Influence of the ultrasound transducer tilt on muscle thickness and echo intensity of the rectus femoris muscle of healthy subjects

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Abstract. [Purpose] This study aimed to assess the influence of ultrasound (US) transducer tilt on muscle thickness and echo intensity of the rectus femoris muscle (RF) in healthy subjects. [Subjects and Methods] Fourteen healthy male subjects (20.8 ± 0.8 years) participated in this study. Transducer tilt was measured during US, with a digital angle gauge. Muscle thickness and echo intensity were measured in 4 transducer tilt conditions: reference angle; +3°; +6°; and +9° cranial from the reference angle. [Results] All differences in transducer tilt relative to the reference condition were larger than the minimal detectable change (MDC) of the reference condition. All differences in muscle thickness relative to the reference condition were not larger than the MDC of the reference condition. All differences in the echo intensity relative to the reference condition, except between the reference and the +3° condition, were larger than the MDC of the reference condition. [Conclusion] Our results indicated that an examiner should maintain a precise transducer tilt during repeated US measurements to quantify the minimal change in the echo intensity of the RF.

Key words: Ultrasound, Muscle thickness, Echo intensity

INTRODUCTION

Over recent years there has been a steady increase in the use of B-mode ultrasound (US) to objectively measure architectural changes of muscle loss and fat infiltration, using thickness and echo intensity, in older individuals with sarcopenia⁴. However, it is important to note that US is associated with an examiner-dependent variation higher than that of other imaging modes, such as bioelectrical impedance, dual energy X-ray absorptiometry, computed tomography, and magnetic resonance imaging⁵. Consequently, during US, diligent attention must be paid to steadying the position, orientation, and inward pressure of the transducer. Previous studies have noted changes in transducer orientation can lead to a measurement error relating to muscle thickness³,⁴. While measuring thickness of the supraspinatus and deltoid muscles, Dupont et al.³) reported that a 15%-20% error was induced by a 30° variation in the transducer angle from the perpendicular to the body surface. Whittaker et al.⁴) further reported that an US transducer orientation of >9° rotation, >5°cranial/caudal tilt, and >5°medial/lateral tilt would result in measurement errors relating to the thickness of the transversus abdominis. More recently, we revealed the influences of inward pressure of the transducer upon muscle thickness and echo intensity⁵–⁷). Such differences in the magnitude of muscle thickness might be meaningful, although differences in the magnitude of echo intensity might be meaningless between 0.5-N and 2.0-N inward pressure of the transducer on the rectus femoris muscle (RF)⁷). However, little is known
about the changes in muscle thickness and echo intensity in relation to changes in US transducer tilt. Therefore, the purpose of this study was to assess the influence of US transducer tilt on muscle thickness and echo intensity.

SUBJECTS AND METHODS

Fourteen healthy male volunteers were recruited through advertisements as physiotherapy students of the Kawasaki University of Medical Welfare. Mean (± standard deviation) age, height, weight, and body mass index of the subjects were 20.8 ± 0.8 years, 168.6 ± 3.9 cm, 60.5 ± 7.7 kg, and 21.3 ± 2.8 kg/m², respectively. None of the subjects had any history of orthopedic or neuromuscular diseases. The protocol for this study was approved by the Ethics Committee of Kawasaki University of Medical Welfare (Approval number: 16-095). Written informed consent was obtained from all subjects.

The first experimenter, who had 6 years of experience in musculoskeletal US, was responsible for handling the US transducer. A B-mode system (Aloka, SSD-3500SX; Aloka Co., Ltd., Tokyo, Japan), with a 10 MHz transducer, was used to acquire and store US images. All equipment settings were maintained throughout testing, including gain (49 dB), dynamic range (56 dB), time gain compensation in the neutral position, and depth setting of 5 cm. The subjects were positioned in a supine posture with a roll (100 × 600 mm) under their knees. Transducer tilt was measured using a digital angle gauge (WR3651; Wixey Co., Ltd., Florida, USA) connected to a US transducer (°). Hereafter, angles of more than 0° represent a cranial tilt from the vertical line, while those less than 0° represent a caudal tilt. Images of the digital angle gauge display the angle of the transducer relative to the neutral position. The order of the conditions tested was chosen randomly and measurements were immediately repeated.

The second experimenter, who had 2 years of experience in musculoskeletal US, performed all muscle thickness and echo intensity measurements; these measurements were performed for each of the 4 transducer tilt conditions. The stored US data were then converted to JPEG files with a resolution of 640 × 480 pixels. The anteroposterior muscle thickness of the RF (mm) was measured as the length between the superficial and the deep epimysium of the RF, using ImageJ (Version 1.45, National Institute of Health, USA). Echo intensity was determined by gray-scale analysis using the standard histogram function in ImageJ. A region of interest (ROI) was drawn by the hand to include as much of the RF as possible, within the surrounding fascia. The echo intensity within the ROI was expressed as values between 0 and 256 (0: black; 256: white).

All statistical analyses were carried out using SPSS Statistics 22.0 (IBM Inc., Chicago, IL, USA). Differences relative to the reference condition were calculated by subtracting the reference condition value from the +3°, +6°, and +9° condition values. The reliability of the measured values for transducer tilt, muscle thickness, and echo intensity of the reference condition were examined by calculating the intra-class correlation coefficient (ICC). The standard error of measurement (SEM=SD × \(\sqrt{1-ICC}\)), and the minimal detectable change for a 95% confidence interval (MDC=SEM × \(\sqrt{2}\)×1.96), were also calculated[9]. One-way repeated-measures analysis of variance (ANOVA) was used to assess differences for each variable. Post-hoc analysis was performed with the Bonferroni test and the level of significance was set at p<0.05.

RESULTS

The reliability of the measured values for the reference condition is listed in Table 1.

Significant differences, arising from ANOVA, were identified for all parameter tested, except for muscle thickness. The mean ± standard deviation of the transducer tilt, muscle thickness, and echo intensity are shown in Table 2; significant differences in transducer tilt were observed for all the conditions tested. Significant differences in echo intensity were identified for all conditions, except between the reference and the +3° condition.

All differences of transducer tilt, relative to the reference condition, were larger than the MDC of the reference condition. All differences of muscle thickness, relative to the reference condition, were not larger than the MDC of the reference condition. Finally, all differences of echo intensity, relative to the reference condition, except between the reference and +3° conditions, were larger than the MDC of the reference condition.
imaging. Compared to the reference condition, the +3°, +6°, and +9° conditions might result in more unclear images of the

and 19.14 mm, respectively. However, in this study, the muscle thickness recorded in the +3°, +6°, and +9° conditions were

+3°, +6°, and +9° conditions, compared to the reference condition, thus leading to reductions in muscle thickness. Further

condition, approximately 2.4 N was applied during the US in this study; this pressure represented the weight combination of

RF epimysium during US, which may subsequently lead to measurement errors. Additionally, to unify the inward pressure condition, approximately 2.4 N was applied during the US in this study; this pressure represented the weight combination of the transducer and the digital angle gauge. Inclining the transducer, would therefore have led to alternations in the contact pressure per unit area at the transducer tip. The cranial part of the transducer tip would therefore have pressed up to the RF in the +3°, +6°, and +9° conditions, compared to the reference condition, thus leading to reductions in muscle thickness. Further studies are now required to quantify the changes in muscle thickness as a result of changes in transducer tilt, however, such studies should deploy a method which avoids direct contact between the transducer and the skin and uses gel as an interface.

In contrast to the muscle thickness data, all differences of echo intensity relative to the reference condition, except between the reference and +3° conditions, were larger than the MDC of the reference condition. In the reference condition, the transducer was tilted to place it in a plane that subjectively gave the RF a more hyper-echoic appearance. However, there was no significant difference between the reference and the +3° conditions. It would therefore be impossible for subjective judgment to position the transducer at a precise position that was perpendicular to the longitudinal axis of the RF perimysium and endomysium. Another possible explanation for the echo intensity results could be lateral inhibition. Visual sensation could not accurately recognize the echo intensity to be affected by neighboring echo intensity. It is possible that there is a limit for visual judgment when placing the transducer into a given plane, which thus gave the RF the most hyper-echoic appearance. Further studies are now required, which should use a luminance meter to objectively determine the most hyper-echoic appearance of US image. Nevertheless, the observed differences in magnitude of the echo intensity might be meaningful when consider the MDC under the conditions of this study. The number of returning echoes per unit area determines the gray

Table 1. Intrarater reliability

|                  | ICC     | 95% CI            | SEM | MDC |
|------------------|---------|-------------------|-----|-----|
| Transducer tilt (°) | 0.961   | (0.888–0.987)     | 0.9 | 2.6 |
| Muscle thickness (mm) | 0.989   | (0.968–0.996)     | 0.4 | 1.0 |
| Echo intensity   | 0.974   | (0.924–0.991)     | 0.6 | 1.7 |

ICC: intra-class correlation coefficients; CI: confidence interval; SEM: standard error of measurement; MDC: minimal detectable change.

Table 2. Mean (± standard deviation) transducer tilt, muscle thickness and echo intensity under the reference and three experimental conditions

|                  | Reference | + 3° | + 6° | + 9° |
|------------------|-----------|------|------|------|
| Transducer tilt (°) | 2.8 ± 4.8 | 5.9 ± 4.8 a | 8.8 ± 4.8 a,b | 11.9 ± 4.7 a,b,c |
| Difference        | 3.1 ± 0.2 | 6.0 ± 0.2 | 9.0 ± 0.2 | |
| Muscle thickness (mm) | 18.9 ± 3.5 | 18.4 ± 3.3 | 18.3 ± 3.4 | 18.3 ± 3.4 |
| Difference        | −0.4 ± 0.5 | −0.5 ± 0.5 | −0.5 ± 0.5 | |
| Echo intensity   | 75.2 ± 3.8 | 73.6 ± 5.3 | 71.7 ± 6.0 a,b | 69.3 ± 6.0 a,b,c |
| Difference        | −1.6 ± 3.7 | −3.5 ± 4.5 | −5.9 ± 5.1 | |

aSignificantly different from the reference condition (p<0.05; Bonferroni’s test).
bSignificantly different from the +3° condition (p<0.05; Bonferroni’s test).
cSignificantly different from the +6° condition (p<0.05; Bonferroni’s test).

DISCUSSION

To our knowledge, this is the first study to quantify changes in muscle thickness and echo intensity of the RF arising from changes in US transducer tilt. In this study, muscle thickness and echo intensity measurements were performed under 4 different transducer tilt conditions (the reference angle, +3°, +6°, and +9° cranial from the reference angle). All differences in transducer tilt relative to the reference condition were larger than the MDC of the reference condition. However, all differences of muscle thickness relative to the reference condition were not larger than the MDC of the reference condition. Consequently, differences in the magnitude of muscle thickness may be meaningless under these conditions. If the RF is a rigid column (18.9 mm in diameter), then muscle thickness could be calculated using trigonometric function: 18.9 mm / sin87°, sin84°, and sin81° in the +3°, +6°, and +9° conditions; these calculations provide muscle thicknesses of 18.92 mm, 19.00 mm, and 19.14 mm, respectively. However, in this study, the muscle thickness recorded in the +3°, +6°, and +9° conditions were 18.4 mm, 18.3 mm, and 18.3 mm, respectively. A US image is created because of acoustic interfacing, wherein sound waves are reflected upon encountering a tissue of a different density. Aligning the direction of the longitudinal muscle fascia so that it is perpendicular to the direction of the US beams in the muscle will provide the clearest edge of the RF epimysium for imaging. Compared to the reference condition, the +3°, +6°, and +9° conditions might result in more unclear images of the RF epimysium during US, which may subsequently lead to measurement errors. Additionally, to unify the inward pressure condition, approximately 2.4 N was applied during the US in this study; this pressure represented the weight combination of the transducer and the digital angle gauge. Inclining the transducer, would therefore have led to alternations in the contact pressure per unit area at the transducer tip. The cranial part of the transducer tip would therefore have pressed up to the RF in the +3°, +6°, and +9° conditions, compared to the reference condition, thus leading to reductions in muscle thickness. Further studies are now required to quantify the changes in muscle thickness as a result of changes in transducer tilt, however, such studies should deploy a method which avoids direct contact between the transducer and the skin and uses gel as an interface.

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value of the image. The direction of US beams incline to the longitudinal axis of the perimysium and endomysium of the RF according to the transducer tilt, which would give the muscle a more hypo-echoic appearance.

This study has some limitations which should be taken into consideration. First, the rotation and medial/lateral tilt of the transducer are commonly related to margins of error in US procedure; consequently, these variables should have been determined exactly during our measurements. Second, the direction of muscle fiber differs among different muscles; consequently, further studies are required on different sets of muscles. Third, only young male individuals were recruited as subjects for the present study; therefore, the influence of gender remains unknown. Finally, architectural changes relating to muscle loss and fat infiltration of the RF have been reported as part of the normative aging process. Thus, further studies, involving a larger sample and other age groups, now needed to determine the true influence of transducer tilt on muscle thickness and echo intensity during US.

In conclusion, our results indicated that the examiner should maintain a precise transducer tilt during repeated US measurements in order to quantify the minimal change of echo intensity arising from the RF.

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