Electromyographic analysis of abdominal muscles during abdominal bracing and hollowing among six different positions

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Abstract

Abdominal bracing exercise is used to enhance all abdominal muscle activity. There are two methods of abdominal bracing—“activate the abdominal muscles without hollowing the lower abdomen” and “activate the abdominal muscles while inflating the lower abdomen”. Although the latter method is widely used in athletic fitness coaching, the electromyographic activities of the abdominal muscles in this method have not been measured yet. This study aimed to clarify the electromyographic activity of all abdominal muscles during abdominal bracing using the latter method of “activating the abdominal muscles while inflating the lower abdomen”. Thirteen healthy men (age: 22 ± 2 years) participated in this study. Transversus abdominis (TrA), internal oblique (IO), external oblique (EO), and rectus abdominis (RA) electromyography was recorded using an intramuscular fine wire and surface electrodes. The participants performed abdominal bracing and hollowing for 5 s (seconds) in six different positions. The electromyographic data during trials were calculated as a percentage of maximal voluntary isometric contraction (%MVIC). A two-way ANOVA was used to compare the %MVIC of each trunk muscle between abdominal bracing and hollowing among the six different positions. In TrA electromyography, there was no difference between abdominal bracing and hollowing. On the other hand, the activities during abdominal hollowing were significantly higher than those during abdominal bracing in IO and EO (p < 0.05). In RA, the activities during abdominal bracing were significantly higher than those during abdominal hollowing (p < 0.05). Abdominal bracing under the method of inflating the lower abdomen is not recommended for high activity of the IO and EO.

Keywords: abdominal muscles, electromyography, abdominal bracing, abdominal hollowing

Introduction

The activity of abdominal muscles is required to increase lumbar spine stability¹,². For example, all the abdominal muscles, the transversus abdominis (TrA), internal oblique (IO), external oblique (EO), and rectus abdominis (RA), show high activity during dynamic movement and when a large external force is applied on the body during sports. It has been suggested that enhanced activity of all the abdominal muscles contributes to performance improvement³,⁴ and lumbar spinal injury prevention⁵.

As an exercise to enhance the activity of all the abdominal muscles, abdominal bracing, advocated by McGill⁶, is used in athletic fitness programs⁷. It is reported that performing abdominal bracing increases spinal stiffness³,⁸ and muscle strength⁹. Tayashiki et al.⁹ indicated that the intervention of abdominal bracing for 8 weeks increased isometric trunk extension and hip extension strength and maximal lifting power. However, there are two methods of abdominal bracing: “activate the abdominal muscles maximally without hollowing the lower abdomen”⁴,¹¹ and “push out the waist (activate abdominal muscles while inflating the lower abdomen)”¹⁲. Koh et al. reported that the intervention of abdominal bracing by the method of “activating abdominal muscles while maximally inflating the lower abdomen” for six weeks increased the cross-sectional areas of the bilateral IO, EO, and RA¹². However, the plank and side plank exercises were also conducted in addition to the abdominal bracing in the study by Koh et al.¹², thus, it is questionable whether the abdominal bracing by this method contributed to the in-
crease in the cross-sectional areas of the IO, EO, and RA. The abdominal bracing of this method was used not only in the previous study,[2] but also has been used in athletic fitness coaching. The aim of this method is to induce high activity of all abdominal muscles due to eccentric contraction, and has the advantage that inflating the lower abdomen makes it easier to visually assess appropriate exercise execution. Although this method of abdominal bracing while inflating the lower abdomen is widely used in athletic fitness coaching, the electromyographic (EMG) activities of the abdominal muscles using this method have not been measured yet.

Another method to enhance the activity of all abdominal muscles is abdominal hollowing which “activates the abdominal muscles while maximally deflating the lower abdomen”. The previous study by Tayashiki et al.[10], which selected the method of “activating the abdominal muscles maximally without hollowing the lower abdomen” during abdominal bracing, indicated that the activity of the IO, EO, and RA was higher during abdominal bracing than abdominal hollowing. However, it is unclear whether abdominal bracing while inflating the lower abdomen shows higher activity of all abdominal muscles than abdominal hollowing. To examine this is important for establishing evidence for the method used in the previous study[2] and athletic fitness coaching.

Attention should be paid not only to a comparison of EMG activity between abdominal bracing and hollowing, but also to a comparison among the different positions. For example, high activity of all abdominal muscles in recumbent positions may be required in sports such as swimming. Additionally, abdominal bracing and hollowing are used not only in athletic fitness coaching, but also in exercise therapy for patients with low back pain. For patients with low back pain who are unable to stand and sit, it is necessary to determine whether performing abdominal bracing and hollowing in recumbent positions induces high activity in all abdominal muscles. Although abdominal bracing and hollowing exercises are performed in various positions such as standing, upright sitting, and recumbent positions, which positions show high activity in all abdominal muscles is unclear.

The purpose of this study was to clarify the EMG activity of the TrA, IO, EO, and RA during abdominal bracing by the method of “activating the abdominal muscles while inflating the lower abdomen” used in the previous study[2] and athletic fitness coaching. For this purpose, we compared the EMG activity of all the abdominal muscles between abdominal bracing and hollowing (activating the abdominal muscles while deflating the lower abdomen) among six different positions such as standing, upright sitting, and four recumbent positions.

Materials and Methods

Participants. Power analysis was performed to estimate the number of participants for the two-way analysis of variance (ANOVA) using the G*Power 3.1.9.2 (Heinrich-Heine Universität, Germany). The number of participants was estimated at eleven with alpha = 0.05, power = 0.95, and partial $\eta^2$ for effect size = 0.14. Thirteen healthy men (mean ± SD age, 22 ± 2 years; height, 173.7 ± 4.5 cm; weight, 71.3 ± 8.0 kg) participated in this study. We excluded participants who had experienced low back pain or lower limb injury within the last 5 years or had a history of spinal or lower limb surgery. All participants provided written informed consent. Furthermore, the experimental protocol followed the Helsinki Declaration and was approved by the Ethics Review Committee on Research with Human Subjects of Waseda University (approval number: 2017-281).

Electromyography. The EMG of the TrA was recorded using intramuscular fine wire electrodes, and those of the IO, EO, and RA were recorded using surface electrodes. All the muscles were measured using the participants’ dominant hand side, and the left-handed participant data were converted to the right side. The bipolar intramuscular fine wire electrodes (Unique Medical Co., Ltd., Tokyo, Japan) were fabricated from two 0.08-mm strands of urethane-coated stainless steel wire, wherein urethane was removed from the end. The fine wire was threaded into a 23 G (gauge) hypodermic needle (0.60 × 60 mm) with the tips bent back to form 4-mm hooks. The fine wire and needle were sterilized at 121°C for 20 min in an autoclave. The TrA electrodes were inserted midway between the rib cage and iliac crest[13,14] by an experienced orthopedic doctor via ultrasound imaging (SONIMAGE HS1 PRO, Konica Minolta Co., Ltd., Japan) (Fig. 1).

Before attachment of the surface electrodes, the skin was abraded with a skin abrasive and alcohol to reduce

![Fig. 1 Ultrasound images of hypodermic needle insertion to the transversus abdominis (TrA). EO: external oblique; IO: internal oblique; TrA: transversus abdominis.](image-url)
the skin impedance to <2 kΩ. Surface electrodes (Blue-Sensor N-00-S, METS Co., Japan) of 8-mm in diameter were attached to each trunk muscle, parallel to the muscle fiber: for the IO, 1 cm medial and downward to the anterior superior iliac spine\(^{15,16}\); for the EO, 15 cm lateral to the umbilicus\(^{14,17}\); and for the RA, 3 cm lateral to the umbilicus\(^{14,17}\). The distance between electrodes was 20 mm. A wireless EMG telemeter system (BioLog DL-5000, S&ME Co., Japan) with a 2000 Hz sampling rate was used to measure both the fine wire and surface EMGs.

**Experimental procedure.** Before the abdominal bracing and hollowing trials, maximal voluntary isometric contraction (MVIC) tests of each trunk muscle were recorded to normalize the EMG data. For the TrA, the participants performed abdominal bracing in the standing position where they showed high activity, whereas some did not show high activity during abdominal hollowing. For the IO, the participants performed trunk flexion and right rotation in the crook lying position and the hands in front of the chest. Manual resistance was applied at the shoulder in trunk extension and left rotation. For the EO, the participants performed in the same manner as the IO, but with trunk rotation to the opposite side. For the RA, the participants performed trunk flexion in the same position of the IO and EO with manual resistance applied to the anterior shoulder aspect in the trunk extension direction. The MVIC tests of each muscle were performed for 5 s. The resting time between each MVIC test was at least 1 min.

The participants performed the abdominal bracing and hollowing trials in six different positions as follows: standing, upright sitting on a 40 cm high chair (upright sitting), supine, prone, side lying while the measurement side was the upper side with both the upper limbs raised (side lying upper), and side lying while the measurement side was the lower side with both the upper limbs raised (side lying lower) (Fig. 2). The order of the trials was randomized. The participants were asked to keep the feet shoulder width apart during four positions except for side lying positions. For the abdominal bracing trial, the participants were instructed to “maximally inflate their lower abdomen and keeping the navel away from the spine” for 5 s (Fig. 3A). For the abdominal hollowing trial, the participants were instructed to “maximally deflate their lower abdomen and drawing the navel in toward the spine” for 5 s (Fig. 3B). During the trials, the participants were asked not to move the pelvis, lumbar spine, and rib under monitoring of the examiners. Participants practiced 3–5 times before recording each trial, with at least 1 min resting time between each trial.

**Data analysis.** The recorded data of EMG were analyzed using biomedical information software (BIMUTAS-Video, Kissei Comtec Co., Ltd., Japan). Raw EMG data were

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![Fig. 2](image_url)  
**Fig. 2** Six different positions during abdominal bracing and hollowing. (A): Standing position, (B): Upright sitting position on 40 cm high chair, (C): Supine position, (D): Prone position, (E): Side lying while the measurement side is the upper side with both the upper limbs raised, and (F): Side lying while the measurement side is the lower side with both the upper limbs raised.
band-pass filtered between 10 Hz and 950 Hz. The EMG data during abdominal bracing and hollowing trials for the middle 3 s were represented as the root mean square (RMS) amplitude. The RMS amplitude was normalized as a percentage (%MVIC) of the highest RMS amplitude obtained over 1 s during MVIC testing.

Statistical analysis. SPSS Statistics 25.0 (IBM Japan Co., Ltd., Japan) was used for all statistical analyses. The %MVIC of each trunk muscle was compared between the abdominal bracing and hollowing trials among six different positions using two-by-six two-way ANOVA. A Bonferroni correction was used for post-hoc tests. Partial $\eta^2$ was calculated to estimate the effect size for two-way ANOVA, with values of $\geq 0.01$ and $<0.06$, $\geq 0.06$ and $<0.14$, and $\geq 0.14$ indicating small, medium, and large effects, respectively.

Results

The EMG data (mean ± SD) of each trunk muscle during abdominal bracing and hollowing in six different positions are shown in Fig. 4. The TrA showed the highest activity during abdominal hollowing in the standing position (107.8 ± 72.0 %MVIC) (Fig. 4A). There were no significant interactions between the trials and positions ($F_{5, 144} = 0.032, P = 0.999, \text{partial } \eta^2 = 0.001$) and main effect for the trials ($F_{1, 144} = 1.699, P = 0.195, \text{partial } \eta^2 = 0.013$). However, there was a significant main effect for the positions ($F_{5, 144} = 2.736, P = 0.022, \text{partial } \eta^2 = 0.094$), indicating that the activities in the standing position were significantly higher than those in the prone and side lying upper positions ($P < 0.046$).

The IO showed the highest activity during abdominal hollowing in the prone position (182.9 ± 87.4 %MVIC) (Fig. 4B). There were no significant interactions between the trials and positions ($F_{5, 144} = 1.279, P = 0.276, \text{partial } \eta^2 = 0.044$) and main effect for the positions ($F_{5, 144} = 0.778, P = 0.567, \text{partial } \eta^2 = 0.027$). However, there was a significant main effect for the trials ($F_{1, 144} = 57.026, P < 0.001$).

Fig. 3 Abdominal appearance during (A) abdominal bracing and (B) abdominal hollowing trials. The participants were instructed to inflate or deflate their lower abdomen maximally for 5 s, respectively.

Fig. 4 Activities (mean ± SD) of the (A) transversus abdominis (TrA), (B) internal oblique (IO), (C) external oblique (EO) and (D) rectus abdominis (RA) during abdominal bracing and hollowing in six different positions. *: There was a significant difference in the prone and side lying upper positions ($p < 0.05$). †: There was a significant difference between abdominal bracing and hollowing ($p < 0.05$). %MVIC: percent of maximal voluntary isometric contraction.
< 0.001, partial $\eta^2$ = 0.289), indicating that the activities during abdominal hollowing were significantly higher than those during abdominal bracing (P < 0.001).

The EO showed the highest activity during abdominal hollowing in the prone position (53.7 ± 21.0 %MVIC) (Fig. 4C). There were no significant interactions between the trials and positions (F5, 144 = 0.473, P = 0.796, partial $\eta^2$ = 0.007) and main effect for the positions (F5, 144 = 1.031, P = 0.402, partial $\eta^2$ = 0.037). However, there was a significant main effect for the trials (F1, 144 = 11.126, P = 0.001, partial $\eta^2$ = 0.076), indicating that the activities during abdominal hollowing were significantly higher than those during abdominal bracing (P = 0.001).

The RA showed the highest activity during abdominal bracing in the prone position (21.0 ± 23.9 %MVIC) (Fig. 4D). There were no significant interactions between the trials and positions (F5, 144 = 0.473, P = 0.796, partial $\eta^2$ = 0.007) and main effect for the positions (F5, 144 = 1.346, P = 0.249, partial $\eta^2$ = 0.048). However, there was a significant main effect for the trials (F1, 144 = 7.612, P = 0.007, partial $\eta^2$ = 0.054), indicating that the activities during abdominal bracing were significantly higher than those during abdominal hollowing (P = 0.007).

Discussion

The purpose of this study was to clarify the TrA, IO, EO, and RA EMG activity during abdominal bracing under the instruction to “activate the abdominal muscles while inflating lower abdomen” used in athletic fitness coaching. There were significant differences in the IO, EO, and RA activity between the trials (large-, medium- and small-sized effect, respectively), and in the TrA activity among the various positions (medium-sized effect). As a new finding, abdominal bracing while inflating the lower abdomen showed lower IO and EO activity than abdominal hollowing.

During abdominal bracing, deep inhalation is performed to stabilize the lumbar spine by increased intra-abdominal pressure. As mentioned in the introduction, there are two instructions for abdominal bracing, namely: “activate the abdominal muscles maximally without hollowing the lower abdomen”6-11 and “push out the waist (inflating the lower abdomen)”12. Tayashiki et al. reported that abdominal bracing under instructions to “activate the abdominal muscles maximally without hollowing the lower abdomen” demonstrated higher IO, EO, and RA activity than abdominal hollowing10, and increased isometric trunk and hip extension strength, as well as maximal lifting power11. However, it is difficult to visually assess appropriate execution of the exercise under this method because the lower abdomen appearance does not change. Therefore, we focused on the method to “activate the abdominal muscles maximally while inflating the lower abdomen”, since it is easier to visually assess the appropriate execution of the exercise, and it is widely used in athletic fitness coaching. As a result, the IO and EO activity was lower during abdominal bracing under this method than abdominal hollowing. Although this method examines the IO and EO activity in eccentric contraction, originally, it is considered that eccentric contraction is not produced voluntarily, but when a large external force is applied to the body. Therefore, this method was unable to induce IO and EO eccentric contraction. Results in a previous study10 and this study indicate that the abdominal bracing method influences the IO and EO EMG activity. That is, for high IO and EO activity, we recommend abdominal bracing method that activates the abdominal muscles without inflating and deflating the lower abdomen which was verified in previous studies6-11.

TrA activity was higher in the standing position than the prone and side lying upper positions. A previous study by Meuw10, measuring the TrA thickness at rest and during abdominal hollowing using ultrasound imaging, reported that the TrA was thicker in the standing position than the crook lying position at rest and during abdominal hollowing. These results mean that the TrA is involved with postural adjustment in the standing position and can be strongly contracted in the same position. These results can be explained through the idea that the greater gravitational pull on the abdomen in the standing position caused greater feedback from the TrA muscle stretch receptors, correspondingly increasing motor-neuron pool excitability20, and increasing TrA activity. Unlike muscle thickness experimentation, although this study measured the EMG activity, it is reported that there was a positive correlation between muscle thickness and EMG activity in the TrA21. Considering the results of TrA thickness in the previous study10 and EMG activity of the TrA in this study, performing abdominal bracing and hollowing in the standing position is recommended for high TrA activity.

The RA showed higher activity during abdominal bracing than abdominal hollowing. As mentioned above, although the method of abdominal bracing differed between previous studies6,10,11,22 and this study, the RA activity level during abdominal bracing was similar. These findings indicate that, unlike the IO and EO, RA activity is not influenced by inflating the lower abdomen. Thus, similar to abdominal bracing, which activates the abdominal muscles without inflating and deflating the lower abdomen, abdominal bracing while inflating the lower abdomen is shown to be more suitable than abdominal hollowing for high RA activity.

There were no differences in the activity of the IO, EO, and RA among six different positions. The IO, EO, and RA are involved in producing a large torque for trunk movement rather than postural control, because they are located more in the surface layer of the trunk than the TrA. Therefore, it is presumed that the difference in the position during abdominal bracing and hollowing did not influence the activity of the IO, EO, and RA. From these results, it is recommended that athletes perform abdomi-
nal bracing and hollowing in a position that matches their playing characteristics (e.g. in recumbent positions for swimming), and patients with low back pain should perform them in a position that does not induce pain.

There were some limitations in this study. First, the abdominal girth was not adequately quantified despite the trials which inflate or deflate the lower abdomen. Although we confirmed the girth of the participants performing the trials at the outset, a change in abdominal girth may influence the EMG activity of the abdominal muscles (e.g. participants with larger changes in abdominal girth show greater EMG activity). Second, a change in intra-abdominal pressure during the trials was not measured. Similar to abdominal girth, a change in intra-abdominal pressure may also influence the EMG activity of the abdominal muscles. Third, abdominal hollowing in this study was performed maximally, rather than as an isolated activity of the TrA, to compare with the EMG activity of abdominal muscles during maximal abdominal bracing. The results of this study might differ from performing abdominal hollowing while aiming at isolated activity of the TrA. Finally, the EMG activity during abdominal bracing, that activates abdominal muscles without inflating and deflating the lower abdomen, which was adopted in previous studies, was not measured. Future study should compare the EMG activity of the abdominal muscles during abdominal bracing when “activating the abdominal muscles without inflating and deflating the lower abdomen”, which was adopted in previous studies, was not measured. Future study should compare the EMG activity of the abdominal muscles during abdominal bracing when “activating the abdominal muscles without inflating and deflating the lower abdomen”, which was adopted in previous studies, was not measured.

In conclusion, this study examined the TrA, IO, EO and RA EMG activity during abdominal bracing and hollowing among six different positions. TrA activity was higher in the standing position than in the prone and side lying upper positions. IO and EO activities were higher during abdominal hollowing than abdominal bracing. Moreover, the RA showed higher activity during abdominal bracing than abdominal hollowing. Abdominal bracing under the method of inflating the lower abdomen maximally is not recommended for high activity of the IO and EO.

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Conflict of Interests

All authors declare that they have no conflict of interests.

Author contributions

All authors conceptualized the study design and protocol, and determined the study institutions. Tomoki Oshikawa, Gen Adachi and Koji Kaneoka collected and assembled the data. Tomoki Oshikawa, Yu Okubo and Koji Kaneoka carried out the analysis and interpretation of data. Tomoki Oshikawa drafted the manuscript. All authors have critically reviewed, revised and approved the manuscript.

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