

The Effect of Real-time Ultrasound Imaging Feedback during Abdominal Hollowing in Four Point Kneeling to Healthy Men



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Purpose: This study investigated the effects of visual feedback during abdominal hollowing (AH) in four point kneeling position, using real-time ultrasound imaging through measurement of the changes in the thickness of transversus abdominis (TrA), internal abdominal oblique (IO), and external abdominal oblique (EO).

Methods: The subjects of this study were 32 healthy males who were divided into the experimental group of 16 subjects and the control group of 16 subjects. The real-time ultrasound feedback was applied to the experimental group while they were educated on the AH exercise in four point kneeling whereas only general education and training were given to the control group. After the training, the changes in the thickness of abdominal muscles during AH in four point kneeling were compared between the experimental group and the control group.

Results: The differences of the changes in the thickness of TrA and EO between the two groups were statistically significant.

Conclusion: The experimental group experienced a higher increase in the thickness of TrA than the control group while the thickness of IO and EO of the experimental group decreased. Therefore, real-time ultrasound feedback was effective for the selective contraction of TrA while reducing the activities of IO and EO during the AH exercise.

Keywords: Four-point kneeling, Abdominal hollowing, Real-time ultrasound imaging, Feedback

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1. Introduction

In recent years, spinal stabilization exercises are gradually gaining popularity as a treatment of low back pain. Two systematic reviews^{1,2} have provided evidence for the effects of spinal stabilization exercises, thus continuing their popularity. The first step in the treatment process of patients with low back pain is to stimulate the selective activity of deep abdominal muscles such as TrA. To achieve this first step, clinicians have tried abdominal hollowing (AH) exercise targeted on deep abdominal muscles. Richardson and Jull³ recommended four point kneeling as the easiest position for activating TrA.

The four point kneeling position is recommended together with the prone position since it can achieve the separate contraction of the lower fibers of the internal oblique abdominal muscle more consistently compared to the prone position⁴ and it

minimizes external load and pain during the rehabilitation of the local system.³ Furthermore, it is a non-anti gravity position that can reduce the load on the spine and easily maintain balance in a spinal neutral position compared to other positions.⁵ Due to these advantages, AH is often performed clinically in four point kneeling. Chanthapetch et al⁶ reported, however, that it is difficult to induce the independent contraction of TrA by removing the activity of EO during AH. Park and Lee⁷ recommended inducing the selective contraction of TrA using real-time ultrasound imaging because it is difficult to remove the activity of the EO.

Real-time ultrasound imaging is a non-invasive tool that provides visual images and enables the measurement of deep structures in the trunk.⁸ It is cost-effective and very practical among imaging modalities. Ultrasound imaging visualizes muscles in real time and can measure the activity, size and

thickness of deep trunk muscles⁹⁻¹¹ The reliability of ultrasound imaging as a tool for measuring muscle thickness has been already demonstrated.⁸ Furthermore, it has been proven that ultrasound imaging improves performance of AH¹² by providing individuals with visual feedback to the movement and changing thickness of deep abdominal muscles through the real-time ultrasound screen, and that it is very effective in the improvement of multifidus (MF) muscle.¹³ As indicated above, real-time ultrasound imaging is widely used for the treatment and management of low back pain and for evaluation of the effects of rehabilitation treatment, but studies using ultrasound imaging with regard to stabilization exercises are still insufficient in the country. Accordingly, this study is intended to investigate the effects of visual feedback through real-time ultrasound imaging during AH in four point kneeling position.

II. Methods

1. Subjects

The subjects of this study were 32 healthy male adults who voluntarily agreed to participate in the experiments after listening to the purpose and method of study. They were divided into the experimental group of 16 subjects who received training with visual feedback and the control group of 16 subjects who received training without visual feedback. Those who had pain or dysfunction in upper limbs or lower limbs during exercise, who had not experienced AH exercise, who had experienced LBP during the last 6 months, who had underwent surgical treatment, or who had a disease in their nervous system were excluded from the experiment.

2. Experiment method

1) Measuring instruments

Sonoace X4 from Medison, Korean was used to measure the thickness of TrA, IO and EO muscles during AH. The thicknesses of muscles were measured using 7.5 MHz linear transducers.

2) Exercise method

According to the protocol by Richardson and Jull,³ before the experiment the subjects were trained for AH to slowly pull the navel inward and upward while not moving the spine, ribs, and

pelvis. The experimental group received training for AH with visual feedback through real-time ultrasound imaging whereas the control group received the same education without visual feedback. Depending on the level of understanding of the subjects, the education time ranged from 15 to 20 min. Once their navel moved closer to their spine, they had to maintain abdominal contraction for 10 seconds while breathing normally. Three measurements were made for each posture while they repeated this procedure three times.⁶ In order to prevent muscle fatigue, they had a rest of 2 minutes after abdominal hollowing. The exercise procedure was as follows: In the four point kneeling position, their eyes were directed to the floor, and while their shoulder and eyes were in line, their wrists were put under their shoulders and their knees under their hips. The thicknesses of TrA, IO, and EO were measured first during resting in this position, and then the thicknesses of the same muscles were measured again during AH in the same position. The averages of three measurements were calculated and compared.

3) Ultrasound recordings

The transducer was transversely placed halfway between the 11th costal cartilage and the iliac crest.¹⁴ Furthermore, to standardize the location of the catheter, it was set in such a way that the space where TrA and thoracolumbar fascia (TLF) meet would appear at the right end of the ultrasound image (Figure 1).¹⁵ To control the effects of respiration,¹⁶ the subjects were educated to perform AH during exhalation. Ultrasound images were captured at the end of the exhalation. The examiner measured the thicknesses of



Figure 1. Real-time ultrasound imaging of abdominal muscles during the abdominal hollowing. TrA: Transversus abdominis, IO: Internal abdominal oblique, EO: External abdominal oblique

muscles at the right-hand side of the subject while the subject was doing AH. The education and measurement of the experimental group and the control group were carried out by the same researchers.

3. Reliability testing

Inter-rater reliability was examined using interclass correlation coefficients (ICC). ICC was demonstrated for 3 repeat measurements of each muscle, whilst resting and AH state, and in both two groups in 9 sets of data. ICC of TrA, IO and EO were shown 0.98, 0.98 and 0.97 in the experimental group. ICC of TrA, IO and EO were shown 0.97, 0.98 and 0.97 in control group.

4. Data analysis

An independent t-test was conducted to compare the change in the thicknesses of abdominal muscles during AH between the experimental group and the control group. For statistical significance, the level of significance was set to $\alpha=0.05$ and the collected data were analyzed using the SPSS 12.0 for Windows.

III. Results

1. Characteristics of the subjects

The mean age, mean height, mean weight, and BMI of the experimental group were 22.5 ± 1.79 years, 174.88 ± 4.95 cm, 68.06 ± 7.42 kg, and 22.31 ± 2.68 kg/m², respectively. The mean age, mean height, mean weight, and BMI of the control group were 22.13 ± 3.81 years, 176.31 ± 6.05 cm, 69.19 ± 10.49 kg, and 22.16 ± 2.32 kg/m², respectively. There were no significant differences between the two groups.

2. Changes in the thicknesses between two groups

The thicknesses of TrA, IO, and EO of the control group during resting were 5.10 ± 0.75 , 8.67 ± 1.89 , and 5.78 ± 1.29 mm, respectively. The thicknesses of TrA, IO, and EO of the control group during AH exercise were 5.84 ± 0.84 , 9.81 ± 1.98 , and 6.76 ± 1.35 mm, respectively. The differences in the thicknesses of TrA, IO, and EO of the control group between resting and AH exercise were 0.75 ± 0.60 , 1.14 ± 0.88 , and 0.99 ± 0.42 mm, respectively. The thicknesses of TrA, IO, and EO of the experimental group during resting were 4.31 ± 0.78 , 8.03 ± 2.16 , and 5.60 ± 1.09 mm, respectively. The thicknesses of TrA, IO, and EO of the experimental group during AH exercise were 5.63 ± 1.10 , 9.10 ± 2.89 , and 6.01 ± 1.28 mm, respectively. The differences in the thicknesses of TrA, IO, and EO of the experimental group between resting and AH exercise were 1.32 ± 0.62 , 1.08 ± 1.07 , and 0.42 ± 0.54 mm, respectively. The differences in the thicknesses of the muscles between the two groups during AH exercise are shown in Table 1. The differences of the changes in the thicknesses of TrA and EO between the two groups were statistically significant.

IV. Discussion

Even though many domestic studies are being conducted using ultrasonography¹⁷ or ultrasound,^{18,19} there are few studies that use ultrasound imaging during spinal stabilization exercises. Hence, this study is intended to investigate the effects of visual feedback through real-time ultrasound imaging during AH which is a spinal stabilization exercise. For the experimental group of this study, the thicknesses of TrA, IO, and EO increased by approximately 30.6%, 13.3%, and 7.3%, respectively during AH exercise compared to resting. For the control group, the thicknesses of the same muscles increased by

Table 1. Change in muscle thicknesses between experimental group and control group during AH in four point kneeling

	Muscle thickness (mm)		Difference	p value
	Control group	Experiment group		
TrA	0.75 ± 0.60	1.32 ± 0.62	+0.57	0.01*
IO	1.14 ± 0.88	1.08 ± 1.07	-0.06	0.87
EO	0.99 ± 0.42	0.42 ± 0.54	-0.57	0.00*

*Significant difference ($p<0.05$)

AH: Abdominal hollowing

TrA: Transversus abdominis, IO: Internal abdominal oblique, EO: External abdominal oblique

approximately 14.5%, 13.1%, and 17%, respectively. Although the AH exercise stimulates the selective contraction of TrA which is a deep abdominal muscle,¹⁵ the subjects of the control group showed similar changes in thickness of TrA to those of other muscles, indicating that no separate contraction of TrA could be achieved. Furthermore, in the study examined thicknesses of abdominal muscles between resting and abdominal hollowing in four point kneeling by Critchley and Coutts²⁰ using ultrasound, the thicknesses of TrA, IO, and EO in control subjects during AH exercise increased by approximately 51%, 18%, and 17%, respectively compared to resting. Even though the change in the thickness of TrA increased considerably, the changes in the thicknesses of IO and EO were also high. This supported the findings of prior studies^{6,7} that the separate contraction of TrA is difficult during AH because the thicknesses of IO and EO also change considerably. For the experimental group of this study, however, the change in the thickness of TrA was higher and the change in the thickness of EO, in particular, was lower compared to the control group. The reason for this appears to be that the feedback through real-time ultrasound imaging improved the motor relearning of specific muscles by providing knowledge of performance.²¹ Knowledge of performance is information concerning the movement itself by real-time ultrasound imaging. This type of feedback is an effective method of motor relearning.

To compare the differences of the changes in the thicknesses of TrA between resting and AH exercise in two groups, the thicknesses of the experimental group increased by approximately 76% more than those of the control group, and this difference was statistically significant. The change in the thickness of IO of the experimental group was lower than the control group by approximately 5.4%, but this difference was not statistically significant. However, the change in the thickness of EO of the experimental group was lower than the control group by approximately 58%, and this difference was statistically significant. The result of IO is due to the activity of IO in maintaining a neutral pelvis and spine positions in four point kneeling. It could be seen that, IO maintained more constant activity than EO in four point kneeling.

The study examined the activities of the abdominal muscles during abdominal hollowing Park and Lee⁷ using EMG reported that only 8.3% of the subjects showed the selective contraction

of muscles from EO to TrA in four point kneeling, indicating the difficulty of the selective contraction of TrA. For the experimental group of this study, however, 75% of the subjects (12/16) induced the separate contraction of TrA while reducing the thickness of EO. The real-time ultrasound feedback applied to the experimental group appears to have given great assistance to the accuracy of the AH exercise by increasing the activity of TrA while reducing the activity of EO. The study examined differences among the 3 feedback groups by Henry and Westervelt¹² using ultrasound also found that the number of trainings for AH exercise decreased in the group to which real-time ultrasound feedback was applied compared to a different feedback group. Another prior study¹³ also reported that the motor learning of the group to which real-time ultrasound feedback was given improved compared to another group to which only the knowledge of result was applied. These results show the advantage of real-time ultrasound feedback which can simultaneously provide visual feedback²² and precise feedback²³ which can improve skill acquisition. Furthermore, these results also support the findings of prior studies^{12,21} which recommended real-time ultrasound feedback during AH training.

Another study²⁴ on the effects of real-time ultrasound feedback for patients with low back pain reported positive results. This study investigated the recurrence of low back pain between the experimental group who performed the contraction exercise of MF muscle and the control group who received general medical care using real-time ultrasound feedback for 4 weeks. The recurrence rate of low back pain after 1 year was approximately 30% for the experimental group, but it was approximately 84% for the control group. After 2-3 years, it was 35% for the experimental group and 75% for the control group. While many such studies found positive results after applying real-time ultrasound feedback, Teyhen et al²⁵ reported that no improvement in motor learning was observed. As shown by this example, different opinions exist because research on the effects of real-time ultrasound feedback is still insufficient. Thus, we hope that more active studies on real-time ultrasound feedback will be conducted.

This study demonstrated that use of real-time ultrasound imaging feedback while teaching AH to subjects without LBP was a beneficial teaching tool. To aid innate difficulties in learning and teaching, we suggest the use of real-time ultrasound

imaging feedback to achieve correct AH exercise in clinical field. However, this study didn't demonstrate that real-time ultrasound imaging feedback was effective for LBP subjects during AH. Thus, further studies to examine the effects of real-time ultrasound imaging feedback in subjects with LBP during AH will be necessary.

V. Conclusion

This study compared the changes in the thicknesses of abdominal muscles during AH exercise in the four point kneeling position between the experimental group, to which real-time ultrasound feedback was applied, and the control group who only received general training. The experiment group experienced a higher increase in the thickness of TrA than the control group while the thickness of IO and EO of the experiment group decreased. Therefore, real-time ultrasound feedback was effective for the selective contraction of TrA while reducing the activities of IO and EO during the AH exercise. More in-depth research on the effects of real-time ultrasound feedback on various postures and exercises is needed.

Author Contributions

Research design: Park DJ

Acquisition of data: Park DJ

Analysis and interpretation of data: Park DJ

Drafting of the manuscript: Park DJ

Research supervision: Park DJ

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