

The Use of Rehabilitative Ultrasound Imaging for Feedback from the Abdominal Muscles during Abdominal Hollowing in Different Positions

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Abstract. [Purpose] This study was conducted to investigate the effects of rehabilitative ultrasound imaging (RUSI) feedback during the abdominal hollowing exercise (AHE) in three different positions by monitoring the changes in the thicknesses of the abdominal muscles. [Subjects] The subjects of this study were 42 healthy male adults who listened to an explanation of the study method and purpose and agreed to participate in the experiments. They were divided into an experimental group of 21 subjects who received RUSI feedback and a control group of 21 subjects who did not receive RUSI feedback. [Methods] The thickness of the abdominal muscles was measured during rest and AHE in three positions. The thickness changes between rest and AHE were compared between the two groups. [Results] The difference in internal abdominal oblique (IO) thickness changes between the groups were significant. The differences in external abdominal oblique (EO) thickness changes were only significant among the positions. A post hoc analysis of the differences in EO thickness changes among the positions found significant differences between the crook lying and four-point kneeling positions. The transversus abdominis (TrA) thickness changes showed significant interaction between group and position. [Conclusion] RUSI feedback assists the independent activities of TrA by decreasing the thickness changes of global muscles such as IO and EO. Furthermore, crook lying is a more effective position in AH training with RUSI feedback than the other two positions as it increases TrA thickness changes while minimizing those of EO.

Key words: Rehabilitative ultrasound imaging, Abdominal hollowing exercise, Three different positions

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INTRODUCTION

Since 2006, rehabilitative ultrasound imaging (RUSI), which was approved by the World Federation of Ultrasound in Medicine and Biology (WFUMB), has been used by physical therapists to evaluate the functions and morphology of deep muscles and organs. RUSI is a non-invasive method for quantifying the morphology and behaviors of muscles and its use as a clinical and research tool for rehabilitation therapies is gradually increasing¹⁾.

The reliability of ultrasound as a tool for muscle thickness measurement has been proven by several studies^{2,3)}. Furthermore, as it can visually show the images of deep structures in the trunk, RUSI is being used as a feedback tool for reinforcing exercise learning and the performance of selected trunk muscles^{4,5)}.

RUSI is mainly used as a feedback tool for the musculoskeletal system, and feedback training for the musculoskeletal system has two main goals. The first goal is to stimulate the central nervous system to reconstruct appropriate sensory-motor loops under volitional control, which may have been damaged by injuries or diseases⁶⁻⁸⁾. The second goal is to assist the development of cognitive awareness⁸⁾. Feedback training of the musculoskeletal

system to achieve these two goals is often conducted in clinical settings.

Feedback training of the musculoskeletal system with RUSI is frequently used in stabilization exercises as well. It is frequently used for the abdominal hollowing exercise (AHE), which is performed in the initial stage to induce selective contraction of the deep trunk muscles, particularly the transversus abdominis (TrA). AHE using RUSI as a feedback tool activates the selective contraction of deep abdominal muscles, while reducing the activities of the superficial abdominal muscles^{4,5,9)}. While the effects of AHE using RUSI feedback have been studied, few studies have included experiments using RUSI feedback in the crook lying, prone lying, four-point kneeling or wall support standing positions recommended by clinicians. Accordingly, this study investigated the effects of RUSI feedback in three of the positions recommended for AHE by clinicians, excepting prone lying, which is difficult to measure with ultrasound.

SUBJECTS AND METHODS

The subjects of this study were 42 healthy male adults who listened to an explanation of the study method and

purpose and agreed to participate in the experiments. They were divided into an experimental group of 21 subjects who received RUSI feedback and a control group of 21 subjects who did not receive RUSI feedback. Those who had dysfunction and pain in their upper or lower limbs, who had experienced AHE, who had experienced back pain in the last 6 months, who had received surgical treatment, or who had other diseases were excluded.

We used a Sonoace X4 (Medison, Korea) for the thickness measurement and feedback from the abdominal muscles during AHE. Muscle measurement requires high resolution. As 7.5MHz linear transducers can provide high resolution for muscle measurement¹⁰⁾, this study measured the thickness of muscles with a 7.5MHz linear transducer in B-mode.

Before starting the experiment, all the subjects were familiarized with AHE based on the protocol of Richardson and Jull¹¹⁾, so that they could breathe normally with no movement of their spine, ribs, or pelvis, with their navel slowly pulling inward and upward. The experimental group performed AHE with RUSI feedback and the control group performed AHE with no RUSI feedback. The training was performed for 30 minutes. The measurement positions were as follows: crook lying with knee flexion of 90°¹²⁾; four-point kneeling with the line of sight directed at the floor, the ears and shoulders positioned horizontally to each other, the wrist directly below the shoulder, and the knee below the hip¹³⁾; and wall support standing with the distance between the wall and the heel maintained at 15 cm¹⁴⁾. To prevent fatigue of the muscles, the subjects rested for 2 minutes after each AHE. The thickness of the abdominal muscles during rest and AHE was measured 3 times in each position and the averages were calculated. The difference in thickness between rest and AHE were compared between the two groups.

The transducer was transversely placed halfway between the 12th costal cartilage and the iliac crest¹⁵⁾. To standardize the location of the transducer, it was set in such a way that the space where TrA and the thoracolumbar fascia (TLF) meet would appear at the right end of the ultrasound image¹⁶⁾. To minimize the effect of breathing, each muscle thickness was measured when the subject was expiring. The ultrasound images were captured at the end of expiration. The examiner made measurements beside the right hand of the subjects while they were performing AHE. The same researchers performed the training and measurement of all the subjects.

A two-way ANOVA was conducted to examine the effects of AHE according to the use of visual feedback and the different positions, and Tukey's multiple comparison was used for post hoc analysis. To test statistical significance, a significance level, α of 0.05 was chosen, and the collected data were analyzed using the SPSS 12.0 for Windows application.

RESULTS

The characteristics of the subjects are listed in Table 1. There were no significant differences in general characteristics between the two groups. The differences in

Table1. General characteristics of subjects (N=42)

	Experimental Group (n=21)	Control Group (n=21)
Age (years)	23.2 ± 2.1	22.6 ± 4.1
Height (cm)	175.1 ± 4.6	176.2 ± 5.7
Weight (kg)	67.9 ± 6.7	67.8 ± 9.9
BMI (kg/m ²)	22.2 ± 2.4	21.8 ± 2.4

Mean ± SD; BMI: Body mass index.

the thickness of abdominal muscles between rest and AHE and between the experimental and control groups are shown in Table 2. The thicknesses of the muscles, except the external abdominal oblique (EO), increased during AHE compared to rest in both the experimental and control groups. The differences in thickness changes of the abdominal muscles by group and position are as follows. The difference in internal abdominal oblique (IO) thickness changes was significant between groups ($p < 0.05$), but there were no significant differences among the positions and no interactions between groups and positions. Furthermore, the differences in EO thickness changes were only significant among the positions ($p < 0.05$). The results of post hoc analysis of the differences in EO thickness changes are shown in Table 3. A significant difference was found between the crook lying and the four-point kneeling positions in the experimental group. The differences in TrA thickness changes showed a significant interaction between group and position ($p < 0.05$), but there were no significant differences between groups and among positions.

DISCUSSION

This study compared the differences in abdominal thickness changes to investigate the effects of RUSI feedback on AHE in three positions. The muscles that showed differences in abdominal thickness change with the use of RUSI feedback were IO and EO. In the control group that did not use RUSI feedback, the IO thickness change was greater than the TrA thickness change between rest and AHE in all positions. This was due to the anatomical characteristics of the lower fibers of IO. Marshall and Murphy¹⁷⁾ reported that it was impossible to distinguish structural differences between TrA and IO, because these muscles are fused in the lower abdominal region, based on the lack of a clear fascial separation in 9 of 10 cadavers. For this reason, the lower fibers of not only TrA but also IO contribute to the compression force on the sacroiliac joint^{18,19)}. Considering the anatomical characteristics of TrA and IO, we believe that the functional activities of TrA and IO partially overlap during AHE and that the increase of TrA thickness influenced the increase of IO thickness in the control group in the present study. The results of the present study support the findings of a study that reported that TrA and IO did not play independent roles during Pilates exercise²⁰⁾, and the study results of Manshadi et al.²¹⁾ who showed IO thickness increased together with increased TrA thickness during AHE.

The control group of this study showed the largest increase in TrA and IO thickness in wall support standing.

Table 2. Comparison of muscle thickness changes between rest and AHE in three positions (N=42)

		Muscle thickness (mm)						Difference
		EG (Rest)	EG (AHE)	CG (Rest)	CG (AHE)	EG (MTC)	CG (MTC)	
CL	TrA	3.30	4.27	3.56	4.39	0.97 ± 0.26	0.83 ± 0.48	+0.14
	IO	7.31	7.84	7.14	8.19	0.53 ± 0.64	1.05 ± 0.83	-0.52
	EO	5.29	4.86	5.35	5.89	-0.43 ± 0.30	0.54 ± 0.41	-0.97
FPK	TrA	4.32	5.27	4.21	5.15	0.95 ± 0.35	0.94 ± 0.36	+0.01
	IO	7.55	8.15	7.32	8.27	0.60 ± 0.78	0.95 ± 0.60	-0.35
	EO	5.53	5.30	5.79	6.57	-0.23 ± 0.26	0.78 ± 0.44	-1.01
WSS	TrA	5.05	5.97	5.27	6.49	0.92 ± 0.21	1.22 ± 0.56	-0.30
	IO	7.80	8.23	8.01	9.37	0.43 ± 0.37	1.36 ± 1.15	-0.93
	EO	5.92	5.52	6.07	6.68	-0.40 ± 0.23	0.61 ± 0.28	-1.01

EG: Experimental group; CG: Control group; AHE: Abdominal hollowing exercise; MTC: Muscle thickness change; CL: Crook lying; FPK: Four-point kneeling; WSS: Wall support standing.

Table 3. Results of post hoc analysis on the differences in EO thickness changes by position

	Crook lying	Four-point kneeling	Wall support standing
Experimental group	-0.43 ± 0.30 ^a	-0.23 ± 0.26 ^b	-0.40 ± 0.23 ^{ab}
Control group	0.54 ± 0.41	0.78 ± 0.44	0.61 ± 0.28

^{a, b} values with different superscripts within the same columns are significantly different at $p < 0.05$.

This result is in agreement with the studies^{19,22)} that indicate the two muscles play an important role in the functional stabilization of the lumbopelvic region. Furthermore, this result agrees with the findings of others studies^{23,24)} that deep muscles can induce activities more effectively in more functional positions. On the other hand, the experimental group who used the RUSI feedback showed a reduction in IO thickness while maintaining constant thickness of TrA between rest and AHE. Compared to the results of a previous study²⁴⁾ on AHE with no feedback, in which the IO thickness changes between rest and AHE were 1.31 mm in crook lying and 0.72 mm in standing, the experimental group in the present study showed a decrease in IO thickness of 0.53 mm in crook lying and to 0.43 mm in standing. In particular, the IO thickness in wall support standing showed the greatest change in our study: 1.36 mm in the control group and 0.43 mm in the experimental group. Furthermore, in a study²⁵⁾ comparing the thickness change between rest and AHE in four-point kneeling, the difference in the IO thickness change of healthy subjects was 1.7 mm, but it was 0.6 mm in the experimental group in the present study. Thus, we believe that RUSI feedback is an excellent tool that can induce the activity of TrA by minimizing the thickness change of IO.

It is difficult to minimize EO contraction during AHE. A study by Beith et al.²⁶⁾ on EMG mentioned the difficulty of eliminating EO activity: 45% of subjects in the four-point kneeling position and 75% of subjects in the prone position showed simultaneous activities of IO and EO during AHE. Another study also mentioned the possibility of the simultaneous action of TrA and IO during AHE due to the characteristics of the fibro-osseous enthetic site of EO. Furthermore, Park and Lee²⁸⁾ reported on the difficulty of eliminating EO activity: only 22% of their subjects could perform independent contraction of TrA during AHE in four

positions while maintaining EO and RA (rectus abdominis) activity at less than 5% of the maximum voluntary contraction (MVC). The experimental group in this study showed a decrease of 0.23~0.43 mm during AHE in all positions compared to resting, with about 1 mm greater EO thickness reduction than the control group. The reason for this seems to be the provision of feedback information related to the movement of the abdominal muscles from real-time ultrasound imaging; that is, the knowledge of performance re-educated individuals' ability to control EO as well as IO. If the muscle thickness can be regarded as an indicator of the muscle function and activity, RUSI feedback can give great assistance to the education of accurate AHE while minimizing the activities of EO and IO.

The thickness changes of abdominal muscles among positions were meaningful only for EO. The post hoc analysis found a significant difference in the EO thickness changes among positions only in the experimental group. For the experimental group, the EO thickness decrease between rest and AHE was 0.43 mm in crook lying and 0.23 mm in four-point kneeling, a significant difference. This agrees with the result of another study²⁷⁾ that crook lying better eliminated the activity of EO during AHE than the other positions. This result also supports the finding²⁷⁾ that the contraction of TrA/IO could be increased in crook lying more than in four-point kneeling because crook lying showed the greatest thickness increase in TrA. AH training with RUSI feedback could be more effective than AH training alone because it showed increased thickness of TrA and decreased thickness of EO compared to the other two positions. A study²⁴⁾ on AHE with no feedback, however, reported that standing was more functional for AHE because the thicknesses of EO and IO decreased in standing more than in crook lying, by 0.87 mm and 0.59 mm, respectively, and the thickness of TrA increased by 0.88

mm. The results of the present study contradicted these results. Both the experimental and control groups of the present study showed no significant differences in EO thickness changes between wall support standing and the other two positions. The wall support standing showed the smallest increase of TrA thickness in the experimental group. The reason for this difference seems to be that the wall support standing position in Mew's study had a narrower, more unstable base than the wall support standing position in the present study, and Mew's study used the modified AHE of Critchley²⁹ that also contracts the pelvic floor. Thus, the TrA activity increased more in his study than in the wall support standing of the present study, which decreased the role of the other two muscles in supporting and maintaining the positions.

As there is an interaction between the use of RUSI feedback and the positions in TrA thickness change, for accurate training of AHE, the thickness change of the transverse muscle of the abdominal muscle must be considered when applying ultrasound feedback in various positions.

If the muscle thickness can be regarded as an indicator of muscle function and activity, RUSI feedback will be helpful for inducing the independent activity of TrA by reducing the activities of global muscles such as IO and EO. Furthermore, crook lying seems to be an effective position for AH training with RUSI feedback as it decreases the EO thickness and increases the TrA thickness, compared to the other two positions.

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