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Original Article

Novel methods to increase core muscle activity in older adults

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Abstract. [Purpose] This study aimed to test whether a combination of specific postures and movements can increase trunk muscle activity in older adults. [Participants and Methods] Forty-six community-dwelling older adults (mean age: 83.9 ± 4.5 years) were living independently without the need for nursing care. The thicknesses of the external oblique, internal oblique, and transversus abdominis muscles were measured during the following three tasks: task I, natural sitting posture; task II, specific sitting posture to promote activity of the deep trunk muscles; and task III, task II plus a pushing down motion using both upper limbs. During each task, an ultrasound imaging device was used to measure the thicknesses of the external oblique, internal oblique, and transversus abdominis muscles on both the left and right sides according to the time required for expiration. [Results] Significant differences were found in the thicknesses of the internal oblique and transversus abdominis muscles between tasks II and III. Among the three muscles, the transversus abdominis showed the highest increase in thickness. [Conclusion] High activity of the trunk muscles, especially the transverse abdominis, can be achieved via specific sitting positions/tasks and further manipulations to increase the intra-abdominal pressure in both upper limbs.

Key words: Core muscle activity, Older adults, Muscle thickness

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INTRODUCTION

In recent years, core stability training has been widely used in various fields, such as rehabilitation medicine, health promotion, care prevention, and sports, to promote the activity of the deep abdominal (DA) muscles and increase the stability of the trunk, thereby improving not only low back pain but also the stable performance of daily activities in older adults, and improving the ability of athletes to compete in athletics[1, 2)]. Core stability is defined as efficient movement both predictably and reflexively in a series of activities of the trunk, scapula, pelvis, and thighs, or a multijoint kinetic chain[3)]. To ensure proper function of the upper and lower extremities, dynamic stability is essential along with strong support by the spine. In addition to the bones, ligaments, joints, and muscles, the nervous system is intricately involved in maintaining this dynamic stability[4)].

Based on differences in lumbar stabilization function, the trunk muscles are classified into two categories: local and global muscles[2)]. Local muscles include the transversus abdominis (TrA), musculus multifidus, and pelvic floor muscles (PFMs), which automatically contract to control the position between spinal segments. These are often collectively referred to as core muscles. Global muscles include the rectus abdominis (RA), internal oblique (IO), and external oblique (EO), which contract voluntarily in response to movement. The diaphragm and PFMs, together with the local and global muscles, form the core cylinder of the trunk and ensure the stability of the core region.

Local muscles, in particular, have attracted much clinical attention because of their diverse functions. The TrA, one of the local muscles, has a feed-forward function during movement execution and plays a major role in trunk stability during limb movement[4, 5)]. This function increases muscle activity around the spine via the thoracodorsal fascia and increases intra-

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abdominal pressure (IAP) in relation to the muscle group. It is known that when intentional quick movements are performed, preceding postural adjustment occurs before movement onset and activation of the TrA is essential for the establishment of this motor control mechanism[6]. In other words, the early activity of the TrA in various movements is responsible for the transmission of force to the limbs and smooth motor control.

The thickness of the TrA is believed to change with postural differences. Previous studies have reported that in the supine and standing positions, the TrA is thinner and its volume of contraction is lower in older people than in younger people[7]. In elderly people, the feed-forward function may not be entirely effective owing to the reduced muscle contractility associated with a decrease in TrA muscle thickness. This might be a factor in accidents, such as falls, due to delayed initiation of limb movements. A previous study reported that patients with chronic low back pain have reduced, delayed, or absent TrA activity and excessive IO and EO muscle activities among global muscles[8].

For these reasons, although we recognize the need for prophylactic training in elderly people in response to reduced muscle thickness and contraction of the trunk muscles, it is practically difficult for them to effectively implement conventional methods of training the trunk muscles on their own.

In our previous study, young participants moved their body forward while grasping a suspension device suspended from the ceiling with both hands so that the body was in the sitting position with 90° of shoulder joint flexion, and changes in TrA muscle thickness were observed during this movement, using an ultrasound imaging system. During the movement, we identified a position where the TrA muscle thickness specifically increased when each participant's body moved forward in the sitting position[9]. However, as this position appeared in the middle of the movement, it was difficult for the participants to identify this position by themselves, making it necessary to use special suspension equipment.

In addition, we previously investigated the possibility of inducing a posture in which the TrA muscle thickness increases by modifying the chair seating surface. We observed an increase in muscle thickness and sustained contraction of the TrA when the seat was set at a forward tilt angle of 12°compared with the normal sitting posture. The sitting posture under these conditions is referred to as the "core-activating position (CAP)", and we have proposed a new training method that is different from conventional core stability training[10].

This study aimed to determine whether the addition of upper limb manipulation in the CAP can increase the activity of the trunk muscles, especially the TrA, in older adults.

PARTICIPNTS AND METHODS

The study included 46 community-dwelling older adults who were living independently without the need for nursing care. Those who had degenerative bone and joint diseases and were currently undergoing treatment and those who could not tolerate the tasks were excluded. Moreover, those who experienced pain during the measurement or felt uneasy about the measurement process were excluded from the study.

There were 12 male and 34 female participants, and the mean age was 83.9 ± 4.5 years (range: 73–91 years). The characteristics of the participants are shown in Table 1.

This study was designed in accordance with the Declaration of Helsinki, and the summary and methods of the study were adequately explained to the participants by providing a written explanation. Individuals who signed the consent form were included in the study. This study was approved by the ethics committee of Teikyo University of Science (approval number: 18014), and all participants provided written informed consent before participation.

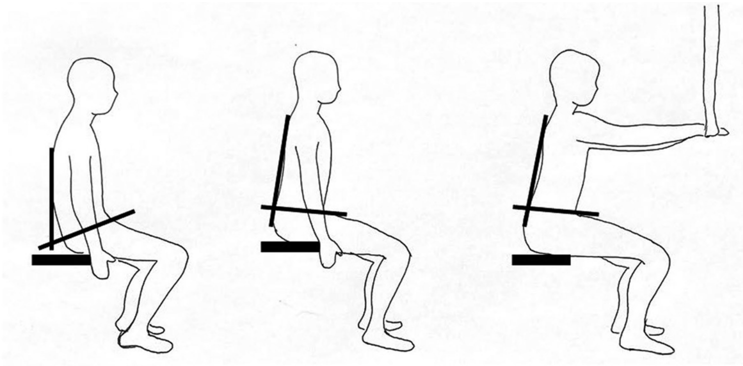
The muscle thickness of the participants was measured in their sitting posture. A commercial chair (stool) with a seat height of 41 cm was used in this study. The seat cushion of the chair was made of urethane foam, and the upholstery was made of vinyl leather.

The following three tasks were assigned to each participant: Task 1, natural sitting position (NSP); Task 2, specific sitting posture to promote muscle activity in the deep trunk muscles (CAP); and Task 3, CAP plus pushing down motion using both upper limbs (CAPPD).

In Task 1, the participant was instructed to assume a normal comfortable posture ("Please sit in this chair as you usually do at home") (Fig. 1, left). In Task 2, instead of setting the seat inclination to 12°, the participant was instructed to support his weight with the ischial tuberosities on both side of the sacrum involved in sitting and to sit at the front end of the chair as much as possible. Simultaneously, the participant was instructed to pull the feet backward until the position of the knee joint was lower than the height of the hip joint when viewed from the sagittal plane. Based on the results of previous studies, we confirmed that the angle between the line segment connecting the superior anterior iliac spine and superior posterior iliac

Table 1. Participant characteristics (mean ± SD)

	Male (N=12)	Female (N=34)
Age (years)	84.7 ± 5.2	83.7 ± 4.3
Body height (cm)	159. 9 ± 7.8	146.8 ± 5.9
Body weight (kg)	58.9 ± 10.9	54.7 ± 7.6



Natural sitting position
NSP

Core activating position
CAP

CAP with hands pushing down
on suspending equipment
CAPPD

Fig. 1. Measurement posture for three tasks.

spine and the line segment connecting the L4 spinous process on the Jacobi line and Th7 spinous process obtained from the height of the subscapularis angle (L-T line) was approximately at a right angle (Fig. 1, center). For Task 3, we decided to follow the procedure described in a previous study[11]. In brief, the participant was instructed to grasp the strap at the end of a cord suspended from the ceiling at the wrist position while maintaining the CAP, flex both shoulder joints at 90°, extend both elbow joints, and then push downward in response to exhalation (Fig. 1, right).

Muscle activity was investigated noninvasively using ultrasound. During each task, an ultrasound imaging device (SonoSite Edge II, FUJIFILM SonoSite, Inc., Bothell, WA, USA) equipped with an 8-MHz linear probe was used to measure the thicknesses of the EO, IO, and TrA on both the left and right sides according to the time required for expiration. As this device is capable of capturing surface images and the fascia can be clearly identified with still images, we used the boundary line of the fascia as a reference line, set the measurement points using the marking function of the imaging device, and acquired the data. The probe was placed at the intersection of a line passing horizontally through the umbilicus and a line descending vertically from the axilla, with the short axis pointing forward, 10 cm outward from the umbilicus. This was a common measurement position for all three muscles (EO, IO, and TrA). The skin and fascia of the EO, IO, and TrA were parallel to each other when the probe was applied.

The order in which the tasks were performed was determined using a randomized chart, and to ensure the reliability of the data, the muscle thickness in all participants was measured once each by someone experienced in taking this type of measurement. The thickness of each muscle was measured to the nearest 0.1 mm based on the boundary line of the fascia by recording a still ultrasound image of the abdomen at the end of expiration.

The percentage increase in muscle thickness in the CAP task relative to the NSP task and the percentage increase in muscle thickness in the CAPPD task relative to the NSP task were calculated based on the actual measurements of the EO, IO, and TrA on the left and right sides separately.

A Shapiro–Wilk test was performed on all data to confirm normality. Next, repeated measures factorial analysis of variance (ANOVA) was performed to examine the changes in each muscle thickness during each task, and Sheffe's multiple comparison test was performed when a significant main effect was found. Friedman test and then Tukey test was also performed if the data failed to show the normality. All statistical analyses were performed using SPSS (IBM Corp., Armonk, NY, USA). The significance level was set at 5%.

RESULTS

No significant differences were found in muscle thickness data between the left and right sides in the EO, IO, and TrA. No sex differences were found in the EO, IO, and TrA for each task. The measured muscle thickness data were calculated and analyzed as the arithmetical mean of the left and right sides.

Table 2 shows the measured thickness of each muscle in the tasks performed, with significant main effects on the thicknesses of IO ($F=15.33$, $p<0.01$) and TrA muscles ($F=17.87$, $p<0.01$) but no significant main effects on EO muscle thickness. Multiple comparison tests revealed significant differences in the thicknesses of IO and TrA muscle between the NSP and CAPPD tasks and between the CAP and CAPPD tasks ($p<0.01$), respectively.

For assessing the percentage increase in the IO and TrA muscle thicknesses in each task, measurements were obtained from all participants individually based on the NSP task, and the mean values were calculated (Table 3). The ANOVA (CAP/NSP, CAPPD/NSP, CAP/CAP×IO, EO, TrA) showed a significant main effect for CAP/NSP ($F=15.74$, $p<0.001$) and

Table 2. Muscle thickness of three abdominal muscles in each task (N=46)

	NSP	CAP	CAPPD
Transverse abdominis (cm)	0.8 ± 0.25	0.8 ± 0.24**	1.3 ± 0.34**
Abdominal internal oblique (cm)	1.3 ± 0.48	1.4 ± 0.41**	1.7 ± 0.49**
Abdominal external oblique (cm)	1.1 ± 0.36	1.1 ± 0.28	1.2 ± 0.30

Measurement variables are expressed as mean and standard deviation (SD).
**p<0.01: NSP and CAPPD, CAP and CAPPD.
NSP: natural sitting position; CAP: core activating position; CAPPD: CAP with hands pushing down on suspending equipment.

Table 3. The percentage increase in muscle thickness in the CAP task relative to the NSP task, in the CAPPD task relative to the NSP task and in the CAPPD task relative to the CAP task (N=46)

	CAP/NSP (%)[a)]	CAPPD/NSP (%)[b)]	CAPPD/CAP (%)[c)]
Transverse abdominis (TrA)	10.7 ± 31.04***	63.1 ± 57.65***#	51.1 ± 48.95#
Abdominal internal oblique (IO)	12.3 ± 36.01	40.5 ± 49.00#	29.2 ± 39.79#
Abdominal external oblique (EO)	9.1 ± 33.36	11.2 ± 26.02#	17.8 ± 32.81#

Measurement variables are expressed as mean and standard deviation (SD).
a) (CAP−NSP)/NSP×100 b) (CAPP−NSP)/NSP×100 c) (CAPPD−CAP)/CAP×100
***p<0.001: CAP/NSP and CAPPD/NSP, CAPPD/NSP and CAPPD/CAP, #: p<0.001: TrA and IO, IO and EO, EO and TrA.
NSP: natural sitting position; CAP: core activating position; CAPPD: CAP with hands pushing down on suspending equipment.

CAPPD/NSP (F=20.32, p<0.001), respectively. Multiple comparison tests showed the CAPPD/NSP statistic in TrA was the largest (p<0.001).

The percentage increase in the TrA muscle thickness increased significantly by 10.7% in the CAP task compared with the NSP task (p<0.001) and by 63.1% in the CAPPD task compared with the NSP task (p<0.001). However, the percentage increase in the IO and the EO muscle thickness failed to show a significant increase among the CAPPD task compared with the NSP task, the CAPPD task compared with the CAP task, and the CAPPD task compared with the NSP task.

DISCUSSION

In this study, we measured muscle thickness using ultrasound to assess the morphology of DA muscles and the degree of contraction. Previous studies have also attempted to use muscle thickness as an indicator of muscle activity by estimating muscle strength from muscle thickness[11)] and by observing changes in muscle thickness with muscle contraction[12)]. As muscle thickness showed a significant correlation with muscle cross-sectional area and muscle volume[13, 14)], it can be regarded as an indicator of muscle cross-sectional area and muscle volume.

Furthermore, studies have reported that muscle thickness measurement using B-mode (brightness mode) ultrasound is useful for examining muscle hypertrophy resulting from training and muscle atrophy resulting from inactivity and aging[15–20)]. Thus, an evaluation method that measures muscle thickness changes using an ultrasound imaging device is considered useful for capturing the activity dynamics of the trunk muscles associated with contraction[21)].

However, it is difficult to capture the morphological changes of the entire muscle during contraction because most muscle thickness measurements using ultrasound are performed at only one part of the muscle and in only one direction.

In the present study, all DA muscles, which encompass the trunk, were not evaluated, as in the case of the TrA.

The results showed that the TrA had the highest rate of increase in muscle thickness among the trunk muscles studied (IO, EO, and TrA). In previous studies, the muscle thickness of the TrA was most markedly changed among the DA muscles[22)], suggesting that particular attention should be paid to the change in TrA muscle thickness when evaluating DA muscle function.

The function of the TrA is to pull the lower ribs downward, decrease abdominal circumference, and increase IAP. The TrA is also related to breathing and functions during forced expiration, and a previous study reported that training the expiratory muscles increases their strength[23)]. In other words, it may be effective to promote contraction of the TrA by retracting the abdomen in response to expiration, as was employed in Task 3 in this study. Furthermore, a previous study reported that this abdominal retraction exercise is more effective for increasing TrA muscle activity in the upright position than in the supine position[24)]. The mechanism is thought to be associated with an increase in the TrA muscle activity in response to the effects of gravity and a reduction in the base of support[24, 25)].

A previous study investigating the relationship between muscle thickness change and muscle activity found significant positive correlations between them in the TrA and IO among trunk muscles (TrA, IO, and EO) and reported that muscle thickness can be an indicator of muscle activity for these two muscles[26].

Furthermore, as previous studies reported a significant positive correlation between the activity of DA muscles and IAP during various tasks, suggesting that DA muscle contraction is highly related to changes in IAP[27, 28]. On the contrary, studies have reported that the activity of not only DA muscles but also the superficial muscles of the trunk, such as the RA and EO, are positively correlated with IAP[29, 30]. These findings help in understanding the significance of using the thickness of DA muscles, especially the TrA, as an indicator when evaluating IAP.

Several training methods have been introduced to target the TrA, including the well-known draw-in method of abdominal hollowing[10] and bracing[31, 32] and the method[33] that promotes TrA contraction by linking it to PFM contraction. The former is a technique to stabilize the lumbar pelvis by retracting the abdomen without lumbar pelvis movement and selectively contracting the DA muscles, including the TrA, IO, lumbar multifidus, and diaphragm. The latter is a technique to stabilize the lumbar pelvis by contracting all trunk muscles, including the DA muscles, without focusing on specific muscle activity.

Systematic reviews have shown that such selective training of deep muscles improves the neuromuscular reaction time of the target muscle[34], triggering early activity of the TrA and multifidus and providing a basis for a functional trunk. However, conventional methods of activating the TrA require voluntary contraction of the same muscle. Therefore, it has been difficult to identify a feature of TrA function in exercises, that is, the automatic contraction of the TrA prior to limb movements to stabilize the trunk.

Moreover, no exercise method can automatically and continuously contract muscles by maintaining a specific posture, as attempted in this study. Therefore, it was necessary to develop a new exercise method to improve motor performance while stabilizing the spinal segments. In particular, as it is difficult for older adults to intentionally contract local muscles owing to their posture[7], a method that is safe and easy.

In a previous study, we reported that in younger participants, an increase in TrA muscle thickness was observed only by verbally inducing a postural change (NSP to CAP)[9]. However, in the present study, no increase in TrA muscle thickness was observed in older adults simply by changing their posture. Therefore, it is assumed that the IAP was increased by the addition of a manipulation in which the strap placed in front was pushed down in response to exhalation, which increased the TrA muscle thickness, resulting in contraction of the muscle and an increase in IAP. Therefore, this combination of posture and movement that specifically increases IAP may be useful for older adults who have difficulty achieving TrA activity.

NSP and CAP differ in that the pelvis is relatively tilted backward in the NSP, whereas the pelvis is tilted forward and the spine is in extension in the CAP, which makes the posture more likely to increase IAP. In daily life, older adults often assume a comfortable sitting posture with the thoracolumbar region relaxed and the pelvis tilted backward ("slump sitting"), making it difficult to achieve TrA activity and increase IAP.

Reeve et al. compared the TrA muscle thickness in different postures and reported that the standing posture had the highest value of 4.63 ± 1.35 mm, the erect sitting posture had a value of 4.30 ± 1.58 mm, and the slouched sitting (rounded back) posture had the lowest value of 3.46 ± 1.13 mm[35].

As can be seen from this report, to increase the TrA muscle thickness and IAP, the trunk must be moved forward by flexing the hip joint while the trunk is held in the upright position (spinal extension). The results revealed that even among participants aged 80 years or older, the rate of change in the TrA muscle thickness increased by more than 50% in the CAPPD task for increasing IAP than in the NSP task. As the operation of pulling down the special strap with both hands performed in Task 3 is similar to the operation of stretching both upper limbs and pushing a table with both palmar surfaces, it can be considered an alternative method to the operation using the strap in real life, and the same effect is expected. In addition, an increase in the TrA muscle thickness can be expected by setting up and continuing the operation to increase IAP by oneself using the CAPPD task performed in this study. In other words, by setting up the CAPPD task using a chair and table at home, trunk muscle training can be performed in daily life, for example, when watching TV or doing light work, and can be easily performed in between daily activities. The finding that the combination of CAPPD posture and movement specifically increased the amount of activity of the DA muscles, especially the TrA, may be useful in considering the trainability of these muscles in older adults.

Our study has a few limitations. We simulated the CAP by changing the positional relationship between the hip and knee joints for each participant instead of using a chair with a 12° forward inclined seat, but it is unclear whether the same conditions could be reproduced. In addition, as in CAPPD, changes in muscle thickness with movement were not uniform, and differences in muscle thickness were observed depending on the site of measurement. Furthermore, it was not clear in this study whether the same effect could be obtained by pushing the table with the palmar surfaces of both hands instead of pushing the special strap downward, and further research is required.

In conclusion, this study developed novel methods to increase core muscle activity and confirmed that the addition of upper limb manipulation in the CAP can increase the activity of the trunk muscles, especially the TrA, in older adults.

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Conflict of interest

The authors have no conflicts of interest directly relevant to the content of this article.

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