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Comparison of abdominal muscle activity with various verbal instructions and onset activity analysis during draw-in maneuver

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Draw-in is a promising intervention for regaining isolated control of the transverse abdominis (TrA). Exercises to stimulate isolated contractions are needed; however, the appropriate methods are unclear. The objectives of this study were to examine how the muscle activity and muscle activity ratio of abdominal muscles change with various verbal instructions and to determine the onset of the abdominal muscles during draw-in. The participants were 21 healthy men. TrA electromyography was performed using fine-wire electrodes, and the internal oblique (IO), external oblique (EO), and rectus abdominis (RA) were determined using surface electrodes. The participants performed seven abdominal exercises according to verbal instructions and isolated voluntary contraction of the TrA for more than 5 sec. The TrA showed higher activity in bracing. IO and EO activities were highest in bracing, whereas RA showed the highest activity in maximum bracing. TrA/IO and TrA/EO were not significantly different between conditions. The results of the onset activity analysis of the abdominal muscles during the draw-in maneuver showed that the TrA was significantly earlier than the other muscles. The activity ratios of TrA to IO and EO were highly individualized and did not differ according to the verbal instruction. Maximum draw-in showed more significant IO activity, and bracing showed co-contraction of the superficial and deep abdominal muscles. During draw-in, the TrA initiated the earliest activity among the abdominal muscles and then isolated activity for 1.1 sec.

Keywords: Electromyography, Abdominal muscles, Verbal instruction, Transverse abdominis

INTRODUCTION

Conservative therapy is widely used for treating chronic low back pain (LBP). A review of national guidelines for treating patients with chronic LBP recommends using nonsteroidal anti-inflammatory drugs and antidepressants, exercise therapy, and psychosocial interventions (Oliveira et al., 2018). Exercise therapy is particularly effective (Maher et al., 2017). Among the various types of exercise therapy, the training effectiveness of isolated voluntary contraction of transverse abdominis (TrA) (draw-in) has been reported in many cases (Tsao and Hodges, 2007, 2008). Patients with prolonged LBP experience a backward shift in the motor cortex of the TrA (Tsao and Hodges, 2008), and a randomized controlled trial of patients with recurrent LBP indicated that abdominal draw-in exercises, but not walking exercises, led to a forward shift in the TrA motor cortex (Tsao et al., 2010). Thus, draw-in exercises have been considered promising interventions to regain isolated control of the TrA.

Numerous fine-wire electromyography (EMG) experiments have shown that the TrA exhibits specific activity in response to various movements and instructions. TrA shows higher activity in the slow lower abdominal draw-in maneuver than in the waist in-

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flation maneuver or pelvic retroversion maneuver (Urquhart et al., 2005b). TrA is associated with pelvic floor muscles, and TrA activity increases with voluntary contraction of the pelvic floor muscles (Sapsford et al., 2001). TrA is more significantly associated with intra-abdominal pressure (IAP) than other trunk muscles (Cresswell et al., 1992). Furthermore, changing the instruction method alters the abdominal muscle activity pattern (Karst and Willett, 2004). Pelvic floor muscles are deep and difficult to palpate, and verbal instruction is crucial to achieving the desired muscle activity. The different instructions used to provide pelvic floor muscle contraction influences the activity pattern (Aljuraifani et al., 2019), and various verbal instructions have been verified (Ben Ami and Dar, 2018). Based on the above, it is conceivable that the degree of muscle activity and the muscle activity ratio of TrA may change, depending on the instructions given for the abdominal exercise. Furthermore, the actual isolated contraction time of the TrA can be calculated by measuring the timing of the onset of muscle activity during draw-in.

Draw-in is an effective exercise for patients with LBP; however, there are still many uncertainties. The TrA attaches to the lumbar spine via the thoracolumbar fascia and stabilizes the spine (Bogduk and Macintosh, 1984). It maintains trunk stability by initiating activity before limb movement (Hodges and Richardson, 1996). TrA in patients with LBP shows a delayed onset of muscle activity and can be relearned through the appropriate activation pattern by draw-in exercise (Tsao et al., 2010). A systematic review shows that these delays and improvements are the same for the TrA and all muscles in the body (Crow et al., 2011). Moreover, adverse effects of overcontraction of outer muscles, such as the internal oblique (IO) and external oblique (EO) muscles, have been reported. Compared to healthy control subjects, patients with LBP show increased activity of simultaneous contraction of global muscles (Radebold et al., 2000). A comparison of TrA and IO muscle thicknesses between healthy subjects and patients with LBP during a one-sided simulated weight-bearing task showed a significant increase in the IO muscle thickness in patients with LBP (Hides et al., 2009; Hyde et al., 2012). Conventional draw-in instruction involve palpating the medial inferior part of the anterior superior iliac spine (ASIS) and exhaling (Hides and Richardson, 2000). In recent years, it has been reported that the traditional method increases the IO activity, and the method of instruction needs to be reconsidered (Lee et al., 2018). Furthermore, no detailed reports examining the contraction patterns of abdominal muscles during isolated contraction of the TrA are available to the best of our knowledge. Therefore, the objectives of this study were to examine how the muscle activity and muscle activity ratio of the abdominal muscles change for various verbal instructions and determine the onset of the abdominal muscles during the draw-in maneuver.

We hypothesized that the degree of TrA muscle activity and the ratios of TrA to IO and EO muscle activity would change with different verbal instructions during abdominal exercise. Furthermore, we hypothesized that instruction of voluntarily isolated contraction of the TrA leads to the earlier activity of the TrA relative to the IO, EO, and rectus abdominis (RA).

MATERIALS AND METHODS

Design

This research was an experimental laboratory investigation. The participants in this study were briefed in advance, and only those who gave their consent signed the consent form and participated in the study. The experimental protocol complied with the Declaration of Helsinki and was approved by the Ethics Review Committee on Research Involving Human Subjects of our affiliation (approval number: 2021-211).

Participants

The participants were 21 healthy men (mean ± standard deviation age = 23 ± 3 years; height = 169.5 ± 5.0 cm; weight = 65.3 ± 7.7 kg). The inclusion criteria were the following: no back pain, no neurological findings, and no previous abdominal or spinal surgery before or during the study.

Electromyography

TrA EMG was performed using fine-wire electrodes, whereas the IO, EO, and RA were recorded using surface electrodes. All the muscles were measured on the participant's dominant side, and data obtained from left-handed participants were converted to the right side. Fine-wire electrodes (Unique Medical Corporation, Tokyo, Japan) were fabricated from two urethane-coated 0.08-mm stainless steel wires with the urethane removed from the ends. The wires were threaded through a 23 G hypodermic needle (0.60 mm × 60 mm), and the tip was folded back to form a 4-mm hook. The wire and needle were sterilized in an autoclave at 121°C for 20 min (Oshikawa et al., 2020).

The wire electrodes were inserted through the abdominal wall at the level of the umbilicus by an experienced orthopedic surgeon after the abdomen was visualized using an ultrasound imaging system (Sonimage HS1 PRO, Konica Minolta, Tokyo, Japan).

Other muscles were attached to 8-mm diameter surface electrodes (BlueSensor N-00-S, METS Corporation, Tokyo, Japan) parallel to the muscle fibers. The surface was degreased with alcohol before attachment to minimize skin resistance. The IO was 1 cm medial and inferior to the ASIS (Ng et al., 1998), EO was 15 cm lateral to the umbilicus (Okubo et al., 2010), and RA was 3 cm lateral to the umbilicus (Okubo et al., 2010). The distance between electrodes was 20 mm. A wireless electromyograph (BioLog DL-5000, S&ME Corporation, Tokyo, Japan) with a sampling rate of 2,000 Hz was used to measure the wire and surface electromyograms.

Experimental procedure

Before the experimental trial, a maximal voluntary contraction (MVIC) test was performed on each trunk muscle to normalize EMG data (Oshikawa et al., 2020). For the TrA, the participant performed abdominal bracing in the supine position. For IO, the participant laid in a crook-lying position with both hands in front of the chest, and the trunk was flexed and rotated to the right. For the EO, the participant rotated his trunk to the opposite side in the same posture as the IO. The RA performed trunk flexion in the same posture as the IO and EO, and manual resistance was applied to the anterior part of the shoulder in the trunk extension direction. The MVIC test of each muscle was performed for 5 sec.

Study 1

The participants performed the following seven abdominal exercises according to verbal instructions, all held for 5 sec while performing the trials with a metronome set at 60 beats/min. Each exercise was performed 3 times, and the order of the exercises was randomized. A draw-in lecture was given by examiner M or O for approximately 10–20 min while showing ultrasound images to the participants. While showing the ultrasound screen, the participants were instructed to contract the TrA selectively and maximize the sliding of the muscle-tendon junction area of the TrA. Breathing was not prescribed during exercise. The following seven exercises were performed. "Isolated TrA contraction was performed while depressing the lower abdomen (draw-in)," "The lower abdomen was maximally deflated, and the navel was drawn towards the spine (maximum draw-in) (Oshikawa et al., 2020)," "The area around the anus was tightened (tighten around the anus) (Glazener et al., 2011)," "The flow of urine was stopped (stop the flow of urine) (Goode et al., 2011)," "A lighted candle 1 m away was blown out for 10 s (blowout a candle)," "The abdomen was tightened without changing the abdominal circumference (bracing) (Tayashiki et al., 2016)" and "The lower abdomen was maximally inflated, and the abdomen was tightened (maximum bracing) (Oshikawa et al., 2020)."

Study 2

Each participant was instructed by examiner M or O for approximately 10–20 min while showing the images on the ultrasound imaging system. Each participant performed an isolated contraction of the TrA for 5 sec with a metronome that sounded once per second.

Data analysis

EMG data were analyzed using bioinformatic analysis software (Bimutas-Video, Kissei Comtec Corp., Nagano, Japan). Raw EMG data were filtered between 10 and 950 Hz, and muscle activity data for all trials were calculated using the root mean square (RMS) values.

Study 1

Three seconds out of the 5 sec for each trial were used as the analysis interval. For the "blow out a candle," the analysis interval was the middle 3 sec of a 10-sec period. The average of three trials was calculated for each exercise. The RMS value was divided by the MVIC obtained in 1 sec during the MVIC test and normalized as a percentage (%MVIC). TrA/IO and TrA/EO values were calculated from the obtained values (Edgerton et al., 1996).

Study 2

We performed an onset activity analysis of each muscle during isolated TrA contraction (draw-in) over a 5-sec period. The 5 sec period from 1 sec before to 4 sec after the exercise was used as the analysis interval. The zero in the onset analysis was 1 sec before the start of the exercise. The onset activity of each muscle during draw-in was defined using the integrated profile method (Allison, 2003).

Statistics

Statistical analyses were performed using IBM SPSS Statistics ver. 22.0 (IBM Co., Armonk, NY, USA). Normality and equal variances of the data were checked using Shapiro–Wilk and Levene tests. One-way analysis of variance (ANOVA) or Kruskal–Wallis test was used to compare the %MVIC values for each of the seven exercises for each muscle (TrA, IO, EO, and RA), depending on the distribution normality. TrA/IO and TrA/EO were calculated from the %MVIC values of each muscle in each test, and both were analyzed in the same manner. The Tukey method

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was used to perform the posttest of one-way ANOVA, and the Bonferroni correction was used for the posttest of the Kruskal–Wallis test. An alpha level of 0.05 was used for all statistical analyses. Partial η^2 was calculated as the effect size for one-way ANOVA, and Cohen *d* was calculated using the Mann–Whitney *U*-test after the Kruskal–Wallis test. Cohen *d* was expressed for the effect size of the comparison between exercise trials, with values ranging from 0.20 to 0.49, 0.50 to 0.79, and >0.80 for small, medium, and large trials, respectively. Partial η^2 was calculated to estimate the effect size for the one-way ANOVA, with ≥0.01 and <0.06, ≥0.06 and <0.14, and ≥0.14, indicating slight, medium, and significant effects, respectively.

RESULTS

The %MVIC values (median [interquartile range]), TrA/IO, and TrA/EO were compared for each muscle during each exercise session. TrA showed higher activity in bracing (42.21 [32.33–73.65]) and maximum bracing (37.21 [25.95–59.84]) than in the other conditions ($P<0.001$) (Fig. 1, Tables 1, 2). There were no significant differences among the other exercises. The IO and EO activities had the highest bracing values (51.7 [33.621–90.267]) and (18.78 [15.636–25.76], respectively), whereas RA showed the highest activity in the maximum bracing (9.86 [7.136–15.121]) (Fig. 1, Tables 1, 2). TrA/IO and TrA/EO were not significantly different between conditions (Fig. 2, Table 1).

The results of the onset activity analysis of the abdominal mus-

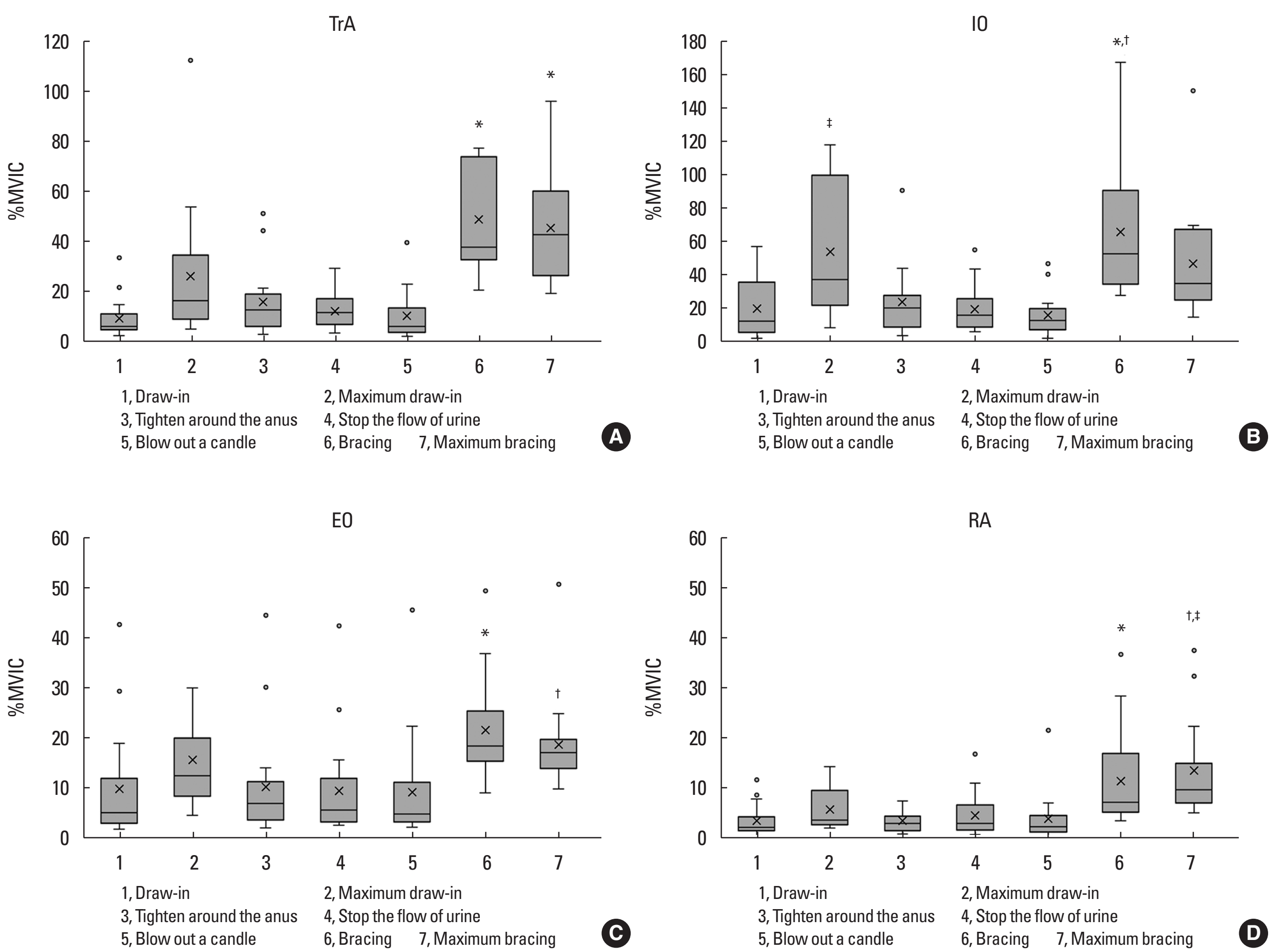

Fig. 1. Muscle activities of the transverse abdominis (TrA) (A), internal oblique (IO) (B), external oblique (EO) (C), and rectus abdominis (RA) (D) between exercise tasks. %MVIC, percent of maximal voluntary isometric contraction; ◦, outlier. *,†,‡ mean there is a significant difference in each trial, respectively. (A) * vs. 1, 2, 3, 4, 5; $P<0.001$. (B) * vs. 1, 4, 5; $P<0.001$, † vs. 3; $P=0.004$, ‡ vs. 5; $P=0.008$. (C) * vs. 1, 3, 4, 5; $P<0.001$, $P<0.006$, $P<0.002$, $P<0.001$, † vs. 5; $P=0.007$. (D) * vs. 1, 3, 5; $P<0.003$, $P<0.007$, $P<0.004$, † vs. 1, 3, 5; $P<0.001$, ‡ vs. 4; $P=0.002$.

Table 1. Comparison of electromyographic muscle activity (%MVIC) and between each task

Muscle	Draw-in	Maximum draw-in	Tighten around the anus	Stop the flow of urine	Blow out a candle	Bracing	Maximum bracing
TrA	5.40 (3.990–10.455)	15.74 (8.408– 34.023)	12.17 (5.550–18.325)	11.00 (6.250–16.623)	5.36 (2.918–12.748)	42.21 (32.33–73.65)	37.21 (25.950–59.84)
IO	9.50 (4.393–34.722)	36.35 (20.719– 99.431)	19.1 (7.711–26.915)	14.90 (7.678–25.017)	11.75 (6.100–18.875)	51.7 (33.621–90.267)	32.85 (24.268–66.605)
EO	5.32 (3.307–12.301)	12.73 (8.743– 20.274)	7.31 (3.974–11.589)	6.41 (3.557–12.296)	5.17 (3.562–11.43)	18.78 (15.636–25.76)	16.96 (14.221–20.008)
RA	2.22 (1.637–4.45)	3.81 (2.804– 9.743)	3.12 (1.635–4.588)	3.37 (1.828–6.857)	2.45 (1.333–4.646)	9.26 (5.294–17.029)	9.86 (7.136–15.121)
Ratio of TrA/IO	0.74 (0.190–1.600)	0.47 (0.185–1.101)	0.64 (0.293–1.459)	0.85 (0.348–1.255)	0.79 (0.329–1.139)	0.96 (0.702–1.391)	0.81 (0.369–1.219)
Ratio of TrA/EO	0.95 (0.725–1.469)	1.11 (0.771–3.143)	1.44 (0.628–2.557)	1.03 (0.775–2.926)	0.69 (0.47–2.138)	1.90 (1.593–3.009)	2.07 (1.547–3.322)

Values were median (interquartile range).
%MVIC, percent of maximal voluntary isometric contraction; TrA, transverse abdominis; IO, internal oblique; EO, external oblique; RA, rectus abdominis.

Table 2. Comparison results of electromyographic muscle activity (%MVIC) between each task

Trial	TrA		IO		EO		RA	
	Post hoc *P*-value	Cohen *d* (95% CI)	*Post hoc* *P*-value	Cohen's *d* (95% CI)	*Post hoc* *P*-value	Cohen's *d* (95% CI)	*Post hoc* *P*-value	Cohen's *d* (95% CI)
Draw-in vs. maximum draw-in	0.169	-0.856 (-1.546 to -0.123)	0.037	-1.107 (-1.821 to -0.337)	0.333	-0.53 (-0.531 to -1.222)	-	-0.600 (-1.292 to 0.123)
Draw-in vs. tighten around the anus	-	-0.581 (-1.253 to 0.118)	-	-0.209 (-0.888 to 0.481)	-	-0.04 (-0.039 to -0.721)	-	-0.011 (-0.693 to 0.672)
Draw-in vs. stop the flow of urine	-	-0.375 (-1.035 to 0.302)	-	0.007 (-0.667 to 0.680)	-	0.03 (0.034 to -0.641)	-	-0.281 (-0.951 to 0.402)
Draw-in vs. blow out a candle	-	-0.109 (-0.790 to 0.577)	-	0.250 (-0.452 to 0.939)	-	0.06 (0.060 to -0.634)	-	-0.099 (-0.789 to 0.597)
Draw-in vs. bracing	< 0.001	-2.116 (-2.843 to -1.304)	< 0.001	-1.018 (-1.627 to -0.376)	0.001	-1.08 (-0.833 to -1.631)	0.003	-1.399 (-2.229 to -0.476)
Draw-in vs. maximum bracing	< 0.001	-2.528 (-3.320 to -1.630)	0.038	-1.612 (-2.251 to -0.925)	0.012	-0.83 (-1.085 to -1.885)	< 0.001	-1.112 (-1.923 to -0.227)
Maximum draw-in vs. tighten around the anus	-	0.488 (-0.216 to 1.168)	0.271	0.959 (0.217 to 1.655)	0.893	0.50 (0.500 to -0.205)	-	0.629 (-0.085 to 1.312)
Maximum draw-in vs. stop the flow of urine	-	0.736 (0.024 to 1.413)	0.06	1.178 (0.423 to 1.877)	0.438	0.60 (0.600 to -0.101)	-	0.283 (-0.401 to 0.953)
Maximum draw-in vs. blow out a candle	0.225	0.777 (0.040 to 1.475)	0.008	1.287 (0.496 to 2.012)	0.232	0.60 (0.603 to -0.120)	-	0.391 (-0.318 to 1.080)
Maximum draw-in vs. bracing	0.177	-0.766 (-1.474 to -0.017)	-	0.188 (-0.522 to 0.889)	-	-0.58 (-0.305 to -1.005)	0.955	-1.057 (-1.779 to -0.280)
Maximum draw-in vs. maximum bracing	0.286	-0.933(-1.649 to -0.169)	-	-0.304 (-0.993 to 0.401)	-	-0.30 (-0.581 to -1.284)	0.15	-0.778 (-1.487 to -0.03)
Tighten around the anus vs. stop the flow of urine	-	0.353 (-0.323 to 1.013)	-	0.237 (-0.434 to 0.897)	-	0.08 (0.076 to -0.589)	-	-0.288 (-0.948 to 0.384)
Tighten around the anus vs. blow out a candle	-	0.458 (-0.244 to 1.138)	-	0.459 (-0.244 to 1.139)	-	0.10 (0.101 to -0.584)	-	-0.096 (-0.776 to 0.590)
Tighten around the anus vs. bracing	0.002	-1.573 (-2.323 to -0.744)	0.004	-0.842 (-1.544 to -0.098)	0.006	-1.07 (-0.808 to -1.508)	0.007	-1.435 (-2.173 to -0.625)
Tighten around the anus vs. maximum bracing	0.003	-1.881 (-2.660 to -1.006)	0.269	-1.436 (-2.162 to -0.639)	0.043	-0.81 (-1.066 to -1.778)	< 0.001	-1.140 (-1.857 to -0.365)
Stop the flow of urine vs. blow out a candle	-	0.209 (-0.471 to 0.880)	-	0.282 (-0.401 to 0.952)	-	0.03 (0.030 to -0.644)	-	0.138 (-0.539 to 0.809)
Stop the flow of urine vs. bracing	0.001	-2.437 (-3.271 to -1.484)	< 0.001	-1.097 (-1.802 to -0.338)	0.002	-1.19 (-0.927 to -1.623)	0.034	-1.241 (-1.955 to -0.466)
Stop the flow of urine vs. maximum bracing	< 0.001	-2.019 (-2.804 to -1.136)	0.062	-1.723 (-2.466 to -0.899)	0.016	-0.93 (-1.193 to -1.905)	0.002	-0.956 (-1.654 to -0.212)
Blow out a candle vs. bracing	< 0.001	-1.970 (-2.770 to -1.068)	< 0.001	-1.236 (-1.969 to -0.438)	0.001	-1.17 (-.914 to -1.628)	0.004	-1.250 (-1.985 to -0.451)
Blow out a candle vs. maximum bracing	< 0.001	-2.347 (-3.192 to -1.380)	0.009	-1.842 (-2.616 to -0.975)	0.007	-0.91 (-1.168 to -1.897)	< 0.001	-0.982 (-1.700 to -0.213)
Bracing vs. maximum bracing	-	0.147 (-0.573 to 0.860)	-	0.530 (-0.200 to 1.232)	-	0.29 (0.292 to -0.435)	-	-0.212 (-0.924 to 0.511)

%MVIC, percent of maximal voluntary isometric contraction; TrA, transverse abdominis; IO, internal oblique; EO, external oblique; RA, rectus abdominis.

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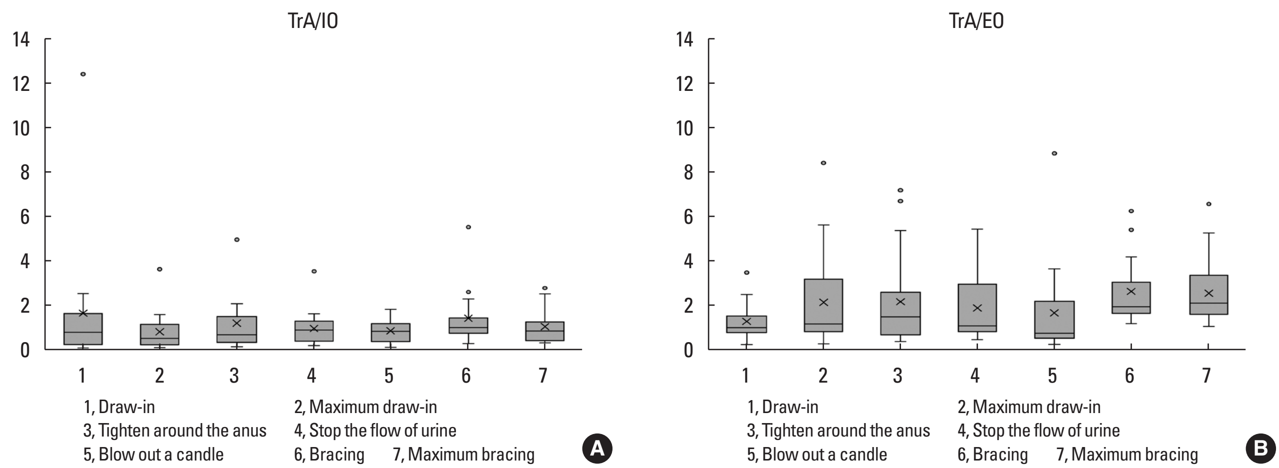

Fig. 2. Differences in TrA/IO (A) and TrA/EO (B) between each trial. There was no significant difference between trials for TrA/IO and TrA/EO, respectively. TrA, transverse abdominis; IO, internal oblique; EO. external oblique; %MVIC, percent of maximal voluntary isometric contraction; ∘, outlier.

Table 3. The onset time of activity for each muscle and difference in TrA activity onset time during draw-in maneuver

	TrA	IO	EO	RA
Onset time	2.28±0.91	3.40±0.61	3.68±0.93	3.60±1.10
Difference from TrA	-	1.14±1.33	1.43±1.45	1.34±1.72
Post hoc P-value[†]	-	0.017	<0.001	0.001

Values are presented as mean±standard deviation.
TrA, transverse abdominis; IO, internal oblique; EO, external oblique; RA, rectus abdominis.
[†]Versus TrA onset time.

cles during the draw-in maneuver are presented in Table 3. The onset time (mean±standard deviation) of each muscle activity was 2.283±0.912 sec for TrA, 3.398±0.612 sec for IO, 3.684±0.928 sec for EO, and 3.597±1.089 sec for RA. The TrA was significantly earlier than the other muscles ($F_{3,68}=7.771$, $P<0.001$, $\eta^2=0.26$).

DISCUSSION

The objectives of this study were to examine how the degree and ratio of muscle activity in the abdominal muscles changed with verbal instructions and clarify the contraction pattern of the abdominal muscles during draw-in. The results showed that the activity ratios of the abdominal muscles did not change with the verbal instructions. Five seconds into the draw-in, the TrA muscles became active first, followed by the IO, EO, and RA muscles approximately 1.1 sec later than the TrA.

The IO activity resulted in higher %MVIC values for bracing and maximum bracing with verbal instructions, and the IO values were equally high with maximum draw-in. Tayashiki et al. (2016) compared the muscle activities during abdominal bracing without abdominal indentation and hollowing with abdominal indentation, and they measured IAP simultaneously (Tayashiki et al., 2016). They reported that the muscle activity and IAP in IO, EO, and RA were higher with bracing than with hollowing. TrA and IO have been known to be associated with IAP. During trunk extension, the IAP is elevated with concomitant activity in the TrA and IO (Cresswell, 1993). They concluded that the TrA contributes to torsional torque and stabilization and plays the most critical role in IAP generation during isometric trunk loading (Cresswell et al., 1992). The bilateral activity of the TrA results in tension in the thoracolumbar fascia, contracting the diameter of the abdominal cavity and increasing IAP. The reason for the increased TrA and IO muscle activities during bracing in the experiment is possibly attributed to IAP. In maximum bracing, the abdominal circumference increased, and the TrA and IO were considered in the extended position. The force-length relationship (Gordon et al., 1966) shows that the muscle activity was higher in the extended position than in the relaxed position.

The TrA/IO and TrA/EO ratios did not differ between exercises. The TrA/IO and TrA/EO ratios were higher when the TrA was performed as an isolated contraction. Lee et al. (2018) used a surface electromyograph to measure muscle activities during draw-in to obtain the TrA-IO/EO was 2.28±0.93. This value increased significantly (3.08±0.92) after practicing the draw-in maneuver with real-time feedback using ultrasound images. Thus far, no studies have shown the results of TrA divided by IO. The results of this experiment were considered reasonable compared with the values reported in previous studies. However, the results of this study varied significantly. These significant individual differences may have been a reason for the lack of significant differences. Isometric contractions in all verbal instructions performed in this experiment may be unsuitable for isolated contractions of the TrA.

When draw-in was performed for 5 sec, TrA first initiated muscle activity, followed by IO, EO, and RA. The average difference in the onset of each muscle, which was considered the time of the actual TrA-isolated contraction, was approximately 1.1 sec. Whether the IO is an outer or inner muscle is debatable, as the presence of posterior IO fibers, which give rise to the term "inner muscle," varies significantly from person to person (Bogduk and Macintosh, 1984). Lower fibers of IO are e connected to EO (Urquhart et al., 2005a), and IO has a large physiological cross-sectional area (Brown et al., 2011) and an extended moment arm (Cholewicki and McGill, 1996). Thus, it is reasonable to classify IO as an "outer muscle." The TrA must contract independently of other muscle groups, and when performing draw-in, a short afferent contraction time may be desired rather than isometric contraction.

During the 5-sec draw-in, the TrA was the fastest to initiate activity among the lateral abdominal muscles. The isolated contraction of the TrA lasted only 1.1 sec. It is s thought that an isolated contraction of the TrA must be performed with very little force. In some cases, pelvic girdle pain occurs during active straight leg raising (Mens et al., 1999). We thought that TrA should act first rather than the IO or EO for creating a stable pelvic ring that contributes to stable lower limb elevation.

This study has several limitations. First, we inserted the middle fibers of the TrA, and different results may have been obtained for the lower and upper fibers. The function of TrA differs from fiber to fiber (Urquhart and Hodges, 2005). Second, only healthy adult males were recruited and small sample size. The female pelvic morphology and genital structure are different from those of males; thus, female muscle activity patterns may differ from those of males. Third, myofascial coupling between the TrA and IO might cause crosstalk (Brown and McGill, 2008).

In conclusion, the activity ratios of TrA to IO and EO were highly individualized and did not differ according to the verbal instruction. Among them, maximum draw-in showed more significant IO activity, and bracing showed a joint contraction of the superficial and deep abdominal muscles. During draw-in, the TrA initiated the earliest activity among the abdominal muscles and then isolated activity for 1.1 sec.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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