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RELIABILITY and VALIDITY of DUAL PROBE-FIXING FRAME for REHABILITATIVE ULTRASOUND IMAGING for EXERCISES with VISUAL FEEDBACK

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Objective: Rehabilitative ultrasound imaging is a safe and noninvasive technique for evaluating muscle thickness. A dual probe-fixing frame (DPF) can provide visual feedback during exercises targeting specific muscles. The purpose of this research was to verify the reliability and validity of the DPF for dual-probe ultrasound (DPU)-based visual feedback exercises, allowing users to use both hands freely.

Design: This cross-sectional study used repeated measures to compare muscle thickness measurements obtained using the handheld device and DPF with DPU.

Methods: Twenty healthy adults participated in the study. Measurements were taken over two sessions, with a two-day interval between the sessions. The thicknesses of the rectus abdominis (RA) and transverse abdominis (TrA) muscles were measured using DPU. The DPF with DPU developed by the research team, was used along with a laptop-based muscle viewer. Bland-Altman analysis and intraclass correlation coefficients (ICCs) calculations were used in statistical analyses to evaluate agreement and reliability, respectively.

Results: The results of the Bland–Altman analysis showed small average differences between the handheld and DPF methods for both RA and TrA muscle thicknesses. Inter-rater reliability analysis showed high ICC values for DPF measurements of both RA (0.908–0.912) and TrA (0.892–741) muscle thicknesses. Intra-rater reliability analysis also showed good ICC values for measurements taken by a single examiner over two days.

Conclusion: The findings of this study demonstrate that the DPF provides reliable and valid measurements of muscle thickness during visual feedback exercises using the DPU.

Key Words: Rehabilitation, Ultrasonography, Reliability and Validity, Test-Retest

INTRODUCTION

Rehabilitation ultrasound imaging (RUSI), is a common technique for assessing muscle movement and structure and providing biofeedback. Physical therapists can use RUSI to measure the length, depth, diameter, cross-sectional area, volume, and pennation angles of muscles, among other morphological characteristics, in order to evaluate how the muscles and related soft tissues change during movement and physical tasks. [1]. RUSI is a non-invasive and painless device that does not use drugs, making it a safe and well-tolerated technique [2]. Additionally, compared to other imaging methods like computed tomography and magnetic resonance imaging, RUSI requires less measurement time and is cost-effective because it does not require consumables such as disposable pads [3].

Recently, significant advancements have been made in RUSI technology, including developing various ultrasound equipment, such as the dual-probe

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ultrasound (DPU). A DPU enables simultaneous real-time measurement of two muscles and increases portability through integration with personal laptops or smartphones [4]. Using RUSI, deep and superficial muscles can be observed simultaneously, and real-time dynamic muscle activity can be captured, making it an effective tool for controlling the body's automatic response, which was previously not possible. Furthermore, RUSI has been utilized as a visual feedback training tool in various conditions, including older people [5] who experience difficulty in controlling movements, stroke patients [6], and postpartum rehabilitation [7].

RUSI has been used as a visual biofeedback tool for a variety of focused exercises, according to prior studies. For instance, Dülger et al. found that RUSI used during abdominal drawing-in maneuver training was more effective than verbal or tactile feedback at activating the transversus abdominis muscle (TrA). [8]. A systematic literature review by Valera-Calero et al. indicated that RUSI, as a visual biofeedback tool, was more effective than verbal or tactile biofeedback in increasing muscle thickness [9-14] and muscle activity [15] than verbal or tactile biofeedback. Similarly, LaCross et al. showed that adults with stress urinary incontinence benefited from RUSI biofeedback during muscle training, which helped them correctly contract their pelvic floor muscles and increase their task-specific self-efficacy, quality of life, and self-ratings of improvement. [7].

However, despite the reported positive effects, applying RUSI to various patient groups remains challenging because both the hands of the user and the physical therapist are occupied. The research team is also interested in postpartum rehabilitation and aims to facilitate the exercise of the rectus abdominis (RA) and TrA, the most crucial muscles in postpartum rehabilitation, through provisioning visual feedback using RUSI. Therefore, we developed a new framework, the dual-probe fixing frame (DPF), to implement visual feedback-based exercises using RUSI in the RA and TrA without the above limitations. This frame enables users to use both hands during exercise while providing visual feedback. The purpose of this study was to develop a DPF for DPU-based visual feedback exercises which emphasize the symmetry of muscles on both sides, and to confirm its validity and reliability.

METHODS

Participants

This was a repeated measures cross-sectional study. Two raters obtained the muscle thickness images of all patients using either the handheld device or the DPF using the DPU. The measurements were conducted over two sessions, with a two-day interval between the sessions. Twenty healthy adults (10 men and women, each) were recruited from the Sahmyook University. The sample size for the reliability analysis was determined following the recommendations of Walter et al. using the intraclass correlation coefficient (ICC) [16]. The inclusion criteria were normal adults without musculoskeletal pain. On the other hand, the exclusion criteria were adults with neuromuscular dysfunction resulting from damage to the central or peripheral nervous system, those suffering from cardiorespiratory diseases, excessive coughing, or sneezing, and those with a history of abdominal surgery. This study was approved by the Institutional Review Board of Sahmyook University, Seoul (IRB No. SYU 2023-02-014).

Procedures

Muscle thicknesses of the RA and TrA were measured using DPU (MicrUS-Duo EXT-1H, REV:C: TELEMED, Vilnius, Lithuania) with a laptop-based muscle viewer (Echo Wave II [X64] 4.2.0, TELEMED, Vilnius, Lithuania) (Figure 1). Images were obtained using a linear probe at a frequency of 12 MHz and a dynamic range of 66 dB. Two raters utilized either a handheld device or the DPF developed by the research team, with dimensions of 74 cm (width) × 12 cm (height) and 39 cm (arm height) × 22 cm (arm length), respectively, capable of adjusting angles with five joints (Figure 2). In addition, measurements were made using the same posture and process when using the hand (Figure 3) and when using the DPF (Figure 4).

The patients were first measured in a state of relaxation in a hook-lying position with a pillow under

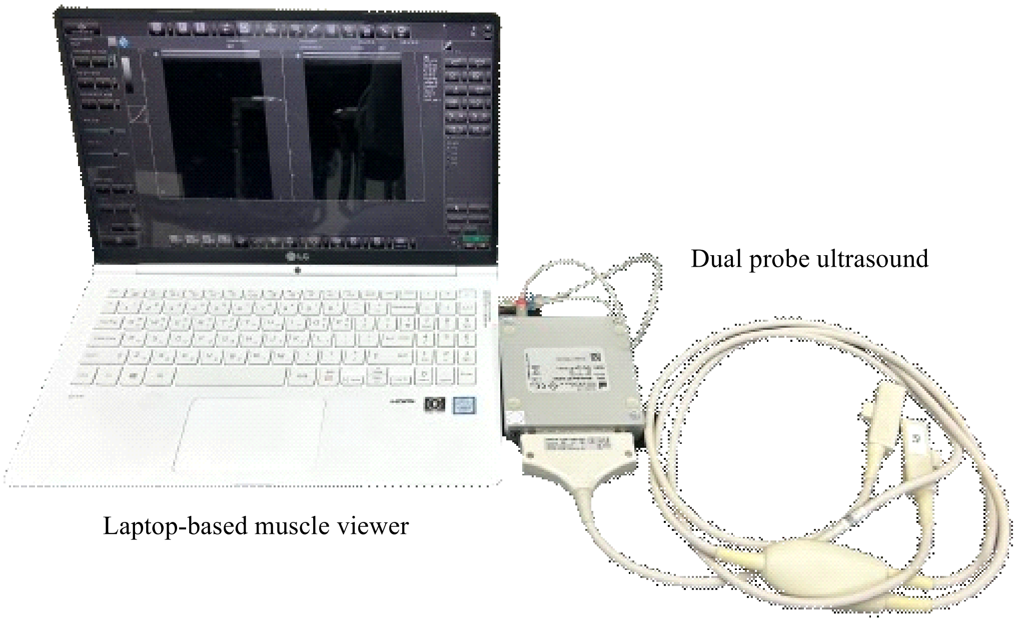

Figure 1. Dual Probe Ultrasound (DPU) with laptop-based muscle viewer

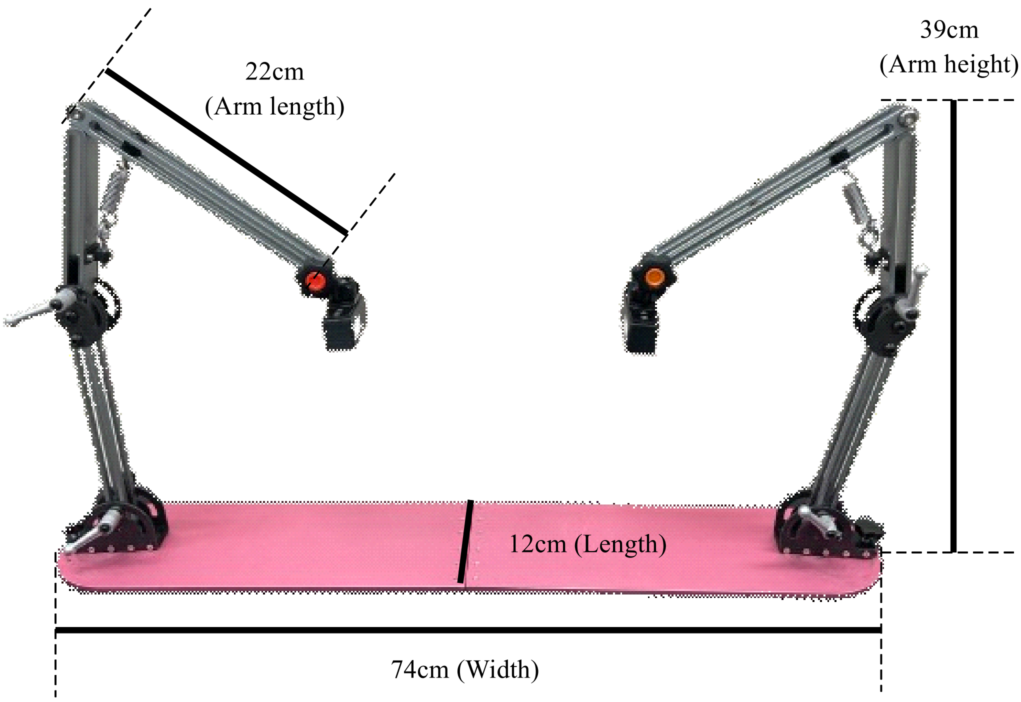

Figure 2. Dual Probe fixing Frame (DPF)

the knees for the measurement of the RA muscle thickness. The transducer was placed 2 cm outward and upward from the umbilicus, and RA thickness on both sides was measured at the midpoint of the belly. The thickness was measured twice, and the average value was calculated.

TrA muscle thickness was measured in the same posture as that used for RA measurement. The transducer was placed 10 cm lateral to the umbilicus and above the iliac crest, along the mid-axillary line,

Figure 3. Measuring muscle thickness using hands

figure 4. Measuring muscle thickness using DPF

and adhered to the transverse plane. Subsequently, the transducer was adjusted until the thoracolumbar fascia boundary was visible on the screen. To achieve optimal image quality, the angle of the transducer on the skin was fine-tuned while ensuring a perpendicular alignment with the skin surface.

To prevent the influence of muscle morphology, the examiner was careful not to apply excessive pressure to the transducer on the subject's skin. Sufficient ultrasound gel was applied during the measurement to minimize the pressure between the transducer and the skin.

Additionally, the final stage of exhalation was chosen to measure muscle thickness considering the potential influence of the breathing cycle on the measurement results. Based on the finding that muscle thickness varies according to the breathing cycle, this method aims to obtain more accurate and reliable measurements. A physical therapist with 3 years of experience who had completed ultrasound training was employed for the measurement.

Statistical analysis

Demographic data were analyzed using descriptive statistics. The agreement between two quantitative measurements acquired using the standard handheld ultrasound device and those obtained using the DPF during DPU measurement was examined using a Bland-Altman analysis [17]. For the Bland–Altman analysis, a dataset consisting of handheld measurements and a dataset generated from DPF measurements were compared. Twenty datasets were created for each variable using Microsoft Excel with random distributions and specific bias ranges. Bland–Altman analysis was conducted on all simulated datasets for each variable to assess the agreement between the two measurement methods. The difference between the upper and lower limits of agreement (LoA) was calculated in order to define the forecast error range. LoA values indicate that 95% of the data points fall within the range defined by the mean difference±1.96 times the standard deviation. By comparing the observed data points to the LoA, researchers were able to evaluate the degree of agreement and determine whether there was good agreement between the two methods [18]. The intra- and inter-rater reliability of bilateral RA and TrA muscle thicknesses at rest was calculated using ICCs and 95% confidence intervals (CIs). Reliability levels of poor, moderate, good, and excellent were identified by ICCs of 0.50, 0.50-0.75, 0.75-0.9, and 0.9, respectively.

RESULTS

Demographic characteristics

Participant’s characteristics were as follows: 20 healthy adults (10 men and women, each) with mean age, 23.75±1.94 years; mean height, 170±9.79 cm; mean weight, 67.1±12.96 kg; and mean body mass index, 23.02±2.59 (Table 1).

Bland-Altman analysis

In order to analyze the agreement between the two measurement methods—handheld and DPF for determining the thicknesses of the RA and TrA muscles, Bland-Altman analysis was conducted. Figure

Table 1. General characteristics of the patients

Parameters	Values
Age (years)	23.75 (1.94)
Height (cm)	170 (9.79)
Weight (kg)	67.1 (12.96)
BMI (kg/m^2)	23.02 (2.59)
Sex (male/female)	10/10

Values are presented as numbers or mean (SD).
BMI, body mass index.

3 and 4 display the Bland–Altman plot illustrating the differences between the handheld and DPF techniques, plotted against the average of the measurements. The RA and TrA's average muscle thicknesses are shown on the x-axis, while the two methods' differences are shown on the y-axis.

On the first day, the average difference between the handheld and DPF methods in RA muscle thickness was 0.0375 mm (95% LoA: -2.267 mm–2.192 mm) on the right side and 0.0375 mm (95% LoA: -2.464 mm–2.539 mm) on the left side. The average difference in TrA muscle thickness was -0.0125 mm (95% LoA: -1.250 mm–1.225 mm) on the right side and 0.2175 mm (95% LoA: -1.208 mm–1.643 mm) on the left side.

On the second day, the average difference between the handheld and DPF techniques in the RA muscle thickness was -0.4725 mm (95% LoA: -1.963 mm to - 1.018 mm) on the right side and -0.9875 mm (95% LoA: -3.270 mm to - 1.295 mm) on the left side. The average difference in TrA muscle thickness was -0.0675 mm (95% LoA: -0.848 mm–0.713 mm) on the right side and -0.1575 mm (95% LoA: -1.048 mm–0.733 mm) on the left side.

Inter–rater reliability analysis

The measures of muscle thickness in the RA and TrA muscles using the DPF technique by two different examiners are shown in Table 2 as the results of the inter-rater reliability analysis. On the right and left sides, respectively, the ICCs for the DPF's inter-rater reliability for RA muscle thickness were 0.908 and 0.912. The ICCs for the inter-rater reliability of the DPF for TrA muscle thickness were 0.892 and 0.741 on the right and left sides, respectively.

Intra–rater reliability analysis

The results of the intra-rater reliability analysis for the DPF-based measurement of muscle thickness in the RA and TrA by one examiner at two-day intervals are shown in Table 3. The right and left sides' ICCs for

Table 2. Inter-rater reliability between repeated measures of the rater1 (R1) and rater2 (R2) for RA & TrA muscle thickness

1st day	R1 - Frame	R2 - Frame	ICC	95% CI	p-value
RA					
Right	11.17 (2.36)	11.61 (2.63)	0.908	0.770–0.963	$p<0.001$
Left	10.96 (2.13)	11.16 (2.29)	0.912	0.778–0.965	$p<0.001$
TrA					
Right	2.64 (0.93)	3.33 (0.92)	0.802	-0.129–0.946	$p<0.001$
Left	2.80 (0.71)	3.27 (0.73)	0.741	0.183–0.907	$p<0.001$

Values are presented as mean (SD).
ICC, intraclass correlation coefficient; CI, confidence interval; RA, rectus abdominis; TrA, transversus abdominis, SD; standard deviation.

Table 3. Intra-rater reliability between repeated measures on the 1st day and 2nd day for RA & TrA muscle thickness

E1 - Frame	1st day	2nd day	ICC	95% CI	p-value
RA					
Right	11.17 (2.36)	11.36 (2.09)	0.922	0.806–0.969	$p<0.001$
Left	10.96 (2.13)	11.38 (1.89)	0.852	0.634–0.941	$p<0.001$
TrA					
Right	2.64 (0.93)	2.39 (0.68)	0.716	0.308–0.886	$p=0.003$
Left	2.80 (0.71)	2.61 (0.69)	0.703	0.266–0.881	$p=0.005$

Values are presented as mean (SD).
ICC, intraclass correlation coefficient; CI, confidence interval; RA, rectus abdominis; TrA, transversus abdominis, SD; standard deviation.

RA muscle thickness were calculated to be 0.922 and 0.852, respectively. On the right and left sides, the ICCs for TrA muscle thickness were 0.716 and 0.703, respectively.

DISCUSSION

This study aimed to develop and evaluate the reliability and validity of a DPF for visual feedback exercises using a DPU in the field of rehabilitation. The DPF was designed to overcome the limitations of traditional handheld ultrasound devices and provide greater freedom of movement for both the measurer and the patient during exercise. The DPF consists of two arms on a wide support surface, and the arms have five joints. By adjusting the angle of each joint, ultrasound can be fixed on the desired muscle. In addition, it has a pressure spring, which makes the ultrasound image clearer by applying a little pressure, while providing a pressure that is not uncomfortable for the subject. In addition, the last joint where the probe can be inserted allows 360 degrees of rotation and inclination from 0 degrees to 260 degrees, so it can be appropriately applied to the round surface of the abdomen. Due to these structural characteristics, the DPU can be used with delicate and appropriate control, just like with the hand. This study revealed important findings regarding the reliability and validity of the DPF.

First, the inter-rater reliability analysis showed high ICC values for measuring muscle thickness using the DPF. The ICCs for the RA muscle thickness were 0.908 and 0.912 on the right and left sides, respectively, indicating excellent reliability. For TrA muscle thickness, the ICCs were 0.892 and 0.741 on the right and left sides, respectively, demonstrating good-to-excellent reliability. These results suggest that the DPF enables consistent measurements of muscle thickness between different raters, highlighting its reliability as a tool for visual feedback exercises. In terms of intra-rater reliability, the ICC values depended on the muscle being measured on the right and left sides. RA muscle thickness showed a high ICC value of 0.922 on the right side, indicating excellent reliability, whereas the ICC value was lower (0.852) on the left side, indicating excellent reliability. Similarly, for TrA muscle thickness, the ICC values were 0.716 and 0.703 on the right and left sides, respectively, indicating moderate reliability. The lower ICC values on the left side for both muscles suggest that there may be some factors influencing the measurements, such as the positioning of the DPF or individual anatomical variations of the participants. In a similar previous study, the intra-rater and inter-rater reliability of RA and TrA thickness were 0.99 and 0.99, respectively. This figure is higher when compared to this study. [19] The results of ultrasound measurements are affected by the skill of the measurer, and unlike this study, this is thought to be because the ultrasound measurements were performed by an experienced medical specialist (obstetrician). Similar to this study, in another previous study, the reliability coefficient of TrA (0.87) was lower than that of RA (0.99). The reason is thought to be because the muscle thickness of TrA is smaller and the landmarks are unclear compared to RA. [20]

Bland–Altman analysis was conducted to assess the agreement between the handheld ultrasound and DPF measurements. The analysis revealed good agreement between the two methods, as indicated by the narrow LoA, and most data points fell within the range defined by the mean difference±1.96 times the standard deviation. These findings suggest that the DPF can provide reliable and comparable measurements to traditional handheld ultrasound, supporting its validity as a tool for visual feedback exercises. The DPF was designed to address the aforementioned limitations, enhance the degrees of freedom in RUSI usage, and enable efficient measurement and exercise in diverse circumstances and settings. Compared to the existing method using hands, using the DPF frees the hands of the measurer and physical therapist, allowing them to activate the subject's target muscles further or correct the posture, thereby enhancing the exercise effect during the visual feedback exercise. To determine the effectiveness of visual feedback exercises utilizing the DPU in various fields and patients, it is vital to study the validity and reliability of the DPF created by this research team.

This study focused on healthy adults without musculoskeletal pain, and considering the generalizability of the results to other populations, such as individuals with neuromuscular dysfunction or specific clinical conditions, is important. Future research should investigate the reliability and validity of the DPF in diverse patient groups to ensure its applicability in various rehabilitation settings.

CONCLUSION

In conclusion, the findings of this study demonstrate that the DPF provides reliable and valid measurements of muscle thickness during visual feedback exercises using the DPU. The DPF overcomes the limitations associated with traditional handheld ultrasound devices, providing increased freedom of movement for both the measurer and the patient, thereby enhancing the effectiveness of visual feedback-based rehabilitation programs. Further studies are required to optimize the DPF design and explore its applicability in different patient populations.

CONFLICT OF INTEREST

The authors declare no conflicts of interest regarding the authorship and/or publication of this article.

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