Abstract. [Purpose] This study examined the activities of the rectus abdominis (RA), external abdominal oblique (EO), transversus abdominis and internal abdominal oblique (TrA/IO) while abdominal hollowing (AH) was performed in four different positions (crook lying, prone lying, four-point kneeling, wall support standing). [Subjects] Experiments were conducted on 36 healthy male adults (mean age=24.44 years) who voluntarily agreed to participate in the experiments. [Methods] Each subject was instructed regarding maximal voluntary contractions (MVC) and AH. While the MVC and AH of individual muscles were being performed, the activity of the muscles was measured using surface electromyography (EMG). The activity of the muscles while performing AH was normalized to percentages of MVC. [Results] TrA/IO showed significant differences among the positions and showed the highest muscle activity for prone lying. [Conclusion] The contraction of the TrA/IO was shown to be the highest muscle activity in prone lying. Therefore, we consider that various kinds of technique can eliminate EO activity during performing AH in prone lying.

Key words: Abdominal muscles, Abdominal hollowing, Four different positions

INTRODUCTION

Abdominal exercises have been widely used as a way of relieving lower back pain (LBP). This approach originated from the finding that strong abdominal muscles contribute greatly towards spinal stability\(^1\). Spinal stability can be achieved by task and posture specific muscle recruitment patterns together with the co-activation of abdominal muscles\(^2,3\). Studies of abdominal muscles, have paid great attention to the function of the deep-lying transverse abdominis (TrA)\(^4,5\). This attention is based on the fact that the activation of the TrA contributes substantially to spinal stability\(^6,7\). The TrA can be activated first, before any fast movements of the extremities occur, and regardless of the direction of movement of the extremities. It can thereby contribute to spinal stability continuously\(^8\). In addition, it increases the tone of the thoracolumbar fascia, further enhancing spinal stability\(^9\). It also enhances intra-abdominal pressure, thereby making a further contribution to spinal stability\(^10\). Based on these findings, Abdominal Hollowing (AH), as a means of improving the functions of TrA, has been presented as a treatment for LBP\(^11,12\). Subsequently, it has been reported that AH reduces pain and disability\(^13\) and the recurrence of LBP in patients suffering from LBP\(^12\). Other studies have also reported that AH was effective as a treatment for LBP\(^14,15\).
The initial stage of treatment for LBP involves training the patient to perform AH in a position that promotes the co-activation of the deep abdominal and back muscles so that the deep-lying TrA can contract effectively. To be effective, the activity of the TrA needs to happen independently from the rectus abdominis (RA) and external abdominal oblique (EO) which are superficial muscles\textsuperscript{12). If} the patient has adequately learnt AH, he/she can perform it in diverse positions. Clinicians have recommended crook lying\textsuperscript{16), prone lying\textsuperscript{11,16), four-point kneeling\textsuperscript{11,16,17) and wall support standing\textsuperscript{17) as positions for this AH. However, studies that have compared and analyzed the activation of TrA, while the patient performed AH in each of these positions, are inadequate. There have been only two studies that have compared the activation of the TrA in the four different positions, while performing AH\textsuperscript{18,19). Therefore, this study analyzed which of the four different positions most effectively induces the activation of the TrA, when a subject performs AH.

**SUBJECTS AND METHODS**

This study was conducted on 36 healthy male adults who listened to explanations about the purpose and method of the study, and then voluntarily agreed to participate in the experiment. Those who had experienced pain while exercising, those who had had operations and those who had rheumatism or any neurologic disorder, were excluded from the experiment. The FlexComp Infiniti\textsuperscript{TM} (Thought Technology Ltd., Canada) electromyograph (EMG), consisting of three poles (Recording, Ground, Reference), was used to measure the muscle activities of RA, EO, and the transversus abdominis/internal abdominal oblique (TrA/IO). In order to reduce skin resistance to the EMG signals, excessive hairs were removed from the skin, the corneum was removed by rubbing the skin with a piece of sandpaper, and the skin was cleaned with disinfectant alcohol. Surface electrodes were attached to muscle fibers in a line as follows: In the case of the RA, a surface electrode was attached to the area 1 cm lateral from and 2 cm below the umbilicus\textsuperscript{20). In the case of the TrA/IO, a surface electrode was attached to the area 2 cm medial from and 2 cm below the anterior superior iliac spine (ASIS), and parallel with it\textsuperscript{21). In the case of the EO, a surface electrode was attached along the line connecting the opposite pubic tuberoue and the most inferior costal margin on the inferior margin in a diagonal direction\textsuperscript{20}. EMG data were bandpass filtered between 50 Hz and 1 kHz. The sampling rate for the signals was set to 2,048 Hz. Collected data were analyzed after calculating RMS (Root Mean Square) values. In order to normalize the activity potentials of the individual muscles, their maximal voluntary contractions (MVC) were measured against manual resistance. The movements that could maximally activate individual muscles were determined to be trunk flexions for the RA, trunk rotations to the ipsilateral side for the TrA/IO and trunk rotation to the contralateral side for the EO. The RA, TrA/IO and the EO were measured once against manual resistance and then in a sitting position\textsuperscript{22). The maximal reading from either sitting or crook lying, whichever was the greatest, was used for each subject. When measuring MVC, each contraction was maintained for 5 seconds, followed by a rest of 2 minutes, in order to prevent muscle fatigue\textsuperscript{23). After measuring the MVC of each subject, one of the four different positions was randomly selected for the experiment. Before the experiment, each subject was trained regarding the method of exercise as follows: All the subjects were instructed not to move their spine, ribs or pelvis, and to slowly draw the umbilicus inward while pulling upward\textsuperscript{11,16,24). After the umbilicus was drawn in, as though to reach the spine, the subjects were instructed to maintain the abdominal contraction for 10 seconds. The exercise was performed three times in each position. To minimize muscle fatigue that might occur with continual exercise, the subjects were allowed to take a rest for 2 minutes after each session. The four different positions are as follows: Position 1 was crook lying with knee flexion of 90\textsuperscript{025). Position 2 was prone lying with the ankles supported by a towel, or a cushion, laid underneath the ankles\textsuperscript{15). Position 3 was four-point kneeling with the line of sight directed at the floor, while the ears and shoulders of the subject were positioned horizontally to each other with the wrist directly below the shoulder and the knee below the hip\textsuperscript{17). Position 4 was wall support standing, with the distance between the wall and the heel of the subject maintained at 15 cm\textsuperscript{24). To provide reference positions for the subjects and measuring devices, markings were made on the floor and the subjects were told to keep their hands and feet on
the designated positions. Each exercise was performed for 10 seconds and the magnitude of the signal from the muscles was measured for 4 seconds, omitting the first 3 seconds and the last 3 seconds.

In this study, one-way ANOVA was used to compare the differences in the activities of the different muscles in the four different positions. Tukey’s multiple comparisons and analyses were conducted as post hoc tests. To test statistical significance, the collected data was analyzed using the SPSS 12.0 for Windows program using a significance level of $\alpha = 0.05$.

**RESULTS**

The average age of the study subjects was 24.44 ± 2.98 years. Their average height was 174.05 ± 6.26 cm and their average weight was 67.72 ± 7.79 kg. The muscles activities of the individual muscles in the four different positions are listed in Table 1. The activity of RA was highest in prone lying, 6.2%, followed by crook lying with knee flexion of 90°, four-point kneeling and wall support standing. No significant differences were found among the different positions. The activity of the EO was highest in four-point kneeling, 13.2%, followed by prone lying, crook lying with knee flexion of 90°, and wall support standing, with no significant differences among the different positions. The activity of the TrA/IO was highest in prone lying, 15.18%, followed by wall support standing, four-point kneeling and crook lying with knee flexion of 90°. A significant difference in TrA/IO between prone lying and crook lying with knee flexion of 90° was found.

**DISCUSSION**

TrA/IO showed higher activity in prone lying than in four-point kneeling. This was consistent with the results reported by Beith et al. that muscle activity was a higher in prone lying (34.7%) than in four-point kneeling (18.5%). Richardson and Jull reported that a muscle force of 25% MVC of local muscle is required to enhance spinal stability. In the present study, the activity of TrA in prone lying was approximately 15%, below the 25% MVC which is reportedly required. However, in the study of Beith et al., the activity of the TrA was found to be approximately 35% MVC, showing greater activity 25% MVC. In addition, the values recorded in our study were less than those reported by Beith et al. In our study the values which 2 positions were approximately 3.18%. The results of Beith et al. were approximately 12.6% higher than those of our study. We consider that these differences resulted from differences in the periods of time taken to train participants in AH, and in the overall intensity of the training.

The findings that the activity of the TrA/IO was higher in prone lying than in crook lying with knee flexion of 90°, were consistent with the results of Chanthapetch et al. However, Urquhart et al. reported a contrary result, indicating that higher contraction of TrA was shown in crook lying with knee flexion of 90° than in prone lying. It is possible that the different results reflect differences in the definition of prone lying. In Urquhart’s study two small boxes were laid on the xiphisternum and pubic symphysis, and the subjects were prostrate so that their abdomens would not come into contact with the boxes. This could be the cause of the contradictory results, because their arrangement would reduce the support plane provided, such that muscles would not be adequately relaxed, and accordingly higher levels of activity would not have been induced.

Chanthapetch et al. reported that in crook lying with knee flexion of 90°, and in prone lying, there
was sufficient support for posture muscles to be relaxed, thus permitting higher activity of TrA/IO resulting in higher levels of TrA/IO contraction in these positions\textsuperscript{18}. However, in the present study, a contrary result was shown because the second highest contraction of TrA/IO was shown in wall support standing. Based on the results of a study by Hodges et al.\textsuperscript{27}, it is possible that when wall support standing is maintained, a little more movement of the extremities is permissible, compared to other positions, thus generally higher levels of activity of the TrA/IO are shown.

Approximately 8.3\% of subjects (3/36) were able to isolate the activity of TrA/IO from EO in four-point kneeling. This result is much lower than that reported in the study by Beith et al.\textsuperscript{22} in which 60\% of subjects (12/20) were able to isolate the activity of IO from EO in four-point kneeling\textsuperscript{22}. The results of that study suggest that elimination of activity in EO was achieved more easily in four-point kneeling than in prone lying (25\%). However, the activity of EO was shown to be the highest in four-point kneeling in the present study. Although normal exercise methods differ from the method used in this study, on reviewing studies in which four-point kneeling was used\textsuperscript{28,29}, it could be seen that, in four-point kneeling, the activities of the oblique muscles were more constant than in other positions, regardless of the form and intensity of the exercises. This is due to the effort of the oblique muscles in maintaining a neutral pelvis and spine posture in four-point kneeling. It is possible that the reason the activities of EO and TrA/IO were shown to be similar in four-point kneeling, was that the oblique muscles were contracted in order to maintain a neutral pelvis and spine posture.

In Urquhart’s study, the highest separate contraction of TrA was shown in crook lying with knee flexion of 90°\textsuperscript{26}. In the present study, a result consistent with this previous study was obtained. Approximately 30.6\% of subjects (11/36) were able to isolate the activity of TrA/IO from EO in crook lying with knee flexion of 90°. In crook lying with knee flexion of 90°, the highest separate contraction of TrA/IO from EO was shown. However, the amount activities of EO and TrA/IO did not show any significant difference, showing a difference of approximately 0.31\%. We consider the reason for this is that both EO and TrA/IO are attached to the costal cartilage, thoracolumbar fascia, iliac crest and pubis and thus share the same attachment sites of bony fibers\textsuperscript{30}, meaning that they unavoidably work together. Accordingly, we consider our present results support those of studies indicating that eliminating the activity of EO while AH is being performed, is more difficult than eliminating the activity of the other abdominal muscles\textsuperscript{18,19,22}. In a preceding study only 25\%, or less, of participants could induce contraction of the TrA without contraction of EO\textsuperscript{18}, and in this study, out of the 36 subjects, only 8, or approximately 22\%, were able to contract the TrA/IO with the activities of RA and EO minimized to less than 5\%. This supports suggestions\textsuperscript{18,22,26} that for AH to manage back pain, independent training of the TrA contraction, while the activity of other abdominal muscles is minimized, is important. Although the contraction of TrA/IO was shown to be highest in prone lying, only 13.9\% of subjects (5/36) were able to isolate the activity of TrA/IO from EO. On the other hand, the contraction of TrA/IO was shown to be lowest with the highest separate contraction of TrA/IO (30.6\%) from EO in crook lying with knee flexion of 90°. To aid innate difficulties in learning and teaching AH, previous studies have suggested the use of real-time ultrasound imaging to help achieve isolated activity in the deep abdominal muscle\textsuperscript{31,32}. One study also reported that the use of real-time ultrasound imaging while teaching AH to subjects without LBP was a beneficial teaching tool\textsuperscript{33}. Therefore, we consider that various kinds of technique can eliminate EO activity during performance of AH in prone lying. Further studies to examine the effects of spine stabilization exercises in various positions will be necessary to select the most effective positions for spinal stabilization exercises.

REFERENCES


