WITHDRAWN: Quantitative assessment of middle deltoid elasticity during different shoulder abduction using shear wave elastography: A preliminary study

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Research article

Keywords: Middle deltoid, Elasticity, Shear wave velocity, Reference ranges, Shear wave elastography

Posted Date: September 11th, 2020

DOI: https://doi.org/10.21203/rs.3.rs-34232/v2

EDITORIAL NOTE:

The full text of this preprint has been withdrawn by the authors while they make corrections to the work. Therefore, the authors do not wish this work to be cited as a reference. Questions should be directed to the corresponding author.

Abstract

Background: To measure the middle deltoid (MD) elasticity in healthy participants during different shoulder abduction (with bilateral shoulder in 0 degree abduction and 90 degree active abduction) using shear wave elastography (SWE) and analyze the factors that may affect the MD elasticity, and the objective of this study is to establish the reference ranges of normal MD elasticity during different shoulder abduction by using SWE.

Methods: Mean shear wave velocity (SWV) of the MD in 70 healthy right-handed participants (35 females, 35 males) were evaluated using SWE during different shoulder abduction, and potential factors that may affect MD elasticity including gender, MD thickness, age, body mass index were analyzed. Different shoulder abduction positions of each participant were as follows: (i) 0° abduction of bilateral shoulder (L0° and R0°), (ii) 90° active abduction of bilateral shoulder (L90° and R90°). Reference ranges of normal MD elasticity were calculated using normal distribution method.

Results: Mean SWV was 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°, and R90° with SWE are different. A separate reference range of normal MD elasticity at L0°, R0°, L90°, and R90° should be used. Moreover, the reference ranges of normal MD elasticity at L0° and R0° shoulder be divided by gender. These values may serve as quantitative baseline measurements for assessment of 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 [2]. Many shoulder pain may be related to instability induced by increased tension of shoulder muscles [1, 3]. Deltoid plays an important role in maintaining shoulder stability and movement. Middle deltoid (MD), a vital segment of deltoid, plays a great role in elevating the arm in the scapular plane and mainly acts on shoulder abduction [1, 4]. MD is prone to muscle strain due to increased tension produced by excessive muscle contraction [3-4]. The initial symptoms of the MD muscle strain mostly manifest as muscle weakness when shoulder movement, and then muscle pain. Although the MD morphology may not change in the early stage of MD muscle strain, the MD muscle function (e.g. muscle force, muscle elasticity) may change. Furthermore, MD muscle strain is hard to be early assessed by conventional methods. Electromyography (EMG) is a popular method for evaluating muscle function. However, it cannot assess individual muscle activity due to the influence of electrical activity in adjacent muscles [5-6]. The isokinetic dynamometer and handheld dynamometer are feasible methods to assess muscle force. Nevertheless, there are some disadvantages such as a more complicated measurement technique with the isokinetic dynamometer and lack of stabilization with the handheld dynamometer. Moreover, they lack the ability to quantitatively assess muscle elasticity [7-8]. The change in elasticity of the MD may result in imbalance of the scapular force and cause shoulder pain [4, 9]. Measuring MD elasticity could help to diagnose whether there is MD muscle strain. Therefore, it is imperative to find a new mean for evaluating the MD elasticity.

Shear wave elastography (SWE) as a new ultrasound-based elastography technique, quantitatively providing the biomechanics parameters of the muscles such as muscle elasticity, has good repeatability and reproducibility [10-11]. Excellent reliability and feasibility for assessing the deltoid using SWE were reported [4, 12-13]. SWE can quantitatively evaluate muscle elasticity through elastic parameters such as shear wave velocity (SWV) and Young's modulus [10, 14]. The original measurement recorded with SWE is SWV, and then SWV is mathematically converted to Young's modulus for each pixel. Furthermore, there are additional potential inaccuracies when converting SWV to Young's modulus [10, 11, 14-15]. Thus, for skeletal muscles, SWV may be a better index for assessing muscle elasticity.

However, there is little research on MD elasticity during different shoulder abduction using SWE. Moreover, the reference range of normal MD elasticity has not yet been established. Studies on potential factors affecting normal MD elasticity are also extremely lacking. Our hypothesis is that if the reference ranges of normal MD elasticity using SWE during different shoulder abduction can be established, it may be helpful to further assess MD muscle strain. Therefore, to assess the reference range of normal MD elasticity during different shoulder abduction is required.

The objective of this study is to determine the reference ranges of normal MD elasticity during shoulder 0° abduction and shoulder 90° active abduction for bilateral examination using SWE. It may serve as a quantitative baseline measurement for the assessment of 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. Participants were recruited between December 2018 and May 2019. The inclusion criteria were as follows: (i) healthy adults (≥18 years old); (ii) all participants were right-handed; (iii) deltoid with grade 5 muscle strength without shoulder pain; (iv) good compliance with examination. The exclusion criteria were as follows: (i) pregnancy in women; (ii) shoulder surgery or trauma; (iii) taking myorelaxants and other drugs affecting muscle elasticity; (iv) a history of tumor, rheumatoid, immune, metabolic, endocrine diseases, or musculoskeletal diseases.

Examination by SWE

The device used to obtain 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. The musculoskeletal mode was preset. The ultrasound probe was placed parallel to the muscle fiber orientation [16]. The tip of the transducer was covered with several millimeters of US gel and placed perpendicularly to the shoulder skin smoothly without applying any pressure on the skin [17]. All participants were prohibited from exercising for 72 hours before the experiment. And they were instructed to stay completely rested for 20 minutes before the examination. The SWE examination was performed on all participants by two experienced sonographers (A and B) who received SWE training. They were blinded to each other's results for the entire study. 20 participants were randomly selected for consistency analysis. These 20 participants were examined by sonographer B and then measured again by sonographer A on the second day. The 20 participants were recalled to be checked again by sonographer A after a 1-wk interval.

Different shoulder abduction positions in this study were as follows: left and right shoulder 0° abduction (L0° and R0°), left and right shoulder 90° active abduction (L90° and R90°). Each participant was asked to stand straight with the head in neutral position. The angle of shoulder active abduction was measured by a manual goniometer to ensure the reliability and consistency. All participants were strictly examined according to the following unified procedure: (i) During shoulder 0° abduction, the participants stayed fully relax, and upper arm rested gently against the chest wall at 0° abduction angle, with elbows at 90 degrees of flexion, with upper arm in the same plane of the chest wall (Fig. 1A, B); (ii) During shoulder 90° active abduction, arm was actively positioned at 90° abduction angle, with the elbow fully extended and palms down, with arm in the same plane of the chest wall (Fig. 1C, D). And they were asked to maintain each shoulder abduction position for thirty seconds to cooperate with our inspection and obtain stable SWE images. To avoid muscle fatigue, the participants were asked to relax for 3 minutes after the examination of every shoulder abduction position.

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. Fig. 2 illustrates that the system automatically calculated the SWV values for the Q-box area expressed in m/s at R0° and R90°. SWV was measured in a round area called Q-box. The size of Q-box was fixed as a diameter of 8 mm in our study, and Q-box positioning was within the square region of interest (ROI) colormap, avoiding the deep and superficial fascia of the MD. The size of the ROI was adjusted according to the thickness of the target MD. The measurement site of the target MD was fixed at the midpoint level of the MD muscle belly. Specifically, skin surface landmark was at the midpoint from deltoid tuberosity to the midpoint of the acromion [18]. In this region, muscle fibers of the targeted MD were basically parallel an the ROI colormap was stable in our study.

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, and goodness of fit (R^2) was obtained by linear regression analysis 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 1.96 × SD (the standard deviation of mean SWV) and mean SWV 1.96 × SD, respectively [17]. Two-sided $P< 0.05$ was considered statistically significant.

Results

Study population

The basic characteristics of 70 healthy subjects were summarized in Table 1. There were 35 males and 35 females in total subjects. The mean age ± SD was 42.10 ± 11.90 years (range, 19-70 years). The mean BMI was 23.20 ± 2.50 kg/m^2. The mean MD thickness was 14.60 ± 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

Table 2 and 3 showed that ICC and R^2 values reflected the excellent intra- and inter- operator reproducibility of the MD elasticity measurement during different shoulder abduction in our study. The intra- and inter-operator reproducibility of the mean SWV of the MD at bilateral shoulder 0° abduction and 90° active abduction were listed in Table 2 and 3. The ICC values showed 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 significantly higher at L90° than L0° ($p< 0.0001$; Fig. 3A), and higher at R90° than R0° ($p< 0.0001$; Fig. 3B). Mean SWV was also significantly higher at R0° than L0° ($p< 0.0001$; Fig. 4A), and higher at R90° than L90° ($p< 0.0001$; Fig. 4B).

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. 5B), but mean SWV at both L0° ($P< 0.05$) and R0° ($P< 0.01$) were significantly higher in males than in females (Fig. 5A).

Influence of MD thickness

MD thickness was not significantly correlated with mean SWV at R0° ($R= -0.13$, $P= 0.3$, > 0.05), L90° ($R= -0.087$, $P= 0.48$, > 0.05) and R90° ($R= -0.004$, $P= 0.97$, > 0.05) (Fig. 6B, C, D). Slight statistically positive correlation can be ignored at L0° ($R= -0.41$, $P< 0.01$) (Fig. 6A) between mean SWV and MD thickness.

Influence of age

There was no 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. 7A, 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. 8B, C, D). Slight statistically positive correlation can be ignored at L0° (R= 0.31, P= 0.0092, < 0.05) (Fig. 8A) 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 only affected by gender, yet the reference ranges of normal MD elasticity at L90° and R90° were not affected by 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

The present study found that MD elasticity was higher on the right than on the left at both shoulder 0° abduction (P< 0.0001) and 90° active abduction (P< 0.0001). It may be because right arm is used more frequently than left one (all participants were right-handed in this study). Moreover, MD elasticity was higher at R90° than R0° (P< 0.0001), at L90° than L0° (P< 0.0001). It may be due to intense contraction of the MD during shoulder 90° active abduction. During shoulder active abduction, the MD produces active tension produced by MD muscle contraction, thereby increasing MD elasticity [3, 19, 20]. Particularly, gender had impact on MD elasticity at both L0° (P< 0.05) and R0° (P< 0.01), maybe indicating there is the obvious difference in the MD muscle size and component at shoulder 0° abduction between different gender [21, 22]. Haizlip et al [23] showed that collagen and elastin architectures of muscle fibers mainly determined muscle elasticity between male and female. We also found excellent inter- and intra-operator reproducibility using SWE to measure MD elasticity at L0°, R0°, L90°, and R90°. The reasons for excellent intra- and inter-operator reproducibility in our study are as follows: standardized examining method and training and skilled sonographers, the basically parallel muscle fibers of the target MD. This shows that SWE is a reliable technique for assessing MD elasticity.

This study is original from several perspectives using SWE. The new technique called SWE can quantitatively reflect biomechanics changes of muscles contractility. Increased muscle elasticity during shoulder active abduction, resulting from muscle contraction, is an especially exciting area for clinical integration of ultrasound elastography [6, 12, 24]. Firstly, it may be the first study to quantitatively assess normal MD elasticity by measuring the SWV during different shoulder active abduction. One the one hand, many previous studies have been about the effects of different head postures on neck or shoulder muscles [25-26]. Meanwhile, reviewing the literature, we found that few studies have focused on muscle elasticity during different shoulder active abduction of bilateral shoulder. On the other hand, elastic parameter of most previous researches on assessing muscle elasticity by SWE have almost been Young's modulus [27-28]. Nevertheless, our study assessed MD elasticity according to the elastic parameter SWV [10, 11, 14]. 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 these potential factors as we did. Thirdly and most importantly, the clinical significance of establishing reference ranges of normal MD elasticity lies in providing preliminary exploration for serving as the baseline measurement of normal MD elasticity. Using this new ultrasound elastography technique SWE, the reference ranges of normal MD elasticity have hardly been studied before [29-30]. If reference ranges of normal MD elasticity can be generalized to a larger healthy population in the future, the clinical significance will be even greater. Moreover, these reference ranges maybe provide a further reference for early diagnosis of MD muscle strain in the future. Our study can also provide some new ideas for future muscle elasticity evaluation under different muscle contractions using SWE.

There are several limitations in the current research. The number of participants is the small sample as a preliminary study. Moreover, as a preliminary study, we only studied the reference range of normal MD elasticity during shoulder active abduction. Therefore, in order to extend the reference ranges of normal MD elasticity to the larger healthy population, we will increase sample size and conduct multi-center studies in the next step. And the normal reference ranges of whole deltoid elasticity during different shoulder passive abduction can also been studied in the future.

Conclusions

Our results suggest that the normal MD elasticity at L0°, R0°, L90°, and R90° with SWE are obviously different. A separate reference range of normal MD elasticity at L0°, R0°, L90°, and R90° should be used. Moreover, the reference ranges of normal MD elasticity at L0° and R0° shoulder be divided by gender. These values may serve as quantitative baseline measurements for assessment of normal MD elasticity.

Declarations

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.

Consent for publication

All the authors consent for publication. All participants gave consent for publication of their identifying images and other clinical details in the case of compromise anonymity.

Availability of data and materials

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

Competing interests

The authors declare that they have no competing interests.

Funding

This study was supported by the Sichuan Science and Technology Program in China (2019YFS0219).

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.

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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° active abduction; R90°: right shoulder 90° active abduction.

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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)	
All	42.10 ± 11.90
Female	45.90 ± 12.30
Male	38.30 ± 11.06
BMI, kg/m^2	
All	23.20 ± 2.50
Female	22.90 ± 2.23
Male	23.50 ± 2.5 9
MD thickness (mm)	
L0°	14.60 ± 0.61
R0°	15.10 ± 0.51
L90°	20.60 ± 1.42
R90°	21.80 ± 1.40

Data presented as mean ± SD 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° active abduction; R90° = right shoulder 90° active abduction.

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

Shoulder abduction	SWV, m/s		ICC	P	R^2
	A1	A2			
L0°	3.48 ± 0.28	3.32 ± 0.56	0.85	< 0.01	0.654
R0°	3.66 ± 0.32	3.59 ± 0.29	0.91	< 0.01	0.929
L90°	5.58 ± 0.41	5.53 ± 0.72	0.95	< 0.01	0.932
R90°	5.93 ± 0.49	5.91 ± 0.66	0.96	< 0.01	0.971

A1 = Operator A first measurement; A2 = operator A second measurement. SWV = mean shear wave velocity; ICC = intra-class correlation coefficient; R^2 = goodness of fit. Data are presented as mean ± standard deviation where applicable.

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

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

SWV = mean shear wave velocity; ICC = intra-class correlation coefficient; R^2 = goodness of fit. Data are presented as mean ± standard deviation where applicable.

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

Shoulder abduction	Gender	SWV, m/s		
		Mean ± SD	95% CI	Reference range
L0°	Male	2.70 ± 0.18	2.7-2.8	2.4-3.1
	Female	2.59 ± 0.16	2.5-2.6	2.2-2.9
R0°	Male	2.90 ± 0.21	2.9-3.0	2.5-3.3
	Female	2.80 ± 0.17	2.8-2.9	2.4-3.2
L90°	Male/Female	5.80 ± 0.46	5.7-5.9	4.9-6.7
R90°	Male/Female	6.10 ± 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° active abduction; R90° = right shoulder 90° active abduction.

Figures

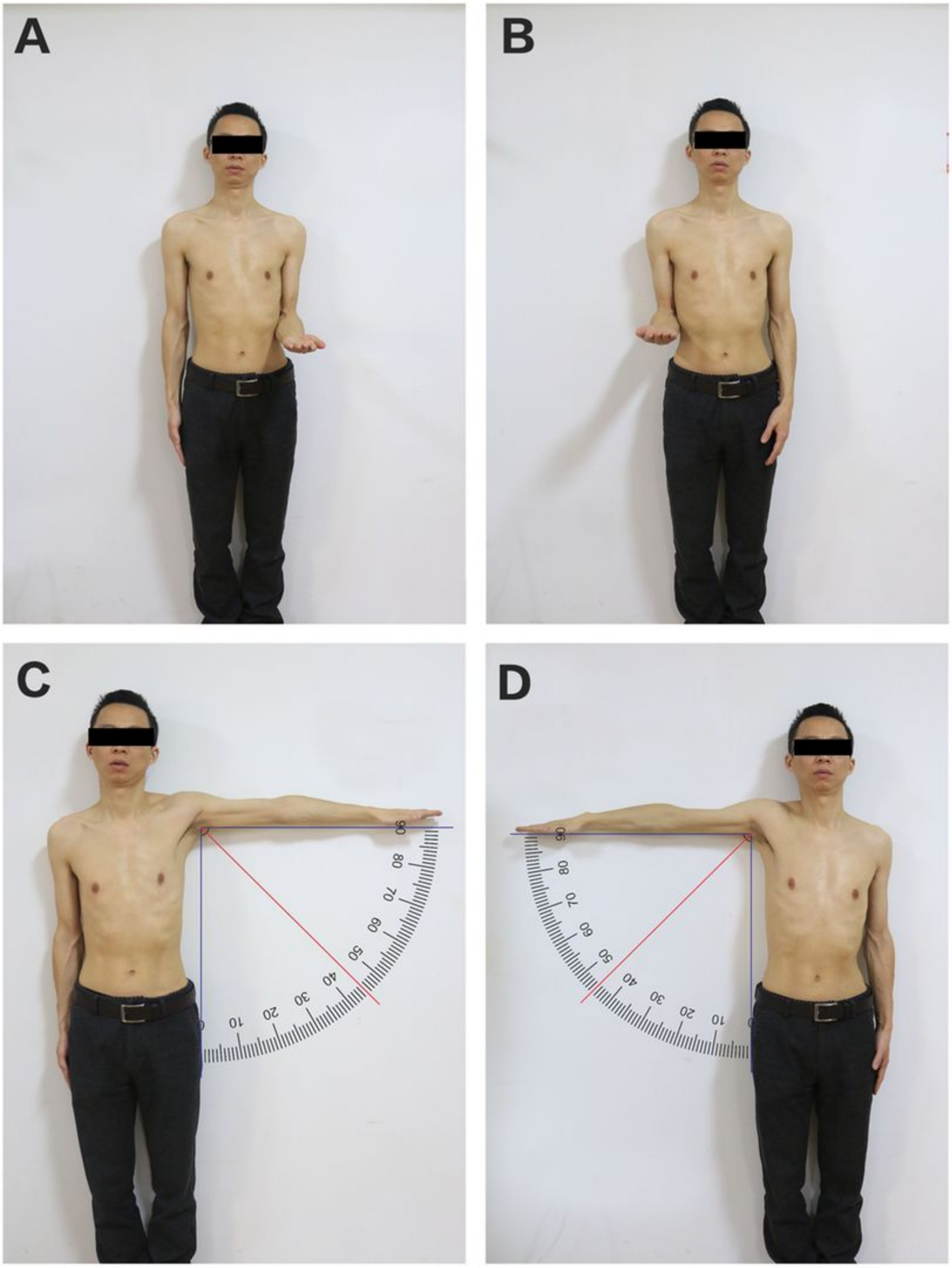

Figure 1

Different shoulder abduction positions of MD elasticity measurements using SWE in this study. L0° = left shoulder 0° abduction (A); R0° = right shoulder 0° abduction (B); L90° = left shoulder 90° active abduction (C); R90° = right shoulder 90° active abduction (D).

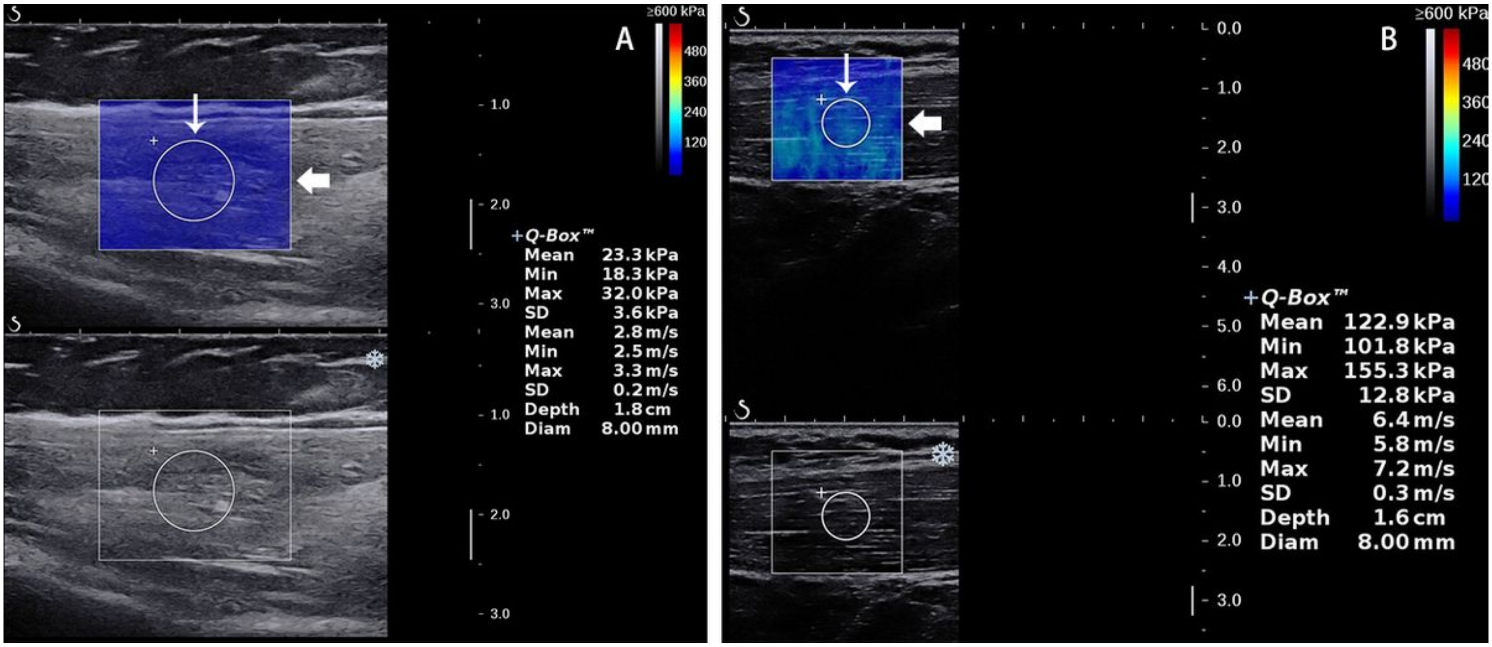

Figure 2

SWE (top panel) and B-mode (bottom panel) ultrasound images of the MD. A color map of MD elasticity is shown in the square ROI (thick arrow) and round Q-box (thin arrow). SWE = shear wave elastography; SWV = mean shear wave velocity; MD = middle deltoid.

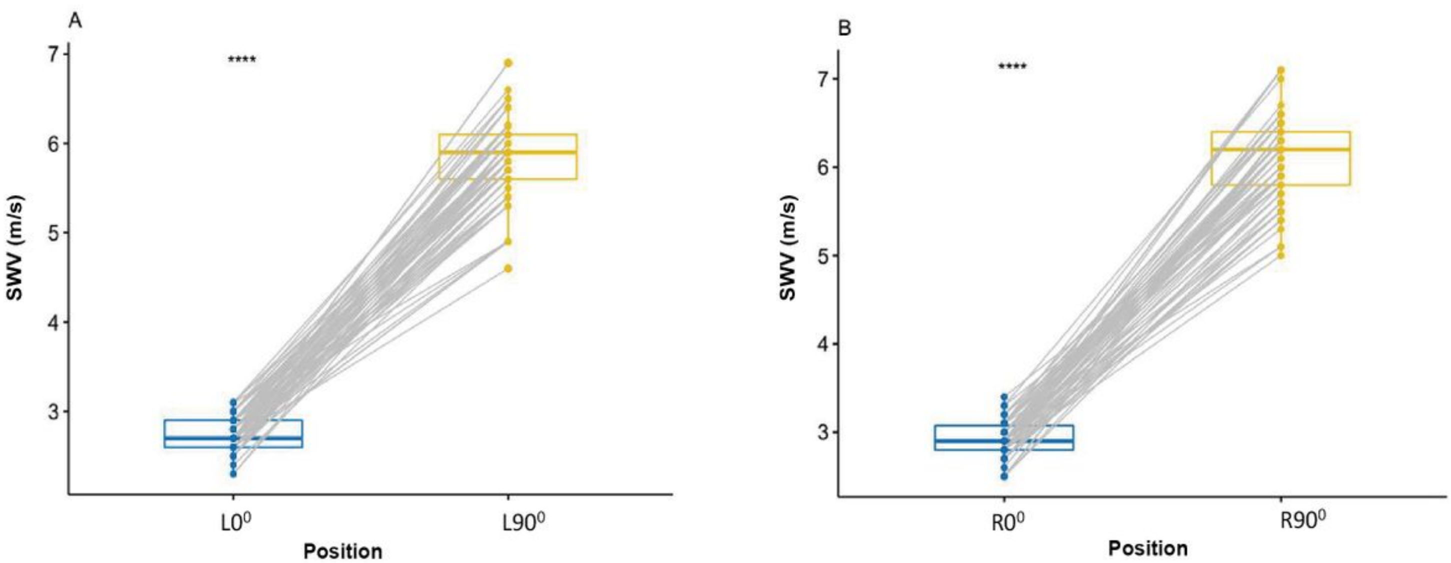

Figure 3

Box-and-whisker plots of the SWV in healthy participants using SWE between L0° and L90° (A), between R0° and R90° (B). (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.

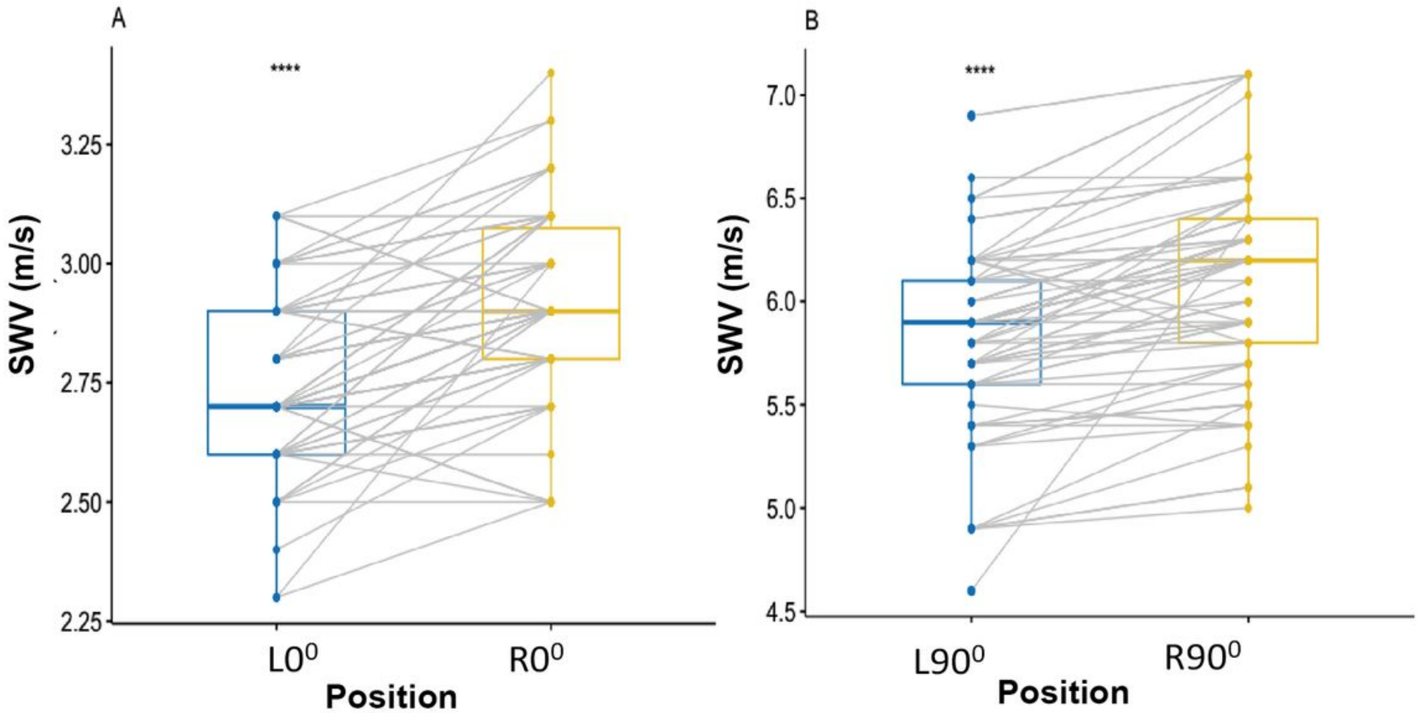

Figure 4

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

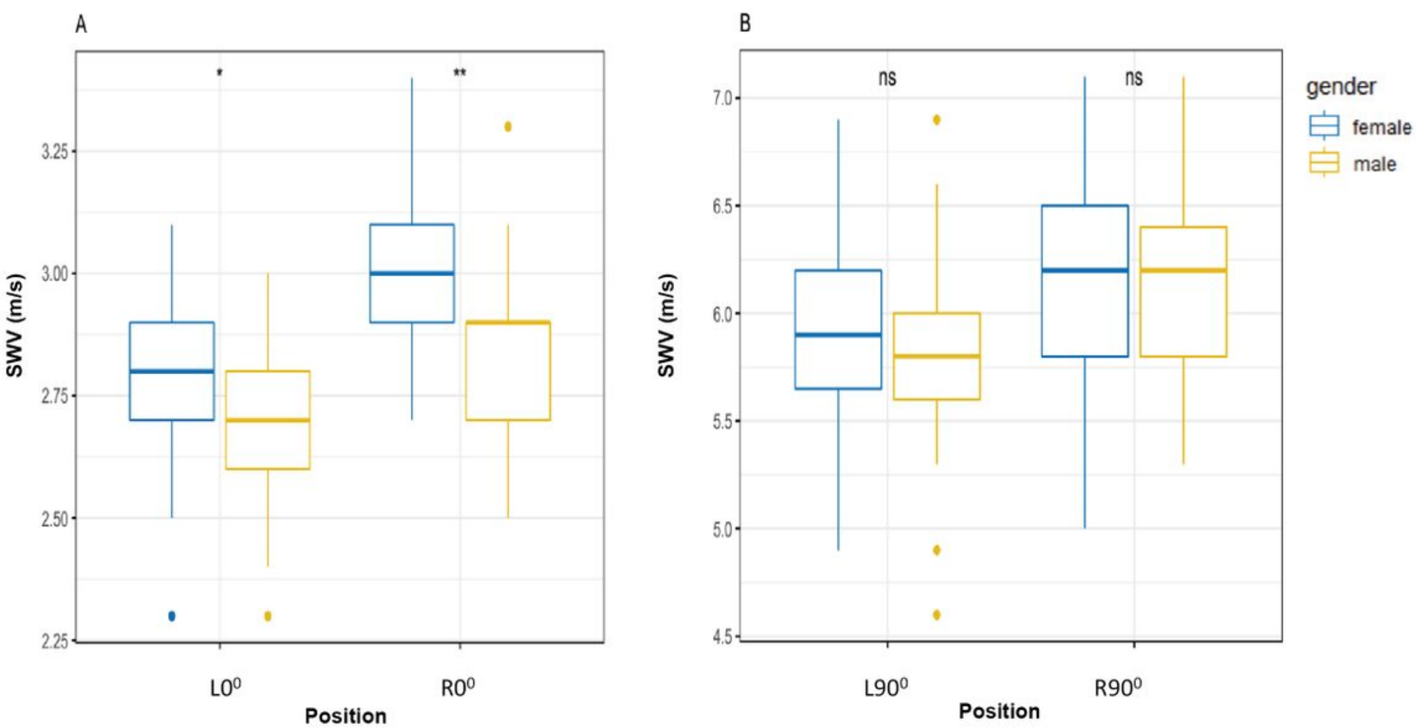

Figure 5

Box-and-whisker plots of the SWV in healthy participants between genders at both L0° and R0°, both L90° and R90°. (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.

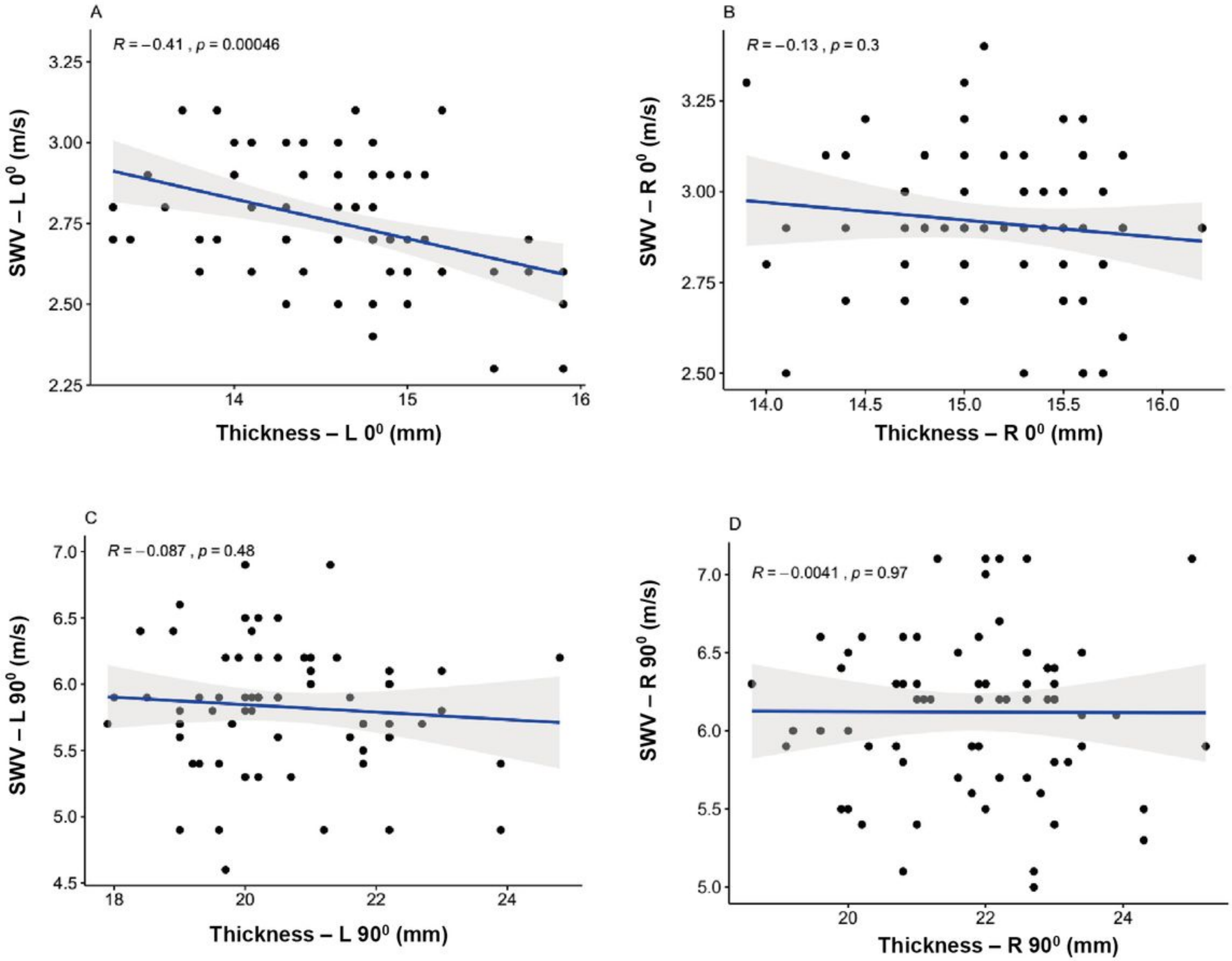

Figure 6

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

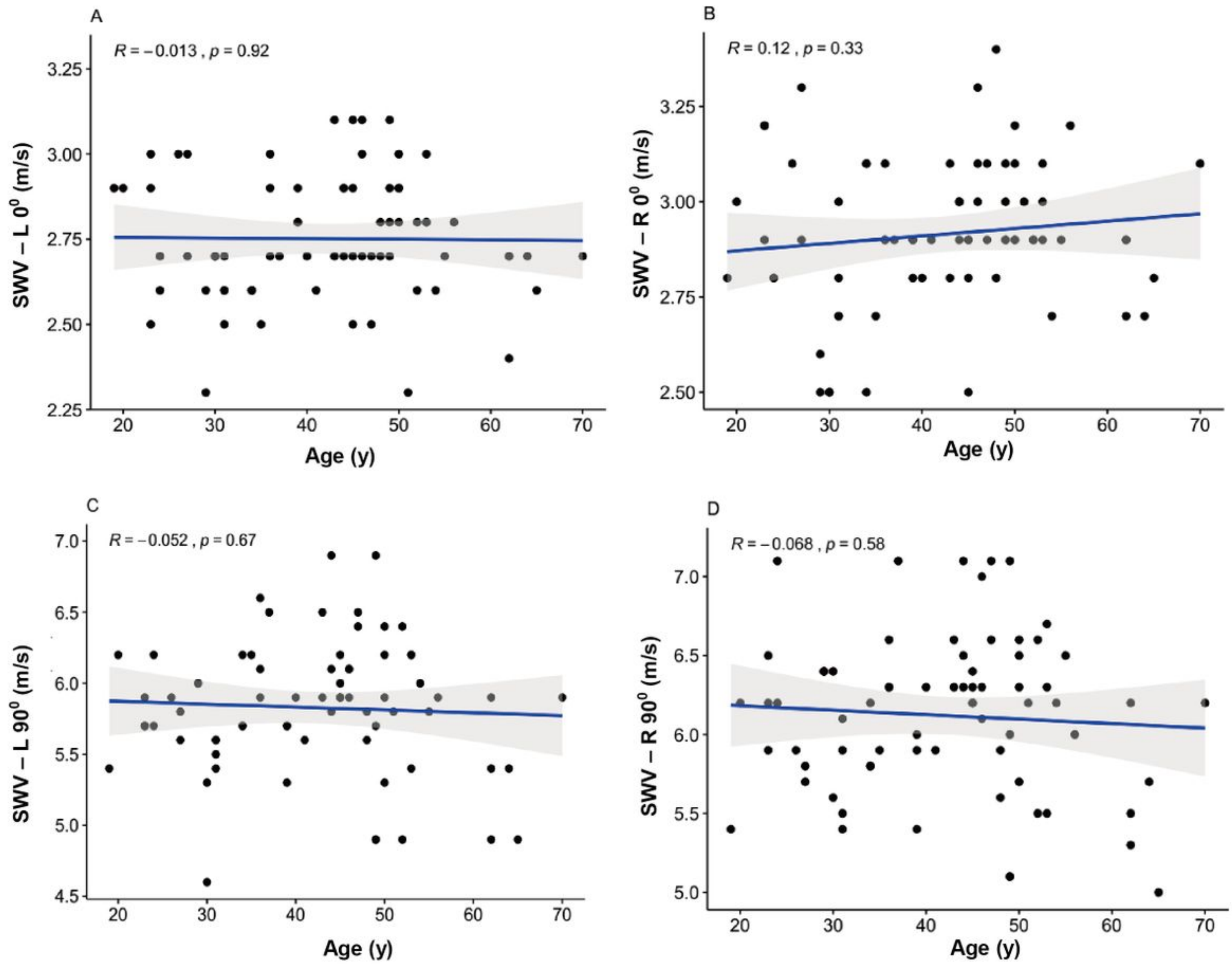

Figure 7

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

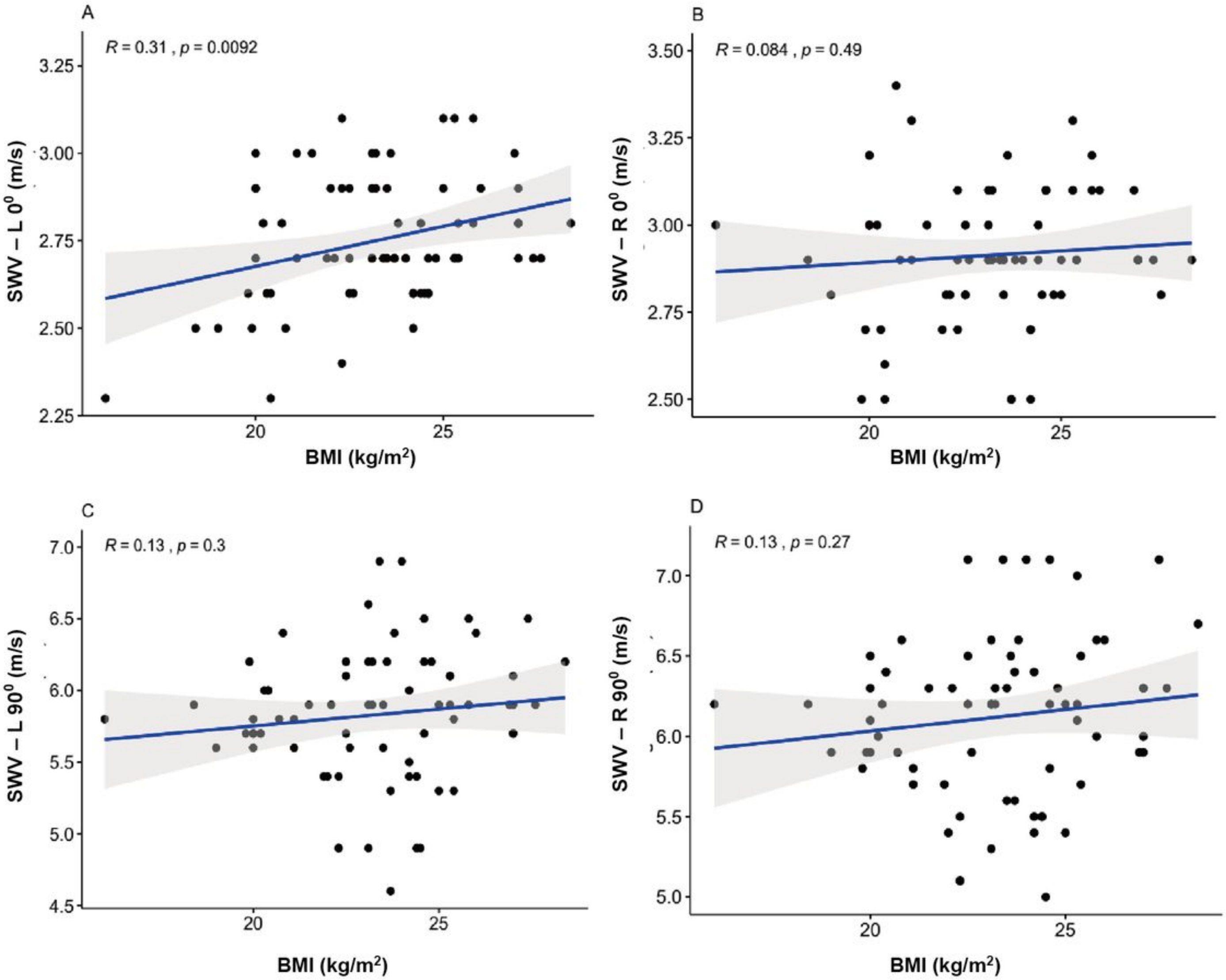

Figure 8

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