Quantitative assessment of middle deltoid elasticity during different shoulder abduction using shear wave elastography: A preliminary study

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Research article

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Abstract

Background: To measure the middle deltoid (MD) muscle elasticity during different shoulder abduction in healthy participants using shear wave elastography (SWE) and analyze the factors that may affect the MD elasticity, and then to establish the reference ranges of the normal MD elasticity during different shoulder abduction.

Methods: Mean shear wave velocity (SWV) of the MD in 70 healthy participants were evaluated at left and right shoulder 0° and 90° abduction (L0°, R0°, L90°, R90°) using SWE, and potential factors that may affect MD elasticity including gender, MD thickness, age, body mass index were analyzed. Normal reference ranges of MD elasticity were calculated using normal distribution method.

Results: Mean SWV was statistically significantly higher at L90° than L0°, higher at R90° than R0°, higher at R0° than L0°, and higher at R90° than L90° (all $p < 0.0001$). Mean SWV was significantly higher in males at both L0° ($p < 0.05$) and R0° ($p < 0.01$) than in females. Neither MD thickness, age nor body mass index influenced MD elasticity. Normal reference ranges of the MD elasticity were 2.4-3.1 m/s in males and 2.2-2.9 m/s in females at L0° and 2.5-3.3 m/s in males and 2.4-3.2 m/s in females at R0°, and were 4.9-6.7 m/s at L90°, 5.2-7.1 m/s at R90° for both males and females.

Conclusions: Our results suggest that the normal MD elasticity at L0°, R0°, L90°, R90° are different and gender should be considered when determining the reference ranges of normal MD elasticity at L0° and R0° with SWE. These values may provide quantitative baseline measurements for assessment of the normal MD elasticity.

Background

Shoulder pain is a global health problem, with a prevalence of 20-33% in the general population [1]. It is the third most common type of musculoskeletal pain after spinal and knee pain. Most of them are closely related to changes in muscle elasticity of shoulder [2]. Deltoid, an important motor muscle of shoulder, plays a vital role in maintaining shoulder stability [3]. The change in elasticity of deltoid may result in imbalance of the scapular force and cause shoulder pain [4]. Middle deltoid (MD) is an important component of deltoid, whose muscle fibers are parallel and easy to be measured. The initial symptoms of the MD muscle strain which easily induces shoulder pain mostly manifest as dizziness and fatigue. It is hard to be early diagnosed by conventional methods. Although the muscle morphology of the MD does not change in the early MD muscle strain, the MD elasticity may change [5]. Measuring middle deltoid (MD) elasticity could help to diagnose whether the pain is caused by MD muscle strain. Therefore, it is imperative to find a mean for evaluating the MD elasticity.

Shear wave elastography (SWE) is the most advanced ultrasonic elastic technique recently. SWE has the advantages of real-time and accuracy. Moreover, SWE provides in vivo quantification of tissue elasticity by measuring the shear wave propagation speed, which can quantitatively measure muscle elasticity through parameters such as shear wave velocity (SWV) and Young's modulus [6-8]. For skeletal muscles,

SWV may be a better index because the original measurement recorded with SWE is SWV, which is then mathematically converted to Young's modulus for each pixel. Furthermore, there are additional potential inaccuracies associated with converting SWV to Young's modulus.

More importantly, if the reference range of the MD elasticity is established in healthy individuals using SWE, it may be helpful to further assess MD muscle strain. However, there is little research on the changes of MD elasticity during different shoulder abduction using SWE [9-10]. Moreover, studies on both the reference ranges of the normal MD elasticity and its potential factors are extremely lacking. Thus, to evaluate the reference range of the MD elasticity in healthy individuals assessed by SWE is required.

In this study, we obtained the MD elasticity at shoulder 0° and 90° abduction from 70 healthy participants. Then, the corresponding reference ranges of normal MD elasticity were determined by statistical analysis. Our results may provide a preliminary quantitative baseline measurements reference for assessment of the normal MD elasticity.

Methods

Study design

This study was approved by the West China Hospital of Sichuan University Ethics Committee and performed in accordance with the Declaration of Helsinki. Informed consent for the acquisition and analysis of imaging data was obtained from the participants before starting their examinations. 70 healthy volunteers were recruited between December 2018 and May 2019. The inclusion criteria were as follows: (i) no pain in the shoulder over the last 2 years, (ii) no fatigue and weakness in the shoulder muscles over the last 6 months, (iii) no regular sports or fitness training during the last year. The exclusion criteria were as follows: (i) pregnancy in women, (ii) a history of neck or shoulder surgery, (iii) patients who are taking myorelaxants and other drugs affecting MD elasticity. (iv) a history of rheumatoid, immune, metabolic, endocrine diseases, shoulder trauma, or musculoskeletal diseases.

Examination by SWE

The device used to obtain B-mode and SWE images of the MD was Aixplorer US system (SuperSonic Imagine, Aix-en-Provence, France), with an SL 15-4 linear probe operating at 4-15 MHz to acquire B-mode and SWE images [11, 12]. In addition, the musculoskeletal mode was preset. The tip of transducer covered with several millimeters of ultrasound gel was placed smoothly to the targeted area of the MD along perpendicular direction to the skin [9, 13]. It was of importance to ensure that there was no pressure between skin and the probe. The volunteers were instructed to stay completely rested for 20 minutes before the procedure. Both mean SWV in SWE images and MD thickness in B-mode were measured three times in each shoulder abduction position by the same investigator, averaged, and expressed in m/s and millimeter, respectively. The four shoulder abduction positions in this study were as follows: left and right shoulder 0° abduction (L0° and R0°) and 90° abduction (L90° and R90°). The angle of shoulder abduction was measured by a manual goniometer to ensure the reliability and consistency. Figure 1 illustrates that

the system automatically calculated the SWV values for the Q-box area expressed in m/s at R0° and R90°. MD thickness and mean SWV were measured where muscle fibers were parallel; The probe was placed at the intersection of the midpoint between the lateral tip of the acromion and deltoid tuberosity [7, 14, 15]. The ultrasound examination was performed on all the participants by two experienced sonographers (A and B) who received SWE training. They were blinded to each other's results for the entire study. All participants were examined by operator A. Furthermore, 20 participants were selected randomly for consistency analysis. These 20 participants were examined by operator B and then measured again by operator A on the second day. Each healthy participant was asked to stand straight with the head in neutral position. The arm was first rested at shoulder 0° abduction and then actively positioned at shoulder 90° abduction. Participants were asked to maintain each abduction position for thirty seconds, with the elbow fully extended and the arm in the plane of the chest wall. The participants were asked to relax for 2 minutes between each measurement to avoid muscle fatigue.

Statistical analysis

The data were analyzed using SPSS v20.0 software (IBM, Armonk, NY, USA). The Kolmogorov-Smirnov test was used to assess the normality of continuous variables. The intraclass correlation coefficient (ICC) was calculated to determine the intra- and inter-operator reproducibility. Independent sample t-test for a binary variable (gender), Paired t-test between different shoulder abduction, and Pearson correlation test for continuous variables (MD thickness, age, BMI) were used. The lower and upper limits of the reference ranges of normal MD elasticity were mean SWV $\pm 1.96 \times$ SD (the standard deviation of mean SWV) and mean SWV $\pm 1.96 \times$ SD, respectively. Two-sided $P < 0.05$ was considered statistically significant.

Results

Study population

The main characteristics of 70 healthy subjects are summarized in Table 1. There were 35 males and 35 females in total subjects. The mean age $\pm$ SD was 42.10 ± 11.90 years (range, 19-70 years). The mean BMI was 23.20 ± 2.50 kg/m². The mean MD thickness was 14.6 ± 0.61 mm at L0°, 15.10 ± 0.51 mm at R0°, 20.60 ± 1.42 mm at L90°, 21.80 ± 1.40 mm at R90°, respectively.

Reliability analysis

The intra- and inter-operator reproducibility of the mean shear wave velocity of the MD at left and right shoulder 0° and 90° abduction are listed in Table 2 and 3. The ICC values show the intra-operator reproducibility at L0° (ICC = 0.85), R0° (ICC = 0.91), L90° (ICC = 0.95), and R90° (ICC = 0.96); and the inter-operator reproducibility at L0° (ICC = 0.89), R0° (ICC = 0.92), L90° (ICC = 0.91), and R90° (ICC = 0.93).

Influence of shoulder abduction position

Mean SWV was statistically significantly higher at L90° than L0° ($p < 0.0001$; Figure 2A), and higher at R90° than R0° ($p < 0.0001$; Figure 2B). Mean SWV was also statistically significantly higher at R0° than L0° ($p < 0.0001$; Figure 3A), and higher at R90° than L90° ($p < 0.0001$; Figure 3B).

Influence of gender

Mean SWV at both L90° ($P = 0.56, > 0.05$) and R90° ($P = 0.71, > 0.05$) were not statistically significantly different between females and males (Fig. 4B), but mean SWV at both L0° ($P < 0.05$) and R0° ($P < 0.01$) were statistically significantly higher in males than in females (Fig. 4A).

Influence of MD thickness

MD thickness was not statistically significantly correlated with mean SWV at R90° ($R = -0.004, P = 0.97, > 0.05$), L90° ($R = -0.087, P = 0.48, > 0.05$) and R0° ($R = -0.13, P = 0.3, > 0.05$) (Fig. 5B, C, D). Slight statistically positive correlation can be ignored at L0° ($R = -0.41, P < 0.01$) (Fig. 5A) between mean SWV and MD thickness.

Influence of age

There was no statistically significant correlation between age and mean SWV at L0° ($R = -0.013, P = 0.92, > 0.05$), R0° ($R = 0.12, P = 0.33, > 0.05$), L90° ($R = -0.052, P = 0.67, > 0.05$) and R90° ($R = -0.068, P = 0.58, > 0.05$) (Fig. 6A, B, C, D).

Influence of BMI

The BMI was not statistically significantly correlated with mean SWV at R0° ($R = 0.084, P = 0.49, > 0.05$), L90° ($R = 0.13, P = 0.3, > 0.05$) and R90° ($R = 0.13, P = 0.27, > 0.05$) (Fig. 7B, C, D). Slight statistically positive correlation can be ignored at L0° ($R = 0.31, P = 0.0092, < 0.05$) (Fig. 7A) between mean SWV and BMI.

Reference ranges setup

According to the above analyses, the reference ranges of normal MD elasticity at L0° and R0° were affected by gender, yet MD elasticity at L90° and R90° could be utilized for combined reference ranges regardless of gender, MD thickness, age, and BMI. Normal reference ranges of the MD elasticity were 2.4-3.1 m/s in males and 2.2-2.9 m/s in females at L0° and 2.5-3.3 m/s in males and 2.4-3.2 m/s in females at R0°, and were 4.9-6.7 m/s at L90°, 5.2-7.1 m/s at R90° for both males and females. Normal reference ranges of the MD elasticity at L0°, R0°, L90° and R90° were listed in Table 4.

Discussion

Taking advantage of the SWE, the present study found that MD elasticity was significantly higher on the right than on the left at both shoulder 0° abduction ($P < 0.0001$) and 90° abduction ($P < 0.0001$). It may be because right arm is used more frequently than left one (all the participants were right-handed in this

study). Moreover, MD elasticity was significantly higher at L90° than L0° ($P < 0.0001$), at R90° than R0° ($P < 0.0001$). It may be due to increased muscle tension and contractility of the MD during shoulder 90° abduction. Particularly, gender had impact on MD elasticity at both L0° ($P < 0.05$) and R0° ($P < 0.01$) in the present study, maybe indicating there is a significant difference in the MD elasticity between genders during shoulder 0° abduction. A possible explanation for this discrepancy may be the obvious difference in the MD muscle size and composition between genders at shoulder 0° abduction [16-20]. Haizlip et al. [21] showed that collagen and elastin architectures of muscle fibers mainly determined MD elasticity, which may vary between different gender. It is also well confirmed that histologic changes in muscle structure could affect increased muscle strain [22-25]. However, there are not obvious difference at shoulder 90° abduction. It may be related to the contractility of deltoid muscle; This is needed to be further studied [26-28]. These findings are clinically valuable because most previous SWE studies were designed to test diagnostic performance for various pathologies without specifically focusing on possible variations induced by different shoulder abduction positions [29-31].

In the present study, we found excellent intra-operator reproducibility in using SWE to measure the elasticity of the MD at L0° (ICC = 0.85), R0° (ICC = 0.91), L90° (ICC = 0.95) and R90° (ICC = 0.96) done by the same operator. This shows that SWE is a reliable technique for assessing MD elasticity. Our results revealed excellent inter-operator reproducibility for the measurements of the MD elasticity at L0° (ICC = 0.89), R0° (ICC = 0.92), L90° (ICC = 0.91) and R90° (ICC = 0.93). The reason for such high reliability in our study might be that we standardized the measuring method of the MD, thus leading to a more repeatable method for assessing MD elasticity.

This study also suggests that reference ranges of MD elasticity in healthy individuals at different shoulder abduction using SWE may be established. For this, the two key points could be summarized as follows. On the one hand, normal reference ranges of MD elasticity maybe provide initial diagnostic reference criteria of MD muscle strain in the future. These reference ranges maybe help to verify whether someone's MD elasticity is within the ranges of normal values using SWE. On the other hand, normal reference ranges of MD elasticity at L0°, R0°, L90°, and R90° provided valuable insight into early diagnosis of shoulder pain caused by MD muscle strain. Early MD muscle strain can be speculated by establishing normal reference ranges of muscle elasticity by using SWE [32]. Our research methods may be extended to the quantitative study of muscle elasticity for early diagnosis of muscle strain in the future.

This study is original from several perspectives and important considerations by using SWE and clinical applications. Firstly, it may be the first study to quantitatively assess MD elasticity by measuring the SWV at different shoulder abduction in healthy individuals. As a new tool to study muscle elasticity, most researches on SWE are almost about the Young's modulus [15,33]. Nevertheless, our studies had been done about the SWV. For skeletal muscles, we recommend the SWV as a surrogate for muscle elasticity instead of the Young's modulus. This will help with reliability of study results and allow more accurate comparison between studies [18, 32, 34]. Reviewing the literature on muscle SWE, we found that most studies performed SWE in a shoulder abduction position because of the time limitations. Secondly, this

work may be the first study to evaluate potential factors that may affect MD elasticity using SWE, including gender, age, MD thickness and BMI. No previous studies have analyzed all above possible effects on muscle elasticity as we did. Thirdly and most importantly, the clinical significance of setting up reference ranges of MD elasticity lies in early quantitative detection and even long-term evaluation for shoulder pain caused by MD muscle strain [35-37]. Traditional B-mode US and other diagnostic methods which only detect morphological changes cannot be able to diagnose early muscle strain. However, SWE can make a quantitative diagnosis for shoulder pain caused by MD muscle strain [38, 39].

There are several limitations in the current research. The number of participants investigated is the small sample number as an initial experience. In order to extend the reference ranges of the normal MD elasticity to the larger healthy population, we will attempt to increase sample size and conduct multi-center clinical studies in the future. Moreover, because this is a preliminary study, the effects of confounding factors, such as age, might have been underestimated. Inclusion of a larger study population with wider age and BMI ranges would be crucial to validate these results and might alter the significance of such confounding factors on the MD elasticity. These aspects need to be further refined in the future.

Conclusions

Our results suggest that the normal MD elasticity at L0°, R0°, L90°, R90° are different and gender should be considered when determining the reference ranges of normal MD elasticity at L0° and R0° with SWE. These values may serve as quantitative baseline measurements for assessment of the normal MD elasticity.

Abbreviations

MD: middle deltoid; SWV: mean shear wave velocity; SWE: shear wave elastography; BMI: body mass index; L0°: left shoulder 0° abduction; R0°: right shoulder 0° abduction; L90°: left shoulder 90° abduction; R90°: right shoulder 90° abduction.

Declarations

Funding

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Availability of data and materials

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Authors' contributions

LW analyzed the data and drafted the manuscript. LQ supervised in study design and critical review of the manuscript. XX collected the data. BZ interpreted the data. All authors read and approved the final manuscript.

Competing interest

The authors declare that they have no competing interests.

Consent for publication

Not applicable.

Ethics approval and consent to participate

The study was approved by the West China Hospital of Sichuan University Ethics Committee. Informed consent was obtained from all healthy participants.

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Tables

Table 1. Basic characteristics of the 70 healthy participants enrolled in this study

Characteristics	Healthy participants
Number	70
Female	35 (50.0%)
Male	35 (50.0%)
Age (y)	
Mean $\pm$ SD (Range)	42.10 $\pm$ 11.90 (19-70)
BMI, kg/m ²	23.20 $\pm$ 2.50
MD thickness (mm)	
L0°	14.6 $\pm$ 0.61
R0°	15.1 $\pm$ 0.51
L90°	20.6 $\pm$ 1.42
R90°	21.8 $\pm$ 1.40

Data are presented as mean $\pm$ SD (range) and number (percent) where applicable. SD = Standard deviation; BMI = body mass index; MD = middle deltoid; mm: millimeter; L0° = left shoulder 0° abduction; R0° = right shoulder 0° abduction; L90° = left shoulder 90° abduction; R90° = right shoulder 90° abduction.

Table 2. Intra-operator reproducibility of mean shear wave velocity of the MD at different shoulder abduction.

Shoulder abduction	SWV, m/s		ICC	P	R ²
	Operator A	Operator A'			
L0°	3.48 $\pm$ 0.28*	3.32 $\pm$ 0.56	0.85	< 0.01	0.654
R0°	3.66 $\pm$ 0.32	3.59 $\pm$ 0.29	0.91	< 0.01	0.929
L90°	5.58 $\pm$ 0.41	5.53 $\pm$ 0.72	0.95	< 0.01	0.932
R90°	5.93 $\pm$ 0.49	5.91 $\pm$ 0.66	0.96	< 0.01	0.971

ICC = intra-class correlation coefficient; SWV = mean shear wave velocity. * Mean $\pm$ standard deviation.

Table 3. Inter-operator reproducibility of mean shear wave velocity of the MD at different shoulder abduction.

Shoulder abduction	SWV, m/s		ICC	P	R ²
	Operator A	Operator B			
L0°	3.48 $\pm$ 0.28*	3.60 $\pm$ 0.39	0.89	< 0.01	0.755
R0°	3.66 $\pm$ 0.32	3.57 $\pm$ 0.78	0.92	< 0.01	0.862
L90°	5.58 $\pm$ 0.41	5.52 $\pm$ 0.61	0.91	< 0.01	0.902
R90°	5.93 $\pm$ 0.49	5.90 $\pm$ 0.52	0.93	< 0.01	0.965

ICC = intra-class correlation coefficient; SWV = mean shear wave velocity. * Mean $\pm$ standard deviation.

Table 4. Reference ranges of MD elasticity in healthy participants by gender at different shoulder abduction positions.

Shoulder abduction	Gender	SWV, m/s		
		Mean $\pm$ SD	95% CI	Reference range
L0°	Male	2.70 $\pm$ 0.18	2.7-2.8	2.4-3.1
	Female	2.59 $\pm$ 0.16	2.5-2.6	2.2-2.9
R0°	Male	2.90 $\pm$ 0.21	2.9-3.0	2.5-3.3
	Female	2.80 $\pm$ 0.17	2.8-2.9	2.4-3.2
L90°	Male/Female	5.80 $\pm$ 0.46	5.7-5.9	4.9-6.7
R90°	Male/Female	6.10 $\pm$ 0.50	6.0-6.2	5.2-7.1

SD, Standard deviation; MD, middle deltoid; SWV, mean shear wave velocity; CI, confidence interval. L0° = left shoulder 0° abduction; R0° = right shoulder 0° abduction; L90° = left shoulder 90° abduction; R90° = right shoulder 90° abduction.

Figures

Figure 1

SWE-mode (top panel) and B-mode (bottom panel) ultrasound images of the MD. A color map of MD elasticity is shown in the SWE box (thick arrow). The SWV in the Q-box (thin arrow) were presented on the right side of the image. The SWV at R0° was 2.8 m/s (Fig 1A), the SWV at R90° was 6.4 m/s (Fig 1B). SWE = shear wave elastography; SWV = mean shear wave velocity; MD = middle deltoid.

Figure 2

Box-and-whisker plots of the SWV in healthy participants with SWE between L0° and L90° (A), between R0° and R90° (B) through the paired t test. (A) . Difference of the SWV between L0° and L90°; (B). Difference of the SWV between R0° and R90°; ****, $p < .0001$. SWV = mean shear wave velocity.

Figure 3

Box-and-whisker plots of the SWV in healthy participants with SWE between $L0^\circ$ and $R0^\circ$ (A), between $L90^\circ$ and $R90^\circ$ (B) through the paired t test. SWV = mean shear wave velocity.

Figure 4

Box-and-whisker plots of the SWV in healthy participants between males and females at both L0° and R0° (A), both L90° and R90° (B). (A) . Difference of the SWV between female and male at L0° and R0°; (B). Difference of the SWV between females and males at L90° and R90°; ns, no significance; *, $p < .05$; **, $p < .01$. SWV = mean shear wave velocity.

Figure 5

Scatterplots of the SWV and MD thickness in healthy participants at L0° (A), R0° (B), L90° (C), and R90° (D). SWV = mean shear wave velocity; MD = middle deltoid.

Figure 6

Scatterplots of the SWV and age in healthy participants at L0° (A), R0° (B), L90° (C), and R90° (D). SWV = mean shear wave velocity.

Figure 7

Scatterplots of the SWV and BMI in healthy participants at L0° (A), R0° (B), L90° (C), and R90° (D). SWV = mean shear wave velocity; BMI = body mass index.