

The reliability of dual rehabilitative ultrasound imaging measurements for muscle co-activation

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Objective: The aim of this study was to determine the intra-rater and inter-rater reliability of the dual rehabilitative ultrasound imaging (D-RUSI) when simultaneously measuring muscle thickness changes at rest and during co-contraction of the biceps brachii (BB) and triceps brachii (TB).

Design: Cross-sectional study.

Methods: This study included 36 healthy participants (23 men, 13 women). The participants sat on a chair in a comfortable position with a cushion placed under their elbow to maintain a 90-degree elbow flexion angle. The muscle thickness of the biceps brachii and triceps brachii was measured twice using the D-RUSI by two examiners during resting and co-contraction states. One week later, the same procedure was performed once again.

Results: The intra-class correlation coefficients (ICCs) for intra-rater reliability ranged from 0.887 to 0.989 and the confidence interval was within an acceptable range of 0.778 to 0.994. The standard error of measurement (SEM) values ranged from 0.303 to 0.866 and the minimal detectable change (MDC) values ranged from 0.84 to 2.40. The ICCs for inter-rater reliability ranged from 0.758 to 0.925. The SEM values ranged from 0.702 to 1.486 and the MDC values ranged from 1.95 to 4.12.

Conclusions: The use of the D-RUSI of the BB muscle had a very good intra-rater reliability and very good inter-rater reliability at the resting state, and a good inter-rater reliability at the co-activation state. ICC values showed very good intra-reliability and inter-reliability for the TB muscle. the D-RUSI is a useful tool for simultaneously measuring the thickness of two muscles when the BB is an agonist and the TB is an antagonist during co-activation of the upper arm.

Key Words: Humerus, Muscle contraction, Reproducibility of results, Ultrasonography

Introduction

Muscle strength is a fundamental aspect of the performance of everyday tasks [1]. It is essential for health, functional ability, and quality of life, and varies greatly according to the circumstances of growth, aging, and lifestyle [2]. In particular, age and disease have been shown to reduce muscle mass and strength, which can lead to adverse physiological changes and functional limitations [3]. The action of

large muscle groups, especially in the upper extremities, is necessary for daily tasks such as carrying, pulling and pushing [1]. Previous research has shown that upper extremity muscle weakness can limit activities of daily living, particularly in the use of instruments [4]. The muscle strength of the upper limbs must be supported to enable skilled hand function, and the muscles of the upper limb are necessary to properly adjust the other joints of the arms, provide hand stability, and perform delicate tasks. Indeed, a decrease in up-

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per limb strength results in an insufficient stability in the proximal arm, which may limit grip strength [1]. Clearly, upper body strength management is a critical determinant of quality of life.

Most strength training methods apply an external force toward the body segment end by lifting heavy equipment to provide resistance to the contraction muscles. However, isometric training has been proposed as a means of strength training using paired contractions of the agonists and antagonists without joint movement [5,6]. In fact, co-activation is the simultaneous activation of the agonist and antagonist muscle groups around the joints. The torque produced during the maximum voluntary contraction corresponds to the algebraic sum of the agonist and antagonist torques and is influenced by the activation of both the agonists and antagonists.

This co-activation is important for joint stabilization, the uniform distribution of pressure within the joint capsule, and prevention of bone displacement [7]. In the case of co-contraction of muscles, only electromyography has been used to measure muscle activity in real time, and the research on rehabilitative ultrasound imaging (RUSI) has only evaluated the measurement of muscle thickness before and after co-contraction training [8,9].

RUSI is a potentially useful tool for the evaluation and treatment of muscular dysfunctions, particularly for measuring the morphological characteristics of muscles and enabling direct observation of muscle contractions for biofeedback [10]. However, since there is only one probe to measure the image, only one muscle can be measured in real time, which is a disadvantage. Recently, the dual RUSI (D-RUSI),

a device capable of simultaneously measuring the action of two muscles in real time was developed, with two probes and two measurement zones displayed on one screen. The purpose of the present study was to determine the reliability of the D-RUSI by simultaneously measuring muscle thickness changes during co-contraction of the biceps and triceps.

Methods

Participants

Thirty-six healthy individuals (23 men, 13 women) voluntarily agreed to participate into the study. All healthy participants were aged in their 20s and 30s and had a full active range of motion. Participants had no history of skeletal muscle pain or disease within the past 3 months. The exclusion criteria was musculoskeletal or neuromuscular disorders in the upper extremity, pregnancy, and body mass index (BMI) $>30 \text{ kg/m}^2$. The study was approved by the Institutional Review Board of Sahmyook University (IRB No. 2-1040781-AB-N-01-2016085HR) in Seoul. All participants were given a written explanatory statement regarding the procedure and the risks involved in this study and then asked to sign a consent form if they were willing to participate.

Procedures

Prior to the experiment, the anthropometric variables of the participants were measured by one skilled rater. The upper arm circumference was measured using a tape measure at the thickest part of the upper arm muscle belly.

The ultrasonography device (dual-MicrUs EXT; Teled, Vilnius, Lithuania) used in the study was an imaging unit set in B mode with 7.5 MHz dual linear array transducer (Figures 1, 2). The muscle thickness was measured during co-con-

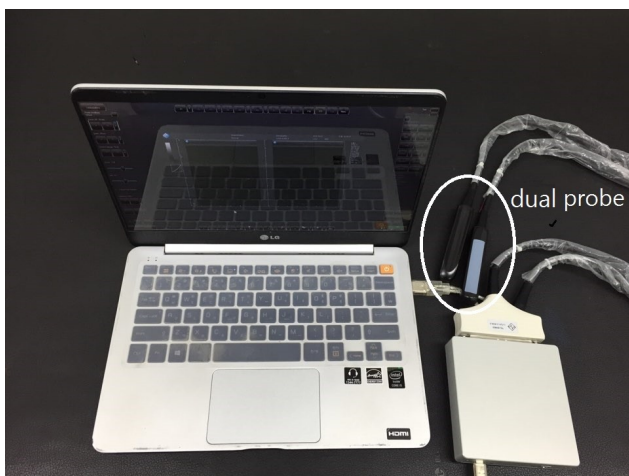


Figure 1. Dual rehabilitative ultrasound imaging.

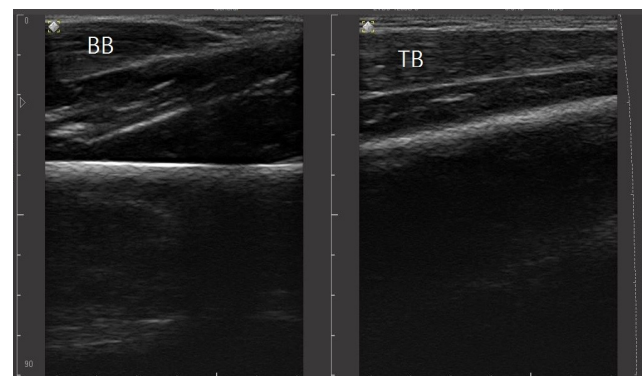


Figure 2. Simultaneously measuring two muscles in real time. BB: biceps brachii, TB: triceps brachii.

traction of the biceps brachii (BB) and triceps brachii (TB) by an experienced physiotherapist. Two raters performed the measurements for the reliability study. Measurements were performed two times at rest and two times at maximal voluntary contraction (MVC) per rater, with one rater measuring first, followed by another rater one minute later. The mean values of the two measurements were used in the analyses. In addition, the same experiment was performed one week later for the analysis of test-retest reliability. When measuring the muscle structure, ultrasound gel was used between the transducer and the skin to increase the area of contact and to minimize the need for inadequate inward probe pressure [11]. The participants sat on a chair in a comfortable position, with a cushion placed under their elbow to maintain a 90-degree elbow flexion angle. The thickness of the BB and TB was measured by placing the transducer vertically and on the anterior and posterior aspect of the upper arm proximal to the crease of the elbow [12,13]. In the resting state, muscle thickness was measured first. Then, the isometric contraction was induced to measure the muscle thickness during co-activation of the BB and TB. The MVC value was measured using a digital manual muscle tester (Power Track II; JTECH Medical Industries, Inc., Midvale, UT, USA) while measuring the thickness at the time of muscle contraction. The measured MVC value was used to make the muscle contraction constant during repeated measurements.

We analyzed both the imaging and calculated measurements of muscle thickness using Echo Wave II 3.6.1.b (Telemed).

Statistical analysis

The analysis was performed using IBM SPSS Statistics ver. 18.0 (IBM Co., Armonk, NY, USA), and the statistical level of significance was set at 0.05. Comparisons of the participants' general characteristics were performed using the independent t-test. To assess the reliability of the D-RUSI, the intra-class correlation coefficient (ICC) was calculated for the muscle thickness of the BB and TB at rest and during co-activation. ICCs of the type (3, 1) were used to assess the reliability of each parameter. ICC values were categorized as follows: poor, ≤ 0.20 ; fair, 0.21-0.40; moderate, 0.41-0.60; good, 0.61-0.80; and very good, ≥ 0.81 [14]. In order to evaluate the accuracy of the measurement, the standard error of the measurement (SEM) was calculated as the standard deviation $\times \sqrt{1-ICC}$. The minimal detectable change (MDC) was calculated as $1.96 \times SEM \times \sqrt{2}$, which is the mini-

mum thickness change when 95% confidence interval (CI) is assumed [15].

Results

Demographic characteristics

The participants' characteristics are presented in Table 1. The 36 healthy participants (male=23, female=13) had a mean age of 26.36 ± 5.57 years, mean weight of 62.19 ± 8.09 kg, mean height of 169.02 ± 7.46 cm, mean BMI of 21.74 ± 2.23 kg/m², and mean upper arm circumference of 37.24 ± 3.09 cm.

Intra-rater reliability analysis

A summary of the results for the intra-rater reliability of the BB and TB muscle thickness for the two sessions performed by two raters is shown in Table 2. The ICCs for intra-rater reliability ranged from 0.887 to 0.989 and the CI was within an acceptable range of 0.778 to 0.994. The SEM values ranged from 0.303 to 0.866 and the MDC values ranged from 0.84 to 2.40.

Inter-rater reliability analysis

The ICCs for inter-rater reliability ranged from 0.758 to 0.925 (Table 3). The SEM values ranged from 0.702 to 1.486 and the MDC values ranged from 1.95 to 4.12.

Discussion

The aim of the study was to investigate the intra- and inter-rater reliability in obtaining D-RUSI muscle thickness measurements of the BB and TB muscles at rest and during the co-activation state. The D-RUSI is the only instrument that can assess and measure two muscles at the same time with two probes; therefore, the results cannot be directly compared with previous studies.

In this study, the D-RUSI of the BB muscle had very good

Table 1. Characteristics of the study participants (N=36)

Parameter	Value
Sex (male/female)	23/13
Age (yr)	26.36 (5.57)
Height (cm)	169.02 (7.46)
Weight (kg)	62.19 (8.09)
Body mass index (kg/m ²)	21.74 (2.23)
Upper arm circumference (cm)	37.24 (3.09)

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

Table 2. Intra-rater reliability between repeated measures on D-RUSI for BB and TB muscle thickness (unit: mm) (N=36)

Variable	MT		ICC	95% CI	SEM	MDC			
	1st test	2nd test							
R1	1st day	Rest	BB	6.18 (1.93)	6.36 (1.94)	0.959	0.920-0.979	0.389	1.08
			TB	6.48 (2.58)	6.69 (2.80)	0.972	0.944-0.986	0.447	1.24
		Co-activation	BB	11.98 (3.34)	12.04 (3.09)	0.983	0.967-0.991	0.416	1.15
			TB	6.69 (3.45)	6.84 (3.29)	0.989	0.978-0.994	0.351	0.97
	2nd day	Rest	BB	6.21 (1.70)	6.16 (1.57)	0.956	0.914-0.978	0.339	0.94
			TB	5.82 (1.43)	5.84 (1.39)	0.953	0.909-0.976	0.303	0.84
		Co-activation	BB	11.99 (2.92)	11.89 (2.97)	0.952	0.905-0.975	0.639	1.77
			TB	5.89 (1.43)	6.03 (1.45)	0.954	0.910-0.977	0.306	0.85
R2	1st day	Rest	BB	6.31 (1.71)	6.30 (1.70)	0.887	0.778-0.942	0.569	1.58
			TB	6.83 (2.71)	6.84 (3.00)	0.939	0.880-0.969	0.701	1.94
		Co-activation	BB	10.86 (2.55)	11.44 (3.03)	0.904	0.813-0.951	0.866	2.40
			TB	6.98 (2.84)	7.11 (3.45)	0.975	0.951-0.987	0.495	1.37
	2nd day	Rest	BB	5.91 (1.62)	5.81 (1.58)	0.899	0.803-0.949	0.505	1.40
			TB	6.35 (1.95)	6.09 (2.05)	0.958	0.917-0.979	0.408	1.13
		Co-activation	BB	10.07 (2.69)	10.54 (2.66)	0.924	0.853-0.962	0.735	2.04
			TB	6.36 (1.86)	6.39 (1.86)	0.946	0.894-0.972	0.429	1.19

Values are presented as mean (SD).

D-RUSI: dual rehabilitative ultrasound imaging, BB: biceps brachii, TB: triceps brachii, MT: muscle thickness, ICC: intra-class correlation coefficient, 95% CI: 95% confidence interval, SEM: standard error of the measurement, MDC: minimal detectable change, R1: rater 1, R2: rater 2.

Table 3. Inter-rater reliability between repeated measures on D-RUSI for BB and TB muscle thickness (unit: mm) (N=36)

Condition	Muscle	MT		ICC	95% CI	SEM	MDC
		E1 ^a	E2 ^a				
Rest	BB	6.27 (1.93)	6.30 (1.69)	0.849	0.759-0.906	0.702	1.95
	TB	6.59 (2.67)	6.83 (2.83)	0.925	0.881-0.953	0.753	2.09
Co-activation	BB	12.01 (3.19)	11.155 (2.79)	0.758	0.614-0.849	1.486	4.12
	TB	6.77 (3.35)	7.04 (3.14)	0.879	0.807-0.925	1.125	3.12

Values are presented as mean (SD).

D-RUSI: dual rehabilitative ultrasound imaging, BB: biceps brachii, TB: triceps brachii, MT: muscle thickness, ICC: intra-class correlation coefficient, 95% CI: 95% confidence interval, SEM: standard error of the measurement, MDC: minimal detectable change, E1: examiner 1, E2: examiner 2.

^aBased on three images taken by the examiner on the same day (day 1).

intra-rater reliability (R1 rest ICC=0.956-0.959, R1 co-activation ICC=0.952-0.983, R2 rest ICC=0.887-0.899, R2 co-activation ICC=0.904-0.924; Table 2), very good inter-rater reliability at rest (ICC=0.849), and good inter-rater reliability at co-activation (ICC=0.758; Table 3). Our data on BT thickness were similar to those reported in a previous study, in which the thickness of the biceps tendon was measured twice in the same posture as in this study and showed very good intra- and inter-rater reliability (ICC=0.98-0.99) [16]. Although the measurement position was different, another study showed very good reliability (ICC=0.90) of biceps thickness measurement [17]. The biceps muscle is rela-

tively easy to capture in ultrasound imaging because it is located in the superficial and the anterior layer relative to the position of the humerus [16]. It is believed that this factor contributed to obtaining the high reliability results. The comparison that resulted in the lowest reliability rating for BT thickness was the inter-rater reliability for co-activation. Muscle contraction can be influenced by many factors such as the evaluator's instructions, the motivation of the participant, and the skill of the participant at the time of motor control, all of which could explain the degradation of reliability. However, regardless of where the specific bias occurs, the actual difference between the measurements was small and

did not cause a significant reduction in reliability.

ICC values showed very good intra-rater reliability (R1 rest ICC=0.953-0.972, R1 co-activation ICC=0.954-0.989, R2 rest ICC=0.939-0.958, R2 co-activation ICC=0.946-0.975) and inter-rater reliability (rest ICC=0.925, co-activation ICC=0.879) for the TB muscle (Tables 2, 3). In a previous study, Thoires and English [18] measured the thickness of several muscle groups by ultrasonography in various postures. Although the measurement posture differed from that in the present study, their intra-examiner reliability was also very good when measuring the thickness of the anterior and posterior upper arm. In the present study, the reliability of the TB measurement was high and the ICC value for the co-activation state was lower than the ICC value for the resting state, for similar reasons as the BB measurement. Overall, D-RUSI measurement can be considered effective in the context of co-activation of the BB and TB muscles.

We also calculated the SEM and MDC values in order to assess measurement errors between repeated measurements and to determine whether changes occurred between these iterations. The SEM value can be used as an estimate for the entire group based on the CI. For example, the SEM value of the BB results measured by the first rater in the resting state on the first day was calculated as [observed score \pm 1.96 (SEM)]. Using this calculated value, there is a 95% probability that the actual average score of the group will be between 5.42 mm and 6.94 mm when the group average is 6.18 mm. The MDC value was calculated to range from 0.84 mm to 4.12 mm. This suggests that we can expect 95% of patients without changes in this population to demonstrate a random variation of less than 0.84 to 4.12 mm in a repeat measurement of the D-RUSI [19].

There are several limitations to this study. First, because the experiment was conducted with a limited number of participants, measurement postures, and ranges, the results may not be generalized. Second, only the co-activation state with the BB acting as an agonist and TB acting as an antagonist was measured. Further studies should continue to investigate the reliability of the D-RUSI measures; in particular, an investigation of the changes in muscle thickness with TB acting as an agonist and BB acting as an antagonist may increase the reliability of the D-RUSI as a tool to measure muscle action during co-activation of the upper arm.

In conclusion, the D-RUSI is a useful tool for the simultaneous measurement of the thickness of two muscles when the BB is an agonist and the TB is an antagonist during co-activation of the upper arm.

Conflict of Interest

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

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