtained in a similar fashion, and TrA was found to be activated by the AHM more selectively than hip flexion in the sitting position.

Two reasons can explain why the thicknesses of the TrA and IO muscle with the AHM combined with hip flexion increased greater than those with either the AHM or hip flexion alone. First, psoas major activation during hip flexion is likely to stress the lumbar spine, which is countered by the TrA. The thoracolumbar fascia and TrA have a synergic role in stabilizing the lumbar spine and sacroiliac joint[21–25)]. The EO and IO muscles differ from the TrA muscle with respect to lumbar spine stability. Even though the EO and IO muscles continue to the middle portion of the thoracolumbar fascia[23, 26)],

Table 3. Pairwise comparison of the changes in the thicknesses of the tested abdominal muscles (in millimeter) between the positions in all the subjects

Muscle	Position and muscle thickness (mean±SE)	Position and muscle thickness (mean±SE)	Mean difference	p value
TrA	A (3.77±0.26)	B (5.01±0.32)	1.33	<0.01
	A (3.77±0.26)	C (6.57±0.39)	2.8	<0.01
	A (3.77±0.26)	D (7.86±0.43)	4.09	<0.01
	B (5.01±0.32)	C (6.57±0.39)	1.47	<0.01
	B (5.01±0.32)	D (7.86±0.43)	2.76	<0.01
	C (6.57±0.39)	D (7.86±0.43)	1.29	<0.01
IO	A (9.58±0.36)	B (13.74±0.55)	4.16	<0.01
	A (9.58±0.36)	C (13.14±0.73)	3.56	<0.01
	A (9.58±0.36)	D (16.84±0.68)	7.26	<0.01
	B (13.74±0.55)	C (13.14±0.73)	0.6	0.8
	B (13.74±0.55)	D (16.84±0.68)	3.11	<0.01
	C (13.14±0.73)	D (16.84±0.68)	3.71	<0.01

TrA: transverse abdominis, IO: internal oblique; (A) sitting, (B) sitting with left hip flexion, (C) sitting with an abdominal hollowing maneuver (AHM), and (D) sitting with an AHM and left hip flexion these two anatomical structures are almost perpendicular and their force is considered relatively weak[26]. A second factor is the function of the contralateral gluteus maximus muscle during the AHM and hip flexion. It has some continuity with the multifididus muscle[27]. Because the deep fibers of the multifidus muscle stabilizes the lumbar spine and is synchronously activated with the TrA muscle[28], it is considered that the AHM together with hip flexion increases tension of the gluteus maximus, thoracolumbar fascia, and TrA. In addition, based on the present results and in accordance with the results reported by Richardson[7], to obtain an ideal contraction pattern for the lumbar spine-stabilizing muscles, the AHM in the sitting position should be chosen because of the increased TrA muscle thickness and suppressed change in IO muscle thickness. In addition, strong exercise demands such as a combination of the AHM and hip flexion might be chosen if both the TrA and IO are required to be highly activated.

The study results indicate that stability of the sitting position alters the perceived difficulty of the exercise task. This difference in perceived difficulty is related to IO muscle thickness, which potentially indicates greater recruitment of that muscle in an attempt to stabilize the lumbar spine. The perceived difficulty of the task is usually an important factor that influences the choice of an exercise. According to the present results, the AHM in sitting on a stable surface might be chosen as an exercise position for people of all levels of ability and with low back pain who want to improve their TrA activation. On the other hand, the AHM with hip flexion should be chosen for those who want to increase activation of both the TrA and IO muscles despite its perceived difficulty.

One limitation of this study was that all of the subjects were young and healthy and without pain. The study results may not be applicable to other groups such as older people or those with low back pain. The motivation and learning ability of the subjects might have also influenced the results. Further studies are needed to measure the thickness of all parts of the TrA and its relationship to other muscles surrounding the hip and lumbar spine.

TrA muscle thickness was influenced by the AHM rather than by hip flexion regardless of stability of the sitting position. Sitting on a stable surface should be chosen as the ideal position for the optimal activation pattern for abdominal muscles that induce TrA muscle activation while suppressing the IO muscle. The AHM with hip flexion might be chosen for maximizing the activation of both the TrA and IO muscles even though its perceived difficulty is increased.

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