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Reliability and validity of a personal computer based muscle viewer for measuring upper trapezius and transverses abdominis muscle thickness

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Objective: This study aimed to investigate the reliability and validity of a personal computer-based muscle viewer (PC-BMW) compared with that of a portable ultrasound (P-US) for measuring upper trapezius (UT) and transversus abdominis (TrA) muscle thickness at rest and during contraction.
Design: Observational inter-rater reliability study.
Methods: Fifty-five healthy participants (25 men, 30 women) participated in this study. PC-BMW and P-US were randomly measured at the UT and TrA muscles. Two examiners randomly obtained the images of all participants in 3 test sessions lasting 2 days. Intra-class correlation coefficients (ICCs), standard error of measurement, contraction ratio, and correlation were used to estimate reliability and validity. Pearson's correlation coefficients were used to analyze the relationship between muscle thickness measures taken from PC-BMW and P-US.
Results: The intra-rater reliability ICCs of UT and TrA muscle thickness for the PC-BMW were >0.995, indicating excellent reliability. Inter-rater reliability ICCs for the PC-BMW ranged from 0.963 to 0.987. The P-US also exhibited high reliability. A high correlation was found between the measurements of the two muscles in PC-BMW and P-US (p<0.01).
Conclusions: PC-BMW provides clear and excellent images, is pocket-sized and less expensive than a conventional ultrasound imaging system. PC-BMW can be utilized variously and has the advantage of rehabilitative ultrasound imaging. More research is needed to evaluate the utility of PC-BMW for rehabilitation.

Key Words: Muscle viewer, Reliability, Transversus abdominis, Ultrasonography, Upper trapezius

Introduction

The structure of the skeletal muscle is key to the performance of functional human movement [1]. Recently, rehabilitative ultrasound imaging (RUSI) has become a common method for evaluating skeletal muscle structure. In addition, like magnetic resonance imaging (MRI), RUSI can clearly distinguish between muscle and tissue, and it is possible to generate a high-quality image of the muscle structure [2]. RUSI has the advantage of being relatively user-friendly, and can quantitatively measure various aspects of muscle structure including muscle fiber size, thickness, length, cross-sectional area, and pennation angle [3-6]. These variables are highly correlated to muscle strength, efficiency and muscle movement [7,8]. Muscle thickness and strength are closely related variables and have been used to identify the most useful structural changes in muscles during therapy [4,9]. Moreover, RUSI may provide real-time visual feedback enabling the proper performance of muscles during exercise [10].

Several studies have investigated the validity and reliability of the ultrasound measurement of the limbs and trunk

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muscles [2,11-19]. Of the many muscles researched using RUSI, the transversus abdominis (TrA), which is associated with lower back pain, has been extensively investigated being one of the muscles with the greatest effect on exercise. Most muscles thickness studies, of muscles at rest and during contraction, using ultrasound have shown high reliability and validity [12,15,20]. However, studies involving RUSI showed that the standard error of measurement (SEM), in the case of the upper trapezius (UT) which contributes to neck and shoulder pain, revealed a slightly higher tendency of contraction and rest conditions when compared to that of the muscles of the trunk [13,21]. Although musculoskeletal ultrasound studies have been variously attempted, more research is needed regarding the measurement of dynamic contraction in the posture that can be resolved in muscle activity.

Despite the many advantages of conventional ultrasound, it is heavy and expensive. Recently, a personal computer-based muscle viewer (PC-BMW) which addresses the disadvantages of conventional ultrasound, has been developed. PC-BMW has created Telemed™ , which provides clear and excellent images, is pocket-sized, and less expensive than a conventional ultrasound imaging system. In addition, one more advantage of this device is that it can be used to download free PC software from anywhere. Unlike conventional portable ultrasound (P-US), not the process of storing and outputting measurement data require additional useful management of data. Therefore, the purpose of the study was to establish the reliability and validity of PC-BMW against ultrasound imaging for measuring UT and TrA muscle thickness.

Methods

Subjects

Fifty-five healthy individuals (25 men, 30 women) with no history of skeletal muscle pain were recruited for the study. Healthy subjects aged between 18 and 50 years, with a full active range of motion, without pain in the neck, shoulder, arm, and lower back were included. The exclusion criteria were: past or present musculoskeletal or neuromuscular disorders in the neck, shoulder, arm, and lower back; pregnancy-; malignant tumors-; and obesity body mass index >30 kg/m^2. The study was approved by the Institutional Review Board of the Sahmyook University (SYUIRB 2-1040781-AB-N-01-2016004HR) in Seoul.

Procedures

Muscle thickness measurements were performed with a PC-BMW (MicrUs EXT-1H; TELEMED, Vilnius, Lithuania) and a Medison Mysono P-US system (U5; Samsung Medison, Seoul, Korea) (Figures 1, 2). The PC-BMW is a new generation of universal serial bus powered small-sized ultrasound imaging equipment. In this study, the PC-BMW system used a 12-MHz linear transducer for both measurement conditions. A P-US was also used with a 12-MHz linear transducer to obtain images. The two imaging measurements via the two devices were conducted by two examiners, with more than 3 years' experience in musculoskeletal ultrasound imaging.

The participants assumed two positions in rest and contraction for the measurement of the UT muscle thickness. For the resting position, the participants were sat upright in a neutral position with the head straight-; the dominant side was measured. For contraction, the participants held the arm at 30° abduction for 10 seconds [21]. In the two positions, the participants were asked to fully extend the elbow and a goniometer was used for the maintenance of the arm's abduction angle. To determine the transducer placement, the examiners drew lines with a kohl pencil from the mid-line between C6 and the angle of the acromion. The probe was placed parallel to the muscle fibers, and the examiners asked

Figure 1. (A) Personal computer-based muscle viewer and (B) portable ultrasound.

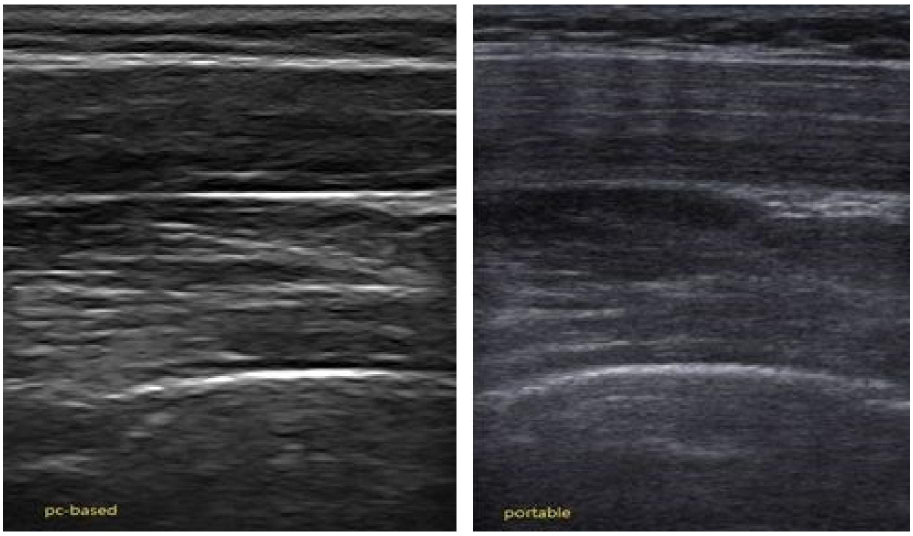

Figure 2. Resolution the difference between the two devices. (A) Personal computer-based muscle viewer. (B) portable ultrasound.

the participants to maintain a fixed position. Scan images of the UT muscle thickness were calculated 2 cm lateral to the triangular myo-fascial junction at a direction of the muscle belly plane [13]. The TrA muscle thickness on the dominant side was measured during rest and in abdominal drawing-in maneuver (ADIM). Participants were examined in the hook-lying position at rest with their knees flexed at 90^o in the supine position [22]. The probe was transversely placed on the middle abdominal region between the border of the 11th costal cartilage and the anterior superior iliac crest [15]. To perform ADIM for TrA contraction, participants were instructed to "take in a deep breath, draw your belly button up and in towards your lumbar spine" [14,23]. For the quantification of the ADIM, we used a pressure biofeedback unit (PBU) (Stabilizer; Chattanooga Group Inc., Hixson, TN, USA) [24]. After setting a pressure of 40 mmHg in the PBU, the ability to contract the TrA muscle resulted in a pressure reduction from 4 to 10 mmHg [25,26].

The participants rested for 1 to 2 minutes after ADIM to reduce the influence of fatigue. The image was measured by drawing a line 1.5 cm apart from the myo-fascial junction and a vertical line was drawn for the 3 muscles layers (external oblique, internal oblique, transverse abdominis) [27]. All images were measured by the two examiners for two days.

Data analysis

All demographic data were analyzed for descriptive statistics. To describe the intra- and inter-rater reliability of UT and TrA muscle thickness at rest and during contraction, intra-class correlation coefficients (ICCs) and 95% confidence intervals (CIs) were calculated. ICCs of the type (3,1) were used to evaluate the reliability of the data. ICCs <0.50 were considered poor; 0.50 to 0.75, moderate to good; and >0.75, excellent reliability [28]. Based on the reliability coefficients, SEM was calculated as standard deviation× $\sqrt{1-\mathrm{ICC}}$. To investigate the linear relationship between the two methods, Pearson's correlation coefficient (r) and the r^2 value were used. The statistical analyses were performed using PASW Statistics ver. 18.0 for Windows (IBM Co., Armonk, NY, USA).

Table 1. Characteristics of the subjects (N=55)

Characteristic	Value
Gender, male/female	25/30
Age (y)	28.41 (3.77)
Height (cm)	166.30 (7.13)
Weight (kg)	62.58 (12.75)
Body mass index (kg/m^2)	22.45 (3.27)
Waist (cm)	74.42 (9.11)
Dominant side, left/right	4/51

Values are presented as number only or mean (SD).

Results

Demographic characteristics

Participants characteristics were as follows: 55 healthy participants (male=25, female=30) with mean age 28.41± 3.77 years, mean weight 62.58±12.75 kg, and mean height 166.30±7.13 cm. The mean body mass index and waist circumference were 22.45±3.27 kg/m^2 and, 74.42±9.11 cm, respectively (Table 1).

Intra-rater reliability analysis

A summary of the results for the intra-examiner reliability of UT muscle thickness for the 3 sessions performed by 2 examiners is shown in Table 2. For UT muscle thickness, the ICCs for intra-rater reliability ranged from 0.990 to 0.999 and the CI was within an acceptable range of 0.992 to 1.000. The SEM values ranged from 0.084 to 0.410 cm for UT. For TrA muscle thickness, the ICCs for intra-rater reliability ranged from 0.924 to 0.998 (Table 3). The SEM values of TrA ranged from 0.058 to 0.373.

Table 2. Intra-rater between repeated measures on PC-BMW and P-US for the upper trapezius MT (2 days; unit: mm) (N=55)

MT		Subheading		1st test	2nd test	3rd test	ICC	95% CI	SEM
E1	1st day	Rest	PC-BMW	11.37 (2.89)	11.29 (2.92)	11.33 (2.85)	0.998	0.998-0.999	0.129
			P-US	11.12 (2.71)	11.09 (2.68)	11.11 (2.72)	0.997	0.995-0.998	0.148
		30° abduction	PC-BMW	13.68 (3.11)	13.63 (3.09)	13.60 (3.06)	0.999	0.998-0.999	0.097
			P-US	14.08 (3.15)	14.09 (3.16)	14.04 (3.11)	0.990	0.984-0.994	0.314
	2nd day	Rest	PC-BMW	11.01 (2.51)	10.97 (2.57)	11.00 (2.57)	0.998	0.996-0.999	0.114
			P-US	10.87 (2.46)	10.73 (2.50)	10.71 (2.48)	0.995	0.992-0.997	0.162
		30° abduction	PC-BMW	13.14 (2.65)	13.14 (2.69)	13.13 (2.66)	0.999	0.998-0.999	0.084
			P-US	13.40 (2.85)	13.48 (2.84)	13.69 (3.17)	0.997	0.996-0.998	0.158
E2	1st day	Rest	PC-BMW	11.31 (2.78)	11.28 (2.81)	11.29 (2.80)	0.999	0.999-0.999	0.088
			P-US	11.65 (2.96)	11.33 (3.19)	11.60 (2.96)	0.998	0.997-0.999	0.136
		30° abduction	PC-BMW	13.60 (3.60)	13.80 (3.24)	13.83 (3.20)	0.985	0.977-0.991	0.410
			P-US	14.21 (3.08)	14.06 (3.05)	14.26 (3.06)	0.996	0.994-0.998	0.194
	2nd day	Rest	PC-BMW	11.16 (2.67)	11.14 (2.71)	11.14 (2.72)	0.999	0.999-1.000	0.085
			P-US	11.21 (2.82)	11.06 (3.11)	11.22 (2.86)	0.997	0.995-0.998	0.160
		30° abduction	PC-BMW	13.42 (3.06)	13.41 (3.03)	13.40 (3.02)	0.999	0.999-1.000	0.096
			P-US	13.66 (2.85)	13.70 (2.85)	13.41 (3.20)	0.998	0.997-0.999	0.132

Values are presented as mean (SD).
PC-BMW: personal computer-based muscle viewer, P-US: portable ultrasound, MT: muscle thickness, ICC: intraclass correlation coefficient, 95% CI: 95% confidence interval, SEM: standard error of the mean, E1: examiner 1, E2: examiner 2.

Table 3. Intra-rater between repeated measures PC-BMW and P-US for the transverses abdominis MT (2 days unit: mm) (N=55)

MT		Subheading		1st test	2nd test	3rd test	ICC	95% CI	SEM
E1	1st day	Rest	PC-BMW	3.02 (1.31)	3.05 (1.28)	3.09 (1.33)	0.998	0.996-0.999	0.058
			P-US	2.87 (0.81)	2.94 (0.86)	2.95 (0.85)	0.980	0.969-0.988	0.119
		ADIM	PC-BMW	4.22 (1.68)	4.26 (1.69)	4.16 (1.69)	0.997	0.996-0.998	0.092
			P-US	4.09 (1.15)	4.15 (1.21)	4.19 (1.20)	0.991	0.986-0.994	0.113
	2nd day	Rest	PC-BMW	3.15 (1.05)	3.20 (1.08)	3.18 (1.07)	0.997	0.995-0.998	0.058
			P-US	2.95 (0.80)	3.00 (0.79)	3.08 (0.87)	0.963	0.942-0.977	0.158
		ADIM	PC-BMW	4.25 (1.33)	4.25 (1.34)	4.28 (1.36)	0.971	0.954-0.982	0.229
			P-US	4.13 (1.03)	4.19 (1.07)	4.17 (1.02)	0.992	0.988-0.995	0.093
E2	1st day	Rest	PC-BMW	3.02 (1.27)	3.06 (1.25)	3.06 (1.24)	0.954	0.928-0.971	0.269
			P-US	2.85 (0.93)	2.92 (0.89)	2.93 (0.90)	0.978	0.966-0.987	0.135
		ADIM	PC-BMW	4.15 (1.49)	4.18 (1.46)	4.18 (1.47)	0.977	0.964-0.986	0.223
			P-US	4.02 (1.16)	4.04 (1.17)	4.01 (1.08)	0.990	0.984-0.994	0.114
	2nd day	Rest	PC-BMW	3.07 (1.08)	3.08 (1.06)	3.10 (1.04)	0.973	0.957-0.983	0.175
			P-US	2.95 (0.80)	3.00 (0.79)	3.08 (0.87)	0.984	0.976-0.990	0.100
		ADIM	PC-BMW	4.21 (1.36)	4.21 (1.34)	4.23 (1.34)	0.924	0.881-0.953	0.373
			P-US	4.13 (1.03)	4.19 (1.07)	4.17 (1.02)	0.991	0.985-0.994	0.090

Values are presented as mean (SD).
PC-BMW: personal computer-based muscle viewer, P-US: portable ultrasound, MT: muscle thickness, ICC: intraclass correlation coefficient, 95% CI: 95% confidence interval, SEM: standard error of the mean, E1: examiner 1, E2: examiner 2, ADIM: abdominal draw-in maneuver.

Table 4. Inter-rater between repeated measures on PC-BMW and P-US for the two muscles (unit: mm) (N=55)

Muscle	Condition		E1[a]	E2[a]	ICC	95% CI	SEM
UT	PC-BMW	Rest	11.33 (2.88)	11.29 (2.79)	0.966	0.942-0.980	0.522
		30° abduction	13.64 (3.08)	13.75 (3.30)	0.964	0.938-0.979	0.605
	P-US	Rest	11.11 (2.70)	11.53 (2.91)	0.892	0.815-0.937	0.921
		30° abduction	14.07 (3.13)	14.18 (2.99)	0.889	0.810-0.935	1.019
TrA	PC-BMW	Rest	3.06 (1.30)	3.04 (1.25)	0.987	0.978-0.992	0.145
		ADIM	4.21 (1.67)	4.17 (1.47)	0.963	0.936-0.978	0.280
	P-US	Rest	2.92 (0.82)	2.90 (0.89)	0.911	0.848-0.948	0.255
		ADIM	4.14 (1.18)	4.02 (1.13)	0.934	0.884-0.962	0.296

Values are presented as mean (SD).
PC-BMW: personal computer-based muscle viewer, P-US: portable ultrasound, E1: examiner 1, E2: examiner 2, ICC: intraclass correlation coefficient, 95% CI: 95% confidence interval, SEM: standard error of the mean, UT: upper trapezius muscle, TrA: transverses abdominis muscle ADIM: abdominal draw-in maneuver.
[a]Measurement are mean (SD) based on three images taken by the examiner on the same day (day 1).

Table 5. Correlation between muscle thickness measurements taken from PC-BMW and P-US (N=55)

Examiner	Muscle	Condition	Pearson's correlation coefficient (r)	*p*	r^2
E1	UT	Rest	0.842	<0.001	0.708
		30° abduction	0.786	<0.001	0.618
	TrA	Rest	0.690	<0.01	0.477
		ADIM	0.727	<0.01	0.529
E2	UT	Rest	0.890	<0.001	0.792
		30° abduction	0.905	<0.001	0.819
	TrA	Rest	0.719	<0.01	0.517
		ADIM	0.805	<0.01	0.648

PC-BMW: personal computer-based muscle viewer, P-US: portable ultrasound, E1: examiner 1, E2: examiner 2, UT: upper trapezius muscle, TrA: transverses abdominis muscle, ADIM: abdominal draw-in maneuver.

Inter-rater reliability analysis

For the muscles, the ICCs for inter-rater reliability ranged from 0.889 to 0.987 (Table 4). The SEM values of UT ranged from 0.522 to 1.019 cm, and the SEM values of TrA ranged from 0.145 to 0.296.

Correlation between muscle thickness measurements taken from PC-BMW and P-US

The results showed a good correlation between PC-BMW and P-US measurements of UT (p<0.001) and TrA (p<0.01) muscle thickness for examiner 1 (E1) and 2 (E2) (Table 5).

Discussion

The aim of this study was to investigate the reliability and validity of PC-BMW compared to that of conventional P-US. PC-BMW is convenient to use and may be employed to quantify muscle structure non-invasively like conventional ultrasound, but is considerably lighter in weight and less expensive.

In this study, PC-BMW of the UT muscle had a good intra-rater reliability (E1 rest ICC=0.998, E1 contraction ICC=0.999, E2 rest ICC=0.999, E2 contraction ICC=0.985-0.999) and a good inter-rater reliability (rest ICC=0.966, contraction ICC=0.964). In the study by Leong *et al.* [21], which involved UT measurement, the reliability of rest and 30° shoulder abduction position tissue stiffness (supersonic shear imaging) was very good (intra-rater rest ICC=0.97, contraction ICC=0.93, inter-rater rest ICC=0.78, contraction ICC=0.83). Similarly, in this study, we used previous research methods, which had shown high reliability. Both devices showed a high reliability for UT measurement, but PC-BMW showed slightly higher values than P-US. When using the two devices during the experiment, the image output of PC-BMW more clear than that of P-US for distinguishing the boundaries of the fascia. The difference in clarity between the two devices is considered to have affected the results.

We found a good intra-rater and inter-rater reliability in the PC-BMW measurement of the TrA muscle (ICC=0.924-0.998, and 0.963-0.987, respectively). In previous studies, the reliability of ultrasound measurement of TrA during rest and ADIM was very high with most values >0.900 [12,15,20]. Properly performing ADIM, depends on the accurate perception of the participants and task repeatability [12]. In this study, to reduce these effects, participants used the PBU to learn how to quantitatively perform ADIM experiments were carried out before the start of sufficient training.

The primary purpose of this study was to investigate the validity of PC-BMW for measuring the muscle thickness of UT and TrA compared to that of P-US. A high correlation was found between measurements of UT muscle thickness in PC-BMW and P-US (rest E1 r=0.842, E2 r=0.890 contraction E1 r=0.786, E2 r=0.905). Moreover, the correlation of TrA muscle thickness was higher (rest E1 r=0.690, E2 r=0.719, contraction E1 r=0.727, E2 r=0.805), and UT showed higher correlation values. In a previous validity study comparing MRI and US, UT showed good correlation values (r=0.52, p<0.001) [13]. The results were used as the proper method to measure the muscle structures. PC-BMW is not determined by anything on the image output as compared to conventional P-US. PC-BMW used proprietary software, the Echo Wave II ver. 3.5, and calculated the length measured at the same time as image viewing. In the case of P-US, after moving image files to the PC, the Sante Dicom viewer program (Dicom Softwere, Santesoft Ltd., Athenes, Greece) was used to view the output. We believe that we were able to observe differences in length and make measurements based on the PC resolution and type of program. Further research evaluating the utility of PC-BMW for rehabilitation and measurement of other muscle contraction conditions is needed. The PC-BMW device is considered as a clinically useful method for assessing muscle structure.

Conflict of Interest

The authors declared no potential conflicts of interest with respect to the authorship and/or publication of this article.

References

1. Neumann DA. Kinesiology of the musculoskeletal system. St. Louis: Elsvier Mosby; 2002.
2. Scott JM, Martin DS, Ploutz-Snyder R, Caine T, Matz T, Arzeno NM, et al. Reliability and validity of panoramic ultrasound for muscle quantification. Ultrasound Med Biol 2012;38:1656-61.
3. Esformes JI, Narici MV, Maganaris CN. Measurement of human muscle volume using ultrasonography. Eur J Appl Physiol 2002; 87:90-2.
4. Freilich RJ, Kirsner RL, Byrne E. Isometric strength and thickness relationships in human quadriceps muscle. Neuromuscul Disord 1995;5:415-22.
5. Bemben MG. Use of diagnostic ultrasound for assessing muscle size. J Strength Cond Res 2002;16:103-8.
6. Yoo JS, Ha HG, Jeong JR, Ko YJ, Lee WH. Physical therapist perception survey for muscle re-education through visual feedback obtained from rehabilitative ultrasound imaging. Phys Ther Rehabil Sci 2016;5:47-52.
7. Gao F, Grant TH, Roth EJ, Zhang LQ. Changes in passive mechanical properties of the gastrocnemius muscle at the muscle fascicle and joint levels in stroke survivors. Arch Phys Med Rehabil 2009;90:819-26.
8. McNee AE, Gough M, Morrissey MC, Shortland AP. Increases in muscle volume after plantarflexor strength training in children with spastic cerebral palsy. Dev Med Child Neurol 2009;51:429-35.
9. Gruther W, Benesch T, Zorn C, Paternostro-Sluga T, Quittan M, Fialka-Moser V, et al. Muscle wasting in intensive care patients: ultrasound observation of the M. quadriceps femoris muscle layer. J Rehabil Med 2008;40:185-9.
10. Henry SM, Westervelt KC. The use of real-time ultrasound feedback in teaching abdominal hollowing exercises to healthy subjects. J Orthop Sports Phys Ther 2005;35:338-45.
11. Nabavi N, Mosallanezhad Z, Haghighatkhah HR, Mohseni Bandpeid MA. Reliability of rehabilitative ultrasonography to measure transverse abdominis and multifidus muscle dimensions. Iran J Radiol 2014;11:e21008.
12. Ishida H, Hirose R, Watanabe S. Comparison of changes in the contraction of the lateral abdominal muscles between the abdominal drawing-in maneuver and breathe held at the maximum expiratory level. Man Ther 2012;17:427-31.
13. O'Sullivan C, Meaney J, Boyle G, Gormley J, Stokes M. The validity of rehabilitative ultrasound imaging for measurement of trapezius muscle thickness. Man Ther 2009;14:572-8.
14. Koppenhaver SL, Hebert JJ, Fritz JM, Parent EC, Teyhen DS, Magel JS. Reliability of rehabilitative ultrasound imaging of the transversus abdominis and lumbar multifidus muscles. Arch Phys Med Rehabil 2009;90:87-94.
15. Teyhen DS, Miltenberger CE, Deiters HM, Del Toro YM, Pulliam JN, Childs JD, et al. The use of ultrasound imaging of the abdominal drawing-in maneuver in subjects with low back pain. J Orthop Sports Phys Ther 2005;35:346-55.
16. Koppenhaver SL, Hebert JJ, Parent EC, Fritz JM. Rehabilitative ultrasound imaging is a valid measure of trunk muscle size and activation during most isometric sub-maximal contractions: a systematic review. Aust J Physiother 2009;55:153-69.
17. Kim MK, Ko YJ, Lee HJ, Ha HG, Lee WH. Ultrasound imaging for age-related differences of lower extremity muscle architecture. Phys Ther Rehabil Sci 2015;4:38-43.
18. Ko YJ, Ha HG, Jeong JR, Lee WH. Variations in lateral abdominal muscle thickness during abdominal drawing-in maneuver in three positions in a young healthy population. Phys Ther Rehabil Sci 2014;3:101-6.
19. Lee HJ, Shin KH, Byun SM, Jeong HS, Hong JS, Jeong SJ, et al. The changes of rectus abdominis muscle thickness according to the angle during active straight leg raise. Phys Ther Rehabil Sci 2013;2:44-8.
20. Ishida H, Watanabe S. Changes in lateral abdominal muscles'

thickness immediately after the abdominal drawing-in maneuver and maximum expiration. J Bodyw Mov Ther 2013;17:254-8.
21. Leong HT, Ng GY, Leung VY, Fu SN. Quantitative estimation of muscle shear elastic modulus of the upper trapezius with supersonic shear imaging during arm positioning. PLoS One 2013;8: e67199.
22. Jung DE, Kim K, Lee SK. Comparison of muscle activities using a pressure biofeedback unit during abdominal muscle training performed by normal adults in the standing and supine positions. J Phys Ther Sci 2014;26:191-3.
23. McGalliard MK, Dedrick GS, Brismée JM, Cook CE, Apte GG, Sizer PS Jr. Changes in transversus abdominis thickness with use of the abdominal drawing-in maneuver during a functional task. PM R 2010;2:187-94; quiz 226.
24. de Paula Lima PO, de Oliveira RR, Costa LO, Laurentino GE. Measurement properties of the pressure biofeedback unit in the evaluation of transversus abdominis muscle activity: a systematic review. Physiotherapy 2011;97:100-6.
25. Chattanooga G. Stabilizer pressure bio-feedback. Operating instructions. Hixson: Chattanooga Group Inc.; 2005.
26. Lima PO, Oliveira RR, Moura Filho AG, Raposo MC, Costa LO, Laurentino GE. Concurrent validity of the pressure biofeedback unit and surface electromyography in measuring transversus abdominis muscle activity in patients with chronic nonspecific low back pain. Rev Bras Fisioter 2012;16:389-95.
27. Hodges PW, Pengel LH, Herbert RD, Gandevia SC. Measurement of muscle contraction with ultrasound imaging. Muscle Nerve 2003;27:682-92.
28. Portney LG, Watkins MP. Foundations of clinical research: Applications to practice. Upper Saddle River, NJ: Prentice Hall Health; 2000.