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Reliability of ultrasound in combination with surface electromyogram for evaluating the activity of abdominal muscles in individuals with and without low back pain

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This study investigated the reliability of ultrasound in combination with surface electromyogram (EMG) for evaluating the activity of the abdominal muscles in individuals with and without low back pain during the abdominal drawing-in maneuver (ADIM). The study recruited ten individuals with or without low back pain, respectively. While the participants were performing the ADIM, the activities of the transversus abdominis (TrA) and the internal oblique (IO) were measured using ultrasound, while the activities of the external oblique (EO) and the rectus abdominis (RA) were measured using surface EMG. Intra-class correlation coefficients (ICC) were used to verify the inter-rater reliability of ultrasound in combination with surface EMG at rest and during the ADIM, and Bland-Altman plots were used to verify intra-rater reliability. The inter-rater reliability for the two groups at rest and during the ADIM was excellent ($ICC_{2,1}$ = 0.77-0.95). In the Bland-Altman plots, the mean differences and 95% limits of agreement in the abdominal muscles of the two groups at rest were -0.03~0.03 mm (-0.66 to 0.60 mm) and -0.12~-0.05 (-0.58 to 0.48% MVIC), respectively. The mean differences and 95% limits of agreement in the abdominal muscles of the two groups during the ADIM were -0.04~0.02 mm (-0.73 to 0.65 mm) and -0.19~0.05% MVIC (-1.24 to 1.34% MVIC), respectively. The ultrasound in combination with surface EMG showed excellent inter-rater and intra-rater reliability at rest and during the ADIM.

Keywords: Ultrasound, Surface EMG, Reliability, Abdominal drawing-in maneuver

INTRODUCTION

The abdominal drawing-in maneuver (ADIM) is a lumbar stabilization exercise that is mainly performed in the early stage of management for patients with low back pain. This exercise can promote the activity of the transversus abdominis (TrA), which is a deep muscle, while minimizing the activity of the rectus abdominis (RA) and the external oblique (EO), which are located in the superficial layers. In particular, reinforcing the selective activity of the TrA is the most important element for patients with low back pain, as the ability of the TrA to adjust the shear force applied to the spinal segments is superior to the RA and the EO. Therefore, many researchers have made efforts to determine the effects of the ADIM (Chanthapetch et al., 2009; Chon et al., 2010; Hwang et al., 2014).

Some researchers used insertion EMG to analyse the activity of the TrA, which is located deeply, while the ADIM is performed (Bjerkefors et al., 2010). However, the use of insertion EMG has been restricted because of ethical problems, as it is an invasive method, and because of difficulties with repeated measurements. To compensate for such problems, Marshall and Murphy (2003) used cadaver studies to design a method for measuring the activity of the TrA using surface EMG. Although this method enabled the observation of TrA activity through surface EMG, the activity of the TrA and the IO could not be observed separately, as the electrode was attached to the area where the fascia of the TrA and the fascia of the IO overlap.

Ultrasonography is a non-invasive method that is preferred over

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other imaging methods, such as CT and MRI, because it is inexpensive, involves less exposure to ionizing radiation and can be conveniently used (Chhem and Kaplan, 1994; Hides et al., 1998). The ultrasonography can measure the changes in the thicknesses of the TrA, the IO and the EO during ADIM. However, the changes of thickness in abdominal muscles are limited to express as the activity of abdominal muscles. In the case of the TrA, changes in the activity and the thickness showed excellent correlations ($P < 0.001$, $R^2 = 0.87$) (McMeeken et al., 2004). Hodges et al. (2003) advised that changes in the thicknesses of the TrA and the IO could show muscle activity. However, in the case of the EO, changes in the activity and the thickness were not correlated with each other (Hodges et al., 2003; John and Beith, 2007). In the case of the RA, studies that investigated the correlation between changes in its thickness and activity are insufficient, and its thickness cannot be easily measured together with the thicknesses of other abdominal muscles.

To supplement such matters, ultrasound has recently been used to measure the activity of the TrA and the IO, which are located deeply, while surface EMG has been used to measure the activity of muscles located in superficial layers, such as the EO (Ishida et al., 2012). However, the studies on this new measuring method that uses both ultrasound and surface EMG are still insufficient. Therefore, this study investigates the reliability of ultrasound in combination with surface EMG in individuals with and without low back pain while the ADIM is performed.

MATERIALS AND METHODS

Participants

The study recruited ten individuals with and without low back pain, respectively (Table 1). They were provided with explanations about the purpose and process of the study, and they voluntarily agreed to participate in the study. With regard to those who had experienced chronic low back pain for at least the previous three months, only those without spinal deformations who had been diagnosed with non-specific low back pain by an expert were selected as participants for this study. With regard to selecting healthy participants for this study, only those who had not experienced low back pain in the previous six months, had no neurologic disease and had not received any surgical interventions were selected. For the consistency of the study, only right-handed participants were selected.

Table 1. Characteristics of study participants (n=20)

	LBP (n=10)	NLBP (n=10)
Gender	Male (5), Female (5)	Male (5), Female (5)
Age	32.00±3.40	30.20±3.68
Height	1.69±0.11	1.70±0.09
Weight	60.50±12.77	61.50±14.68
BMI	20.86±2.14	21.01±3.19
VAS (0-10)	3.7±1.64	None

LBP, low back pain; NLBP, no low back pain.

Observers

To verify inter-rater reliability, there were a total of three observers. Two of the observers were physical therapists who had experience using ultrasound and surface EMG. The other observer was selected from among the students at the Department of Physical Therapy and had no experience in related studies. This observer received education on the use of ultrasound and surface EMG for one week before participating in this experiment. In addition, intra-rater reliability was verified by the physical therapist, who was the primary observer (Fig. 1).

ADIM training

To ensure accurate performance of the ADIM, all the participants received 30 min of education using pressure biofeedback units (PBU). First, in a crook lying, a PBU pressurized to 40 mmHg was placed below the lumbar lordosis. In all cases, the pressure of the PBU was increased by 0-2 mmHg while the ADIM was performed by the participants (Park and Lee, 2013). This study was conducted only with participants who performed the ADIM successfully in a crook lying.

Maximal voluntary isometric contraction (MVIC)

MVIC was used to normalize the activity of various muscles. The MVICs of the RA and the EO were measured as follows. The

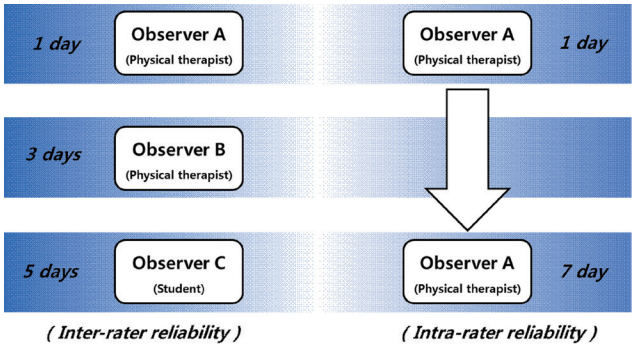

Fig. 1. How the reliability tests were performed.

MVIC of the RA was measured during maximal manual resistance while the participant was bending his/her trunk, with his two hands crossed in the form of an X on his chest, while in a crook lying. The MVIC of the EO was measured during maximal manual resistance while the participant was bending his trunk toward the opposite side knee while in a crook lying. The MVIC was repeated three times for five seconds each time, and the average value was obtained for a three-second period, excluding the first second and the last second. To prevent muscle fatigue, a two-minute rest was provided after each measurement.

Measurement equipment

A Sonoace X4 (Medison, Korea) was used to measure changes in the thickness of the TrA and the IO, and 7.5 MHz linear transducers were used. A surface EMG MP150WSW (BIOPAC System Inc., USA) was used to measure the activity of the EO and the RA. A sampling rate of 1,000 Hz and a band width of 20-450 Hz were set.

The placement of the transducers and electrodes

To attach surface electrodes, hair was removed where necessary or the skin was cleaned using disposable alcohol swabs. The transducers and surface electrodes (Ludlow Technical Products, Canada) were attached to the right side of all the participants (Fig. 2). The transducer was placed transversely on the right side of the body, with its center positioned at a point 25 mm anterior to the mid-axillary line at the midpoint between the inferior rib and the iliac crest (Mannion et al., 2008). The surface electrodes for the EO were attached along the line that connects the pubic tuberele on the opposite side and the bottom of the costal cartilage in the diagonal direction from the bottom corner of the costal cartilage (Chanthapetch et al., 2009; Ng et al., 1998). The surface electrode for the RA was attached at a point 1 cm lateral to and 2 cm below the navel (Ng et al., 1998).

Measurement methods

To control the effects of breathing, all data were collected at the end point of expiration. The thickness and activity of the abdominal muscles were first measured at rest and then measured while the ADIM was performed. All the participants performed two conditions three times each, and the average value of the three repetitions was used. To prevent muscle fatigue, the participants rested

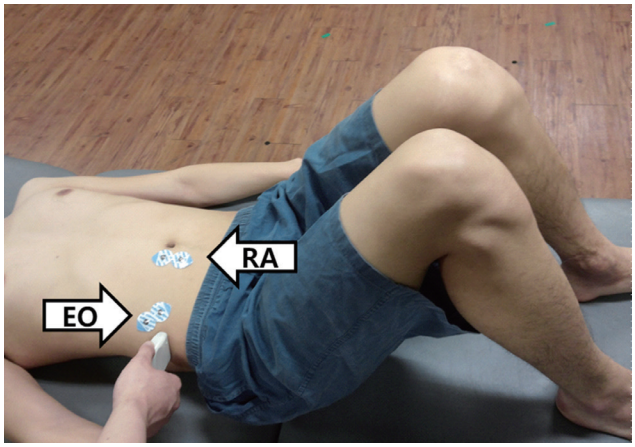

Fig. 2. The placement of the transducers and electrodes.

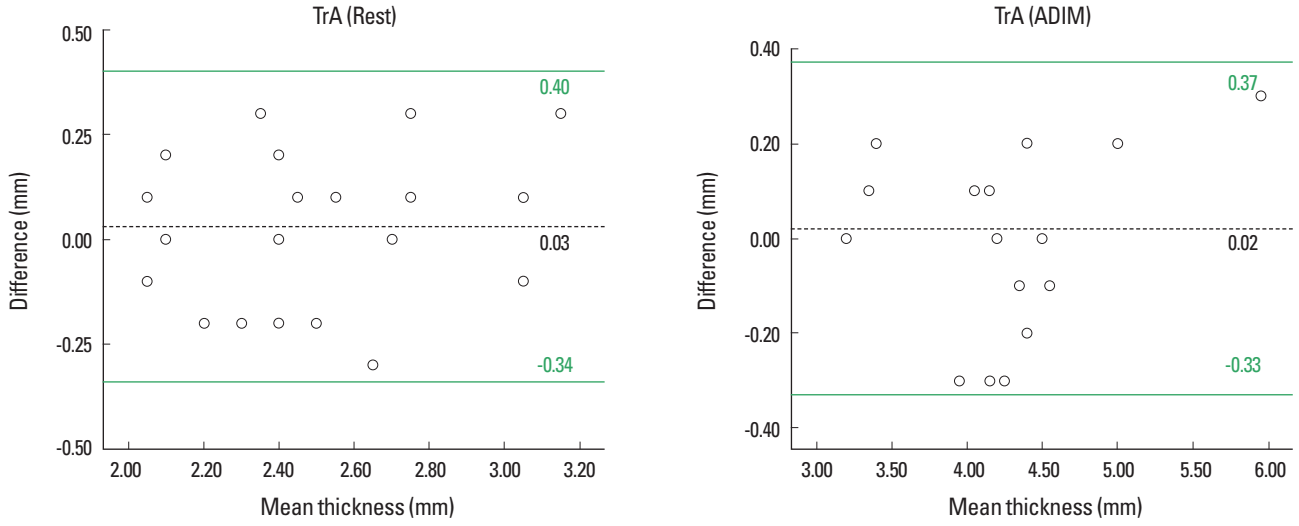

Fig. 3. Bland-Altman plot showing the intra-rater reliability of TrA measurement at rest and during ADIM in individuals with and without LBP. The dotted line shows the mean difference. The 95% upper and lower limits of agreement represent 1.96 standard deviations above and below the mean difference.

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for two minutes after each exercise.

The thickness of the TrA and the IO were measured at the middle point during ADIM for five seconds, while the activity of the EO and the RA were measured while the ADIM was performed for five seconds each (Fig. 3). Out of the five seconds of data, three seconds were used in the data analysis, as the first second and the last second were excluded.

Statistical analysis

Intra-class correlation coefficients (ICC) were used to verify the inter-rater reliability of the ultrasound in combination with the surface EMG at rest and while the ADIM was performed, and Bland-Altman plots were used to verify the intra-rater reliability.

RESULTS

ICCs (2,1) were used to verify inter-rater reliability. At rest, the ICCs of the TrA, the IO, the EO and the RA of individuals without low back pain were 0.91, 0.82, 0.84, and 0.77, respectively (Table 2). While the ADIM was being performed, the ICCs of the TrA, the IO, the EO and the RA of individuals without low back pain were 0.95, 0.80, 0.78, and 0.87, respectively (Table 2). At rest, the ICCs of the TrA, the IO, the EO and the RA of individuals with low back pain were 0.93, 0.91, 0.89, and 0.89, respectively. While the ADIM was being performed, the ICCs of the TrA, the IO, the EO and the RA of individuals with low back pain were 0.93, 0.83, 0.84, and 0.90, respectively.

Intra-rater reliability was verified using Bland-Altman plots. At rest, the mean differences and 95% limits of agreement in the TrA, the IO, the EO and the RA of all groups were 0.03 mm (-0.34 to 0.40 mm; Fig. 3), -0.03 mm (-0.66 to 0.60 mm; Fig. 4), -0.05% MVIC (-0.58 to 0.48% MVIC; Fig. 5) and -0.12% MVIC (-0.49 to 0.25% MVIC; Fig. 6), respectively. While the ADIM was being performed, the mean differences and 95% limits of agreement in the TrA, the IO, the EO and the RA of all groups were 0.02 mm (-0.33 to 0.37 mm; Fig. 3), -0.04 mm (-0.73 to 0.65 mm; Fig. 4), 0.05% MVIC (-1.24 to 1.34% MVIC; Fig. 5) and -0.19% MVIC (-0.93 to 0.55% MVIC; Fig. 6), respectively.

DISCUSSION

In this study, the inter-rater reliability for the measurement of the TrA and IO activity in the two groups at rest and during the ADIM showed excellent results, with values in the range of 0.80-

Table 2. Inter-rater reliability of measurements of abdominal muscles in individuals with and without LBP

		LBP (n=10)		NLBP (n=10)	
		$ICC_{2,1}$ (95% CI)	SEM	$ICC_{2,1}$ (95% CI)	SEM
TrA	Rest	0.93 (0.79-0.98)	0.09 (mm)	0.91 (0.76-0.97)	0.13 (mm)
	ADIM	0.93 (0.80-0.98)	0.18 (mm)	0.95 (0.86-0.99)	0.19 (mm)
IO	Rest	0.91 (0.76-0.97)	0.23 (mm)	0.82 (0.59-0.95)	0.16 (mm)
	ADIM	0.83 (0.59-0.95)	0.21 (mm)	0.80 (0.54-0.94)	0.15 (mm)
EO	Rest	0.89 (0.73-0.97)	0.36 (%MVIC)	0.84 (0.61-0.95)	0.30 (%MVIC)
	ADIM	0.84 (0.61-0.95)	0.36 (%MVIC)	0.78 (0.49-0.93)	0.48 (%MVIC)
RA	Rest	0.89 (0.72-0.97)	0.21 (%MVIC)	0.77 (0.49-0.93)	0.19 (%MVIC)
	ADIM	0.90 (0.75-0.97)	0.27 (%MVIC)	0.87 (0.68-0.96)	0.31 (%MVIC)

LBP, low back pain; NLBP, no low back pain; ADIM, abdominal drawing-in maneuver; CI, confidence interval; SEM, standard error of measurement.

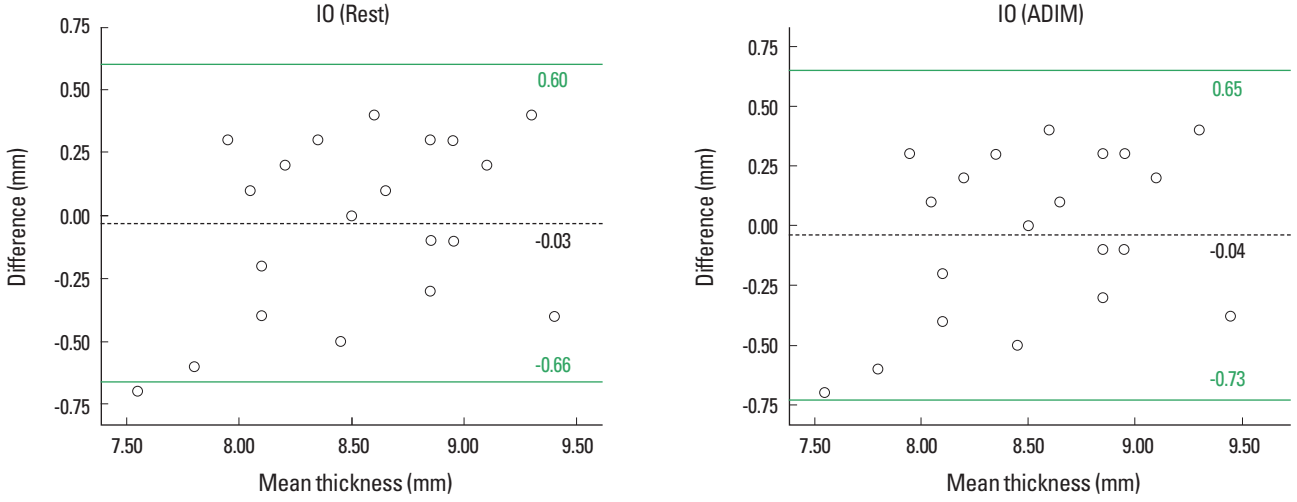

Fig. 4. Bland-Altman plot showing the intra-rater reliability of IO measurement at rest and during ADIM in individuals with and without LBP.

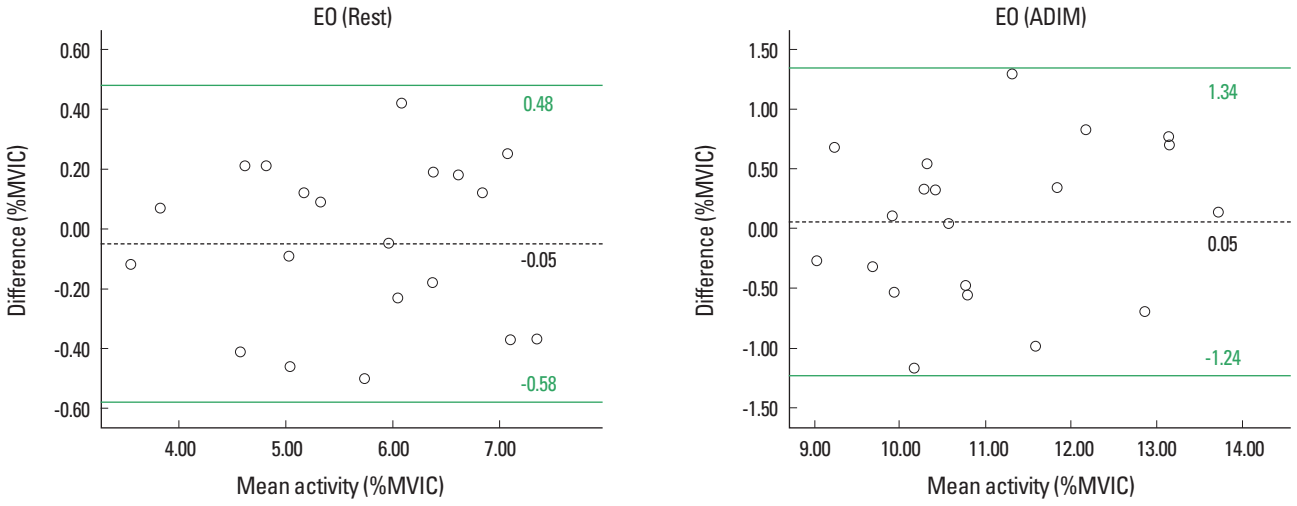

Fig. 5. Bland-Altman plot showing the intra-rater reliability of EO measurement at rest and during ADIM in individuals with and without LBP.

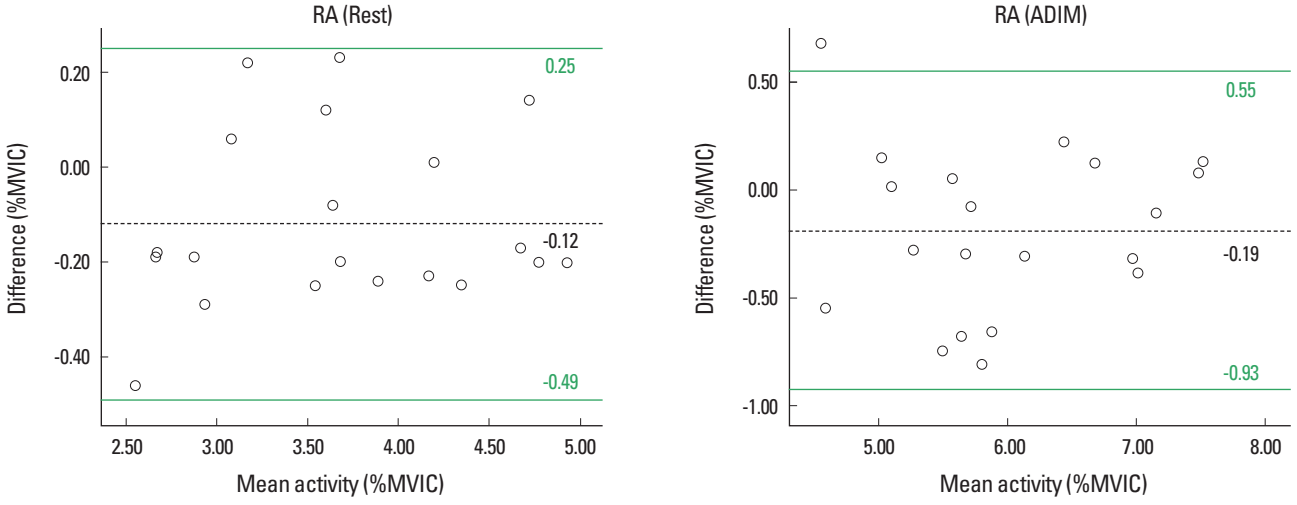

Fig. 6. Bland-Altman plot showing the intra-rater reliability of RA measurement at rest and during ADIM in individuals with and without LBP.

0.95. This supports the results of previous studies (Chon et al., 2010; Costa et al., 2009), which showed excellent reliability in measuring the thickness of the TrA and the IO while tasks were performed by individuals with low back pain or without low back pain, that used ICC (2,1) models similar to the one used in this study. Furthermore, the activity of the EO and the RA measured using surface EMG also showed excellent reliability, which was in the range of 0.77-0.90. These results can be grounds for the wide use of ultrasound in combination with surface EMG, not only in studies but also in clinical evaluation.

Inter-rater reliability was verified using Bland-Altman plots. In this study, the activity of the TrA and the EO of all participants at rest and during contraction were included in the 95% limits of agreement. This shows excellent reliability. In addition, in the case of the activity of the IO and the RA, only one participant was out of the 95% limits of agreement at rest and during contraction. When these results are considered together, ultrasound imaging in combination with surface EMG shows excellent intra-rater reliability.

Recently, Lima et al. (2012) wanted to use insertion EMG to observe TrA activity, but they used surface EMG because insertion EMG was not approved by the research ethics committee. There are ethical problems with the use of insertion EMG due to the pain or inflammation resulting from the invasive method. As a result of the emphasis on the rights of study participants, the use of insertion EMG has gradually decreased. The use of ultrasound as

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an alternative for insertion EMG has problems, such as the limitation in the measurement of the thickness of the EO and the difficulties with regard to the simultaneous measurement of the RA.

One method that can solve these problems is thought to be the use of both ultrasound and surface EMG. Although this method has been explored in recent studies (Ishida et al., 2012), the reliability of the method has not been verified. Based on the results of this study, the use of both ultrasound and surface EMG showed excellent inter-rater and intra-rater reliability for measuring the activity of abdominal muscles while the ADIM was performed. This indicates that this measuring method has excellent reliability based on ethical consideration about study participants using non-invasive tools. Later, the reliability of applying the measuring method during the performance of diverse tasks should be verified. In addition, the authors hope that this measuring method will be widely used in clinical studies.

CONFLICT OF INTEREST

There are no potential conflicts of interest relevant to this article.

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