Contents lists available at ScienceDirect

Asia-Pacific Journal of Sports Medicine, Arthroscopy, Rehabilitation and Technology

journal homepage: www.ap-smart.com

Original Article

Agreement in rotator cuff muscles measurement between ultrasonography and magnetic resonance imaging

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ARTICLE INFO

ABSTRACT

Background/objective: It is important to assess the atrophy of the rotator cuff to better understand shoulder function and pain. Previously, magnetic resonance imaging has been used for the evaluation of atrophy of rotator cuff muscles, which is time consuming. Therefore, a measurement tool requiring little time and easy accessibility is clinically desirable to be used frequently in rehabilitation. Recently, rotator cuff muscles have been evaluated using ultrasonography. However, little is known about the agreement of evaluation in rotator cuff muscles between magnetic resonance imaging and ultrasonography. The purpose of this study was to demonstrate the agreement between the muscle thickness measurements of supraspinatus, infraspinatus, and teres minor muscles by ultrasonography and the cross-sectional area measured by magnetic resonance imaging in the patient with rotator cuff tears.
Methods: A total of 47 patients with rotator cuff tears were enrolled. There were the 37 small tears, four medium tears, and six large tears, and the involved rotator cuff muscles were the supraspinatus in 37 shoulders, and the supraspinatus and infraspinatus in 10 shoulders. The measuring variables were muscle thickness and cross-sectional area of supraspinatus, infraspinatus, and teres minor muscles by using magnetic resonance imaging. Further, the muscle thickness of the rotator cuff were assessed using ultrasonography. A single regression model was used for demonstrating the agreement between the cross-sectional area measurement by magnetic resonance imaging and the muscle thickness measured using ultrasonography and magnetic resonance imaging of rotator cuff muscles. Additionally, the Bland-Altman plots between magnetic resonance imaging and ultrasonography was analyzed.
Results: The cross-sectional area were correlated with the muscle thickness measurement of rotator cuff muscles by magnetic resonance imaging, significantly (supraspinatus: $r = 0.84$, infraspinatus: $\rho = 0.63$, teres minor: $\rho = 0.61$, all $p < 0.001$). There were significant agreements between the cross-sectional area measured by magnetic resonance imaging and muscle thickness measured by ultrasonography (supraspinatus: $r = 0.80$, infraspinatus: $\rho = 0.78$, teres minor: $\rho = 0.74$, all $p < 0.001$). Bland-Altman plots revealed significant correlations between the average and the difference of the two measurements in supraspinatus ($r = 0.36$, $p = 0.012$), infraspinatus ($r = 0.38$, $p < 0.001$), and teres minor ($r = 0.42$, $p < 0.001$). These results clarified the proportional bias between MRI and US.
Conclusion: This study showed that, similar to magnetic resonance imaging, ultrasonography is a useful tool for assessing muscle atrophy of supraspinatus, infraspinatus, and teres minor muscles.

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1. Introduction

It has been reported thatthe atrophy of rotator cuff muscles influences the conservative and postoperative clinical outcomes.[1–6]Preoperative atrophy of the supraspinatus (SSP) muscle is known to correlate withthehigh recurrence rate of repaired tendon tear after the surgery.[4]Therefore,Melis et al.[7]suggested that surgery for rotator cuff tears should be done before the appearance of atrophy of the SSP.On the other hand,the unaffected rotator cuff could hypertrophy tocompensatefor the lost function in thepatientswith rotator cuff tears.Kikukawa et al.[8,9]demonstrated that patients withSSP andinfraspinatus (ISP) tear showed hypertrophy of the teres minor (TM) muscle, and thishypertrophicchangecontributedto the greater strength and range of motion in external rotation in RCT patients. Thereby,the goal of the rehabilitation targeted the improvement of the atrophy in rotator cuff muscles because the shoulder function was determined by the muscle size. For this reason, it is important to assess the atrophy of rotator cuff to confirm the effect of the rehabilitation.Previously, magnetic resonance imaging (MRI) has been used for the evaluation of atrophy of rotator cuff muscles.[1,2,5,7,10–13]However, MRI evaluation is time consuming; hence, a measurement tool requiring little time and easy accessibility is clinicallydesirable to be used frequently in rehabilitation.Therefore, ultrasonography (US) is an alternative imaging maneuver in rotator cuff pathology because of the measurement easily many times.

Recently, the presence or absence of rotator cuff tear has been determined using ultrasonography (US).[14]Atrophy of rotator cuff muscles has also been evaluated with US.[15,16]In these previous studies, the atrophy of SSP muscle was assessed by the occupation ratio with US; cross-sectional area of SSP muscle belly divided by the surface area of scapular fossa.[17–20]However, the agreement between occupation ratio measured by US and MRI was 0.43 shown by Kim et al.,[20]and 0.90byKhoury et al.[17] Thus, discrepancy was reported for this agreement. Additionally, priorresearchedhave demonstrated the intra-rater reliability of the occupation ratio using US, and thesevalues were 0.43, 0.52, and 0.91,[18,20,21]indicatinginconsistentresults. The measurement for the occupation ratio has an advantagethat it cannormalizethebody size.Nevertheless, it takes much times and efforts to analyze this ratio. Therefore, the measurement of muscle thickness could be a more suitable evaluation for muscle atrophy in clinical practice.Asinprevious literatures, the correlation between muscle thickness of SSP measured by US and the cross-sectional area using MRI was 0.60, and 0.76.[19,21]Nevertheless, little research has been conducted to showthe agreement betweenthe cross-sectional area of ISP and TM measured by MRIandthe muscle thicknessmeasuredby US. Also, the muscle thickness of SSP was evaluated at the scapular notch.[21]However, Yanagisawa et al.[22]demonstrated that the thickest of SSP was measured at the mid-point of scapular spine. Therefore, the stronger correlationinSSPmeasurementbetween US and MRI could possibly be expected at this site.

The purpose of this study was to demonstrate the agreement between the muscle thickness measurements ofSSP, ISP, and TMby US and the cross-sectional area measured by MRI in the patient with rotator cuff tears.

2. Materials and methods

This study was the case series with no comparison groups. All participants were recruited at Nobuhara hospital (Hyogo pref., Japan). Written informed consent was obtained from all subjects before participation, and the study was approved by the institutional review board.

2.1. Subjects

The patients with rotator cuff tears participated in this study, and rotator cuff tear was diagnosed using MRI (APERTO Eterna; Hitachi Medical Corporation, Tokyo, Japan). Fatty infiltration was assessed by Goutallier classification; grade 0: no fatty degeneration, grade I: fatty streaks, grade II: fat < muscle, grade III: fat = muscle, grade IV: fat > muscle.[23] The exclusion criteria were rotator cuff tears with supraspinatus tendon retracted to the humeral head; Patte classification stage II & III,[24] massive rotator cuff tears; two or more tendon tears,[25] previous shoulder surgery, rheumatoid arthritis, cervical spine disease, and neurological disease. The preliminary calculation for the sample size by using G* Power 3.1 software (Heinrich Heine University, Duesseldorf, Germany) showed that 42 subjects were needed for this study (effect size = 0.5, α = 0.05, power = 0.95) based on the data by O'Sullivan et al.[26]

2.2. MRI

MRI was performed to obtain shoulder images (0.4 T, echo time = 98 ms, repetition time = 3500 ms, flip angle = 90°, reconstruction matrix = 512, bandwidth = 24.1 kHz, field of view = 170 mm, slice thickness = 4 mm, gap space = 0.5 mm). The patients were set in supine position with the shoulder coil at arm dependent position in neutral position. The cross-sectional area and muscle thickness of the SSP, ISP, and TM were measured using T2 weighted oblique sagittal plane MR images, in which the coracoid process and the scapular plane led to the Y section, following previous studies (Fig. 1).[2,10] The cross-sectional area was analyzed using the contour line of the SSP, ISP, and TM, which was drawn along the muscle belly without the fat. The muscle thickness of the SSP and ISP were measured at the intersectional point between the coracoid process and the scapular plane, and TM was quantified at the inferior angle of the scapula. MRI was performed by the radiologist (Y. T.) with 19 years experiences of musculoskeletal scanning.

2.3. US images

The thickness of the muscle belly of SSP, ISP and TM in B mode images were obtained with US(UF450AX Bettius; Fukuda Denshi Co. Ltd., Tokyo, Japan) with a 38 mm linear array transducer (7 MHz), following previous studies.[15,16,27] The patients were asked to relax in sitting position. The measurement was taken twice, and the mean values were analyzed. The SSP was measured in the modified Crass position (the subject's hand was placed on the iliac crest).27 For the measurements of the ISP and TM, the subjects were asked to place their hand on the contralateral shoulder and stay relaxed; horizontal adduction position. The muscle belly thickness of the SSP was measured using transverse images taken with the transducer placed above the midpoint between the acromial angle and the medial edge of the scapular spine (Fig. 2A). To measure the muscle belly thickness of the ISP, the transducer was placed below the midpoint between the acromial angle and the medial edge of the scapular spine to scan the transverse images (Fig. 2B). The muscle belly of the TM was measured using transverse images taken with the transducer placed perpendicular to the muscle belly at the midpoint between the acromial angle and the inferior angle of the scapula (Fig. 2C). The thickness of the muscle belly of the rotator cuff muscles was measured at the center of the images. Ultrasound scanning was performed by the physical therapist (Y. U.), who had been working at an orthopedic hospital for 13 years and was experienced in musculoskeletal ultrasound scanning. The software Image J (National Institutes of Health, Bethesda,
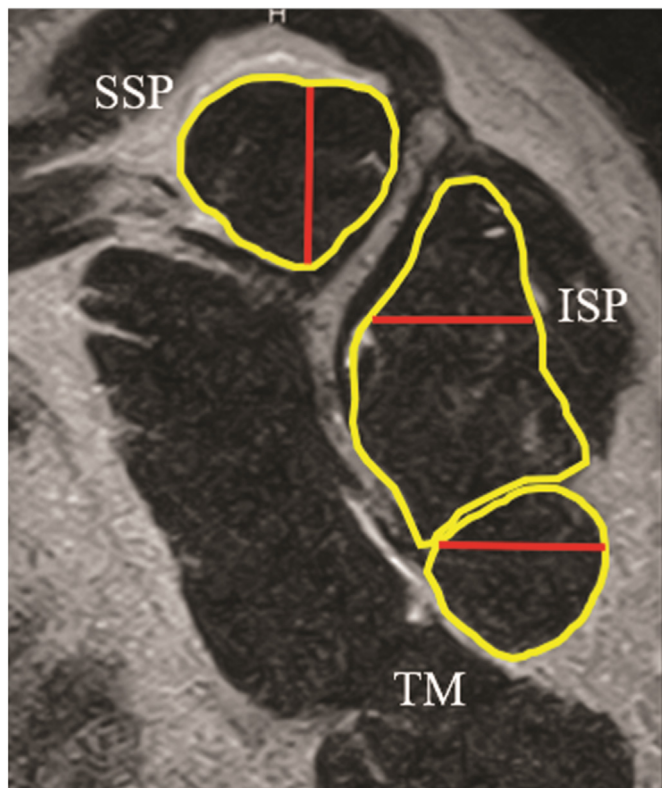
Fig. 1. Measurements of the cross-sectional area and muscle thickness of rotator cuff muscles with MRI Cross-sectional area of rotator cuff muscles are indicated with yellow encircling lines, and the muscle thickness are marked by red lines. SSP, supraspinatus; ISP, infraspinatus; TM, teres minor. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

MD, USA) was used for the analyses of the thickness and cross-sectional area of rotator cuff muscles with MRI and US by a single physical therapist (Y. U.).

2.4. Statistical analysis

A statistical package (SPSS version 22; IBM, Armonk, NY, USA) was used for calculations. First, data normality was examined using the Shapiro Wilk test, and the intrarater reliability and standard error of measurement (SEM) with US were obtained to check the intraclass correlation coefficient (ICC). The ICC model was based on a one-way analysis for variance (twice measures). Then, the coefficient of determination and the root mean squared error (RMSE) from single linear regression were calculated to predict the cross-sectional area measured by MRI from the thickness of the rotator cuff muscles measured by MRI and US. Additionally, a correlation analysis was performed to demonstrate the relationship between the muscle thickness of rotator cuff muscles measured by MRI and US. Pearson or Spearman correlation analysis was conducted according to the distribution of data.

Coefficient of variations (CV) was calculated for comparing the variation of the two measurements. Additionally, Bland and Altman plots[28] were generated to analyze the systematic errors between the cross-sectional area estimated from the thickness of the rotator cuff muscles measured using US and the measured values of cross-sectional area by MRI. These plots could show systematic errors by demonstrating the averages of the two measurements plotted on the horizontal axis against the differences between the two measurements plotted on the vertical axis. The proportional bias between the two measurements was determined using the significant correlation obtained through linear regression analysis of the Bland and Altman plots. To evaluate the presence of fixed bias between the two measurements, the 95% confidence limit for the mean difference (mean $\pm$ 1.96 standard deviation) was used to determine whether the mean difference was identical to zero. If the 95% confidence limits excluded zero, the two measurements were assessed to have fixed bias. Statistical significance was set at $p < 0.05$ for all calculations.

3. Results

Sixty-four patients were recruited in this study, however 17 patients were excluded because of the tear size, the history of shoulder surgery, and cervical spine disease. Therefore, 47 patients with rotator cuff tears participated in this study (mean age: 66.4 ± 6.7, 26 men and 21 women). MRI revealed 25 shoulders with partial thickness tear and 22 shoulders with full thickness tear. There were the 37 small tears, four medium tears, and six large tears, and the involved rotator cuff muscles were the SSP (37 shoulders), the SSP and ISP (ten shoulders). Moreover, Goutallier classification in the subjects was grade 0 in three, grade I in 28, grade II in 13, grade III in three patients, and no patients were graded IV.

The Shapiro Wilk test showed that the measurement data of the cross-sectional area of the ISP ($p = 0.030$) and TM ($p = 0.005$) measured by MRI were not normally distributed. On the other hand, the other measurement data by US and MRI demonstrated a normal distribution. With respect to the intrarater reliability of muscle thickness measured using US, the $ICC_{1,2}$ and SEM values were 0.97 [95% confidence interval (CI): 0.94 to 0.99] and the 0.5 mm for the SSP, 0.98 (95% CI: 0.95 to 0.99) and 0.5 mm for the ISP, and 0.96 (95% CI: 0.93 to 0.98) and 0.5 mm for the TM respectively. Measurement data by MRI and US were shown on Table 1.

The results of single linear regression between the muscle thickness and cross-sectional area of the rotator cuff measured by MRI were shown in Fig. 3 (SSP: $r = 0.84$, RMSE = 81.4 mm^2; ISP: $\rho = 0.63$, RMSE = 141.6 mm^2; TM: $\rho = 0.61$, RMSE = 58.4 mm^2). Further, there were significant correlations between the

Fig. 2. Measurement of the muscle thickness of the rotator cuff with US The illustration image shows the measurement of the muscle thickness of the SSP (A), ISP (B), and TM (C). UFT, Upper fibers of trapezius; SSP, supraspinatus; ISP, infraspinatus; TM, teres minor.

Table 1
Measurement values of cross-sectional area and muscle thickness by US and MRI.

	Cross-sectional area by MRI, mm^2	Muscle thickness by MRI, mm	Muscle thickness by US, mm
SSP	376.8 ± 148.9 [39.5]	20.3 ± 3.6 [17.9]	16.1 ± 2.8 [17.3]
ISP	742.5 ± 244.3 [32.9]	21.7 ± 5.1 [23.6]	21.6 ± 3.2 [14.8]
TM	261.2 ± 96.2 [36.8]	18.3 ± 5.4 [29.3]	13.6 ± 3.1 [22.7]

Data are reported as mean ± SD [CV%].
US, ultrasonography; MRI, magnetic resonance imaging; SSP, supraspinatus; ISP, infraspinatus; TM, teres minor; SD, standard deviation; CV, coefficient of variation.

measurements of muscle thickness of the rotator cuff by MRI and those by US (SSP: $r = 0.67$, $p < 0.001$; ISP: $r = 0.63$, $p < 0.001$; TM: $r = 0.61$, $p < 0.001$). In addition, the analyses of the correlation between the cross-sectional area of the rotator cuff measured by MRI and the muscle thickness measured by US demonstrated similar results to those of MRI (SSP: $r = 0.80$, RMSE = 91.3 mm^2; ISP: $\rho = 0.78$, RMSE = 155.8 mm^2; TM: $\rho = 0.74$, RMSE = 65.9 mm^2; Fig. 4).

Bland and Altman plots revealed significant correlations between the average and the difference of the two measurements in all rotator cuff muscles (SSP: $r = 0.36$, $p = 0.012$; ISP: $r = 0.38$, $p < 0.001$; TM: $r = 0.42$, $p < 0.001$; Fig. 5). These results clarified the proportional bias between MRI and US in all rotator cuff muscles. Furthermore, the 95% limits of agreement for SSP, ISP, and TM were −176.9 to 176.9 mm^2, -302.1 to 302.1 mm^2, and -127.6 to 127.6 mm^2, respectively. However, there was no fixed bias in all rotator cuff muscles.

4. Discussion

The present study was performed to demonstrate the agreement the muscle thickness measurements of rotator cuff muscles by US and the cross-sectional area measured by MRI in patients with rotator cuff tears. The results showed high agreement between the muscle thickness measurements with US and the cross-sectional area measured by MRI in not only SSP, but also ISP and TM.

With respect to the reliability of measuring the SSP in healthy subjects with US, prior studies reported that the $ICC_{1.1}$ for the SSP muscle belly was 0.91–0.92.[16] This study demonstrated that the $ICC_{1.2}$ for the SSP muscle belly measured by US was 0.95. Preliminary study showed lower $ICC_{1.1}$ in patients with RCT compared to Schneebeli's study[16] in healthy subjects. It might be because the indistinct borders of bursitis in RCT patients affected the results. Therefore, in this study the muscle thickness were measured twice using US to improve the reliability. Further, previous studies showed that the SEM of the SSP muscle belly in healthy subjects was 0.74 mm, and that for the ISP muscle belly was 0.50–1.06 mm.[15] The SEM values in this study coincided with those reported in previous studies.

This study considered the agreement between muscle thickness measurements of the rotator cuff by US and the cross-sectional area measured by MRI. First, the correlations were demonstrated between the muscle thickness and cross-sectional area of rotator cuff muscles measured by MRI. These results indicated that the good agreement between the cross-sectional area and the thickness of rotator cuff muscles. Therefore, the muscle thickness measured by US were investigated to correlated with the cross-sectional area measured by MRI in rotator cuff muscles. Our results showed that the correlation coefficients in single linear regression were 0.80 for the SSP, 0.78 for the ISP, and 0.74 for the TM. The prior researches reported that the correlation coefficient for the SSP between muscle thickness by US and cross-sectional area by MRI were 0.76 in Yi et al.,[21] and 0.60 in Kretic et al.[19] Although the measurement site was

different between our study and Yi's research[21]; our results indicated similar correlation coefficient. Takai et al.[29] reported this relationship in the iliopsoas muscle and demonstrated that the correlation coefficient was 0.95 in the right side and 0.92 in the left side, which were higher than our data. The reason for this discrepancy might be because our measurement were performed in different positions regarding the muscle thickness with US and the cross-sectional area with MRI, whereas Takai et al.[29] performed all measurements in the same position. The cross-sectional area of rotator cuff muscles has been evaluated using oblique sagittal plane MRI images in which the coracoid process and the scapular spine met on Y view,[10] and previous studies reported that this evaluation widely correlated with clinical outcomes.[1–5] However, it was difficult to visualize the rotator cuff muscles with US at the SSP fossa on Y view in the same measurement position as that used in MRI. Nevertheless, our results demonstrated the good agreement between the cross-sectional area measured by MRI and the muscle thickness measured by US. Further, the Bland and Altman plots in this study showed proportional bias between MRI and US in the SSP, ISP, and TM muscles. These results indicate that the presence of greater residuals in the case of a large rotator cuff muscle volume should be taken into account when using the muscle thickness measured by US instead of the cross-sectional area measured by MRI.

This study has some limitations. As the MRI scans were acquired with a slice thickness of 4 mm, the positions of measurements for the tendon and muscle thickness might be different within this interval. The reasons for setting the slice thickness at 4 mm in this study was that MRI images were acquired using a slice thickness of 5 mm in a previous study[10] and MRI slices for evaluating the rotator cuff muscles were made through at an interval of 4 mm clinically. Moreover, the measurement position might be influenced by tendon retraction due to the rotator cuff tear. Fukuta et al.[30] reported that patients with large or massive rotator cuff tears with tendon retraction demonstrated decreased cross-sectional area of the rotator cuff muscles. Patients with large tears were also included in this study. However, tendon retraction was considered to have little effect on the results because the correlation of measurement values using MRI and US were analyzed in this study. Additionally, the assessments of cross-sectional area might not indicate atrophy of all rotator cuff muscles, although the correlations were investigated between the cross-sectional area measured by MRI and the muscle thickness measured by US. Hence, measurements considering the agreement with the whole muscle volume of the rotator cuff would be required in future studies.

In conclusion, this study demonstrated the agreement between the muscle thickness measurements in SSP, ISP, and TM with US and the cross-sectional area measured by MRI. The results showed the good coefficients of determination of the cross-sectional area. This study demonstrated that there was a medium or strong correlation of muscle thickness and cross-sectional area measurements between US and MRI. Therefore, US evaluation could be useful for the evaluation in patients with the diseases of the rotator cuff.
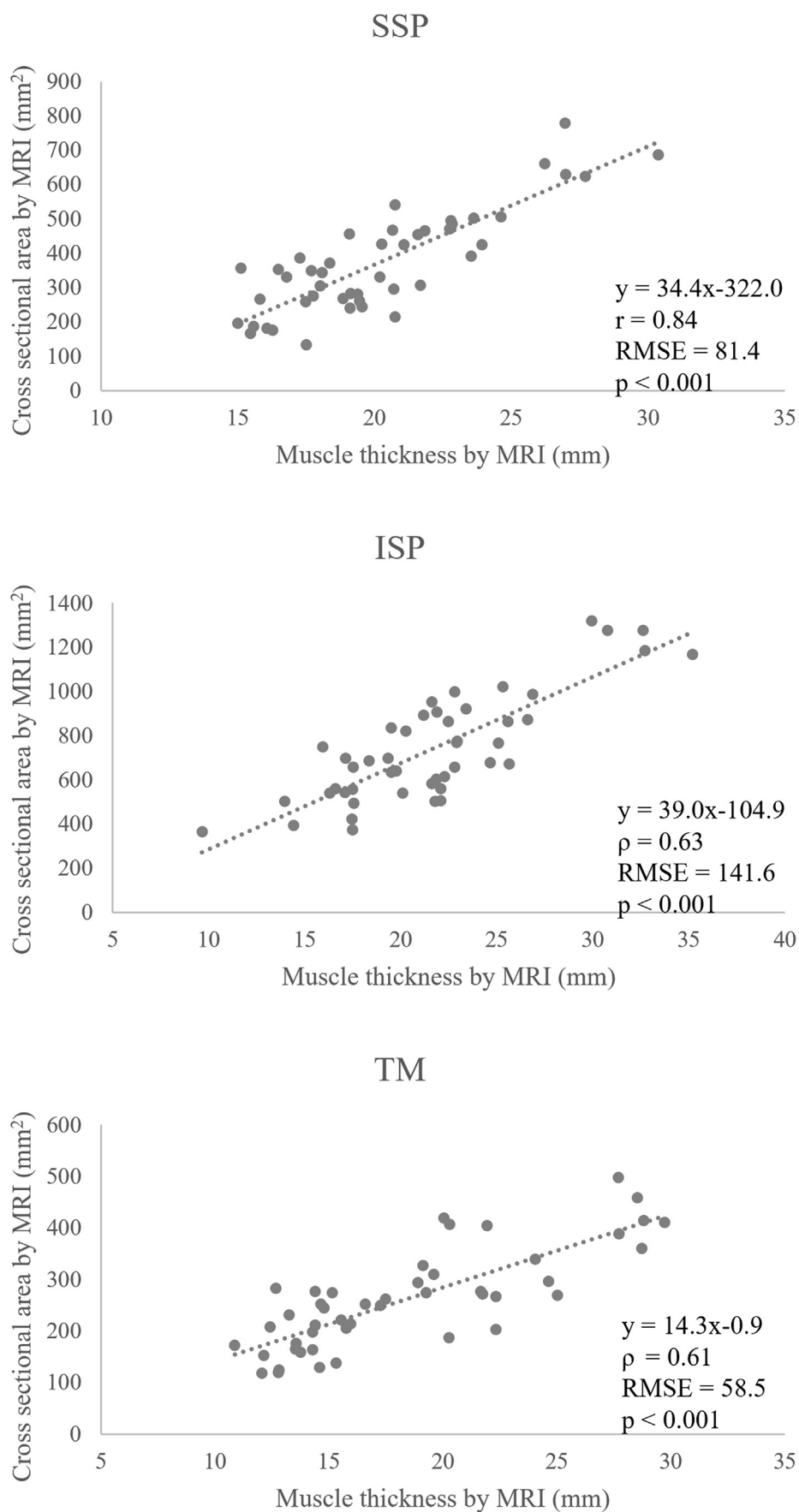
Fig. 3. Relationship between muscle thickness and cross-sectional area of the rotator cuff measured by MRI MRI, magnetic resonance imaging; RMSE, root mean squared error; SSP, supraspinatus; ISP, infraspinatus; TM, teres minor.
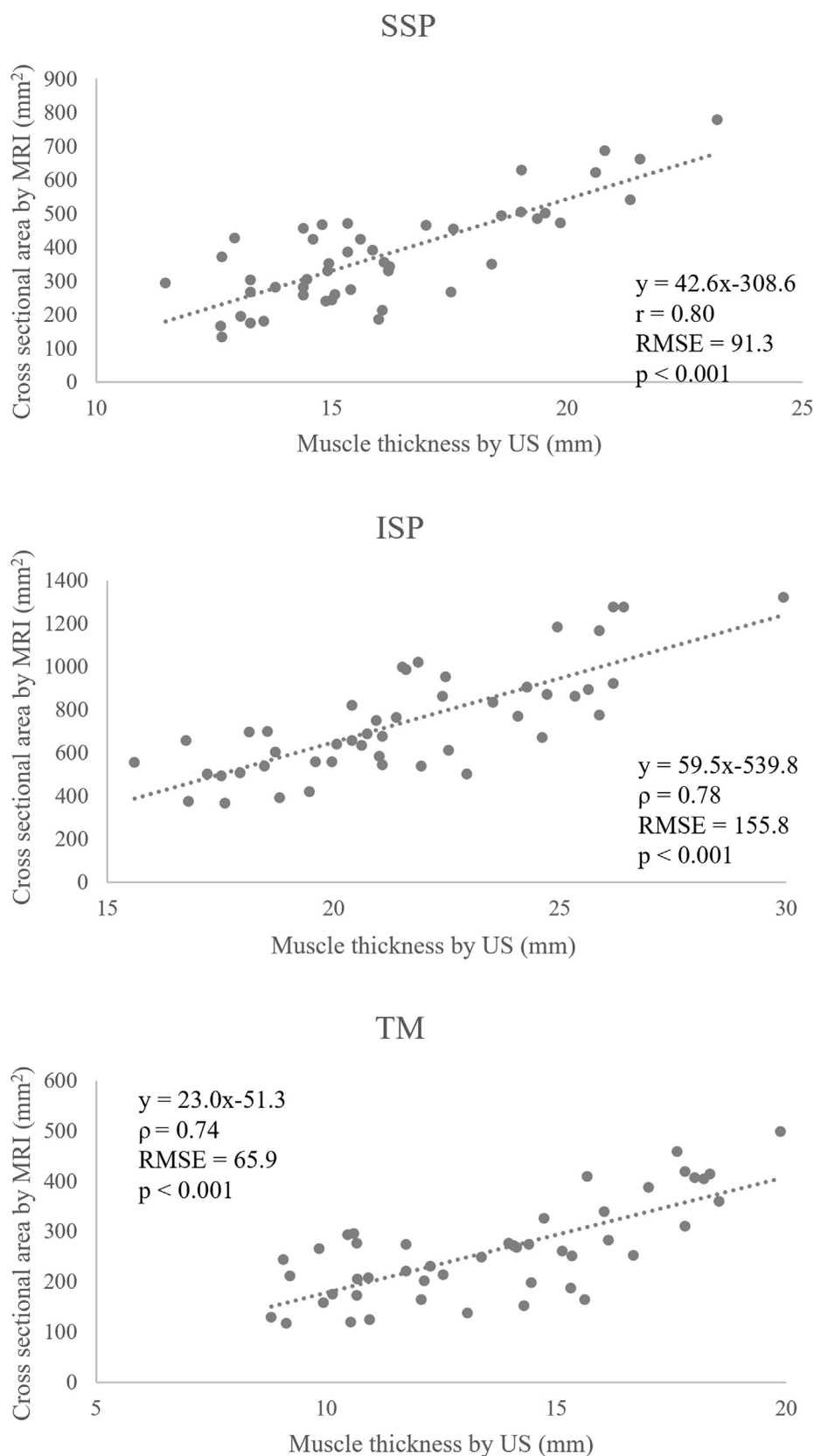
Fig. 4. Relationship between muscle thickness measured by US and cross-sectional area measured by MRI in rotator cuff muscles MRI, magnetic resonance imaging; RMSE, root mean squared error; SSP, supraspinatus; ISP, infraspinatus; TM, teres minor.
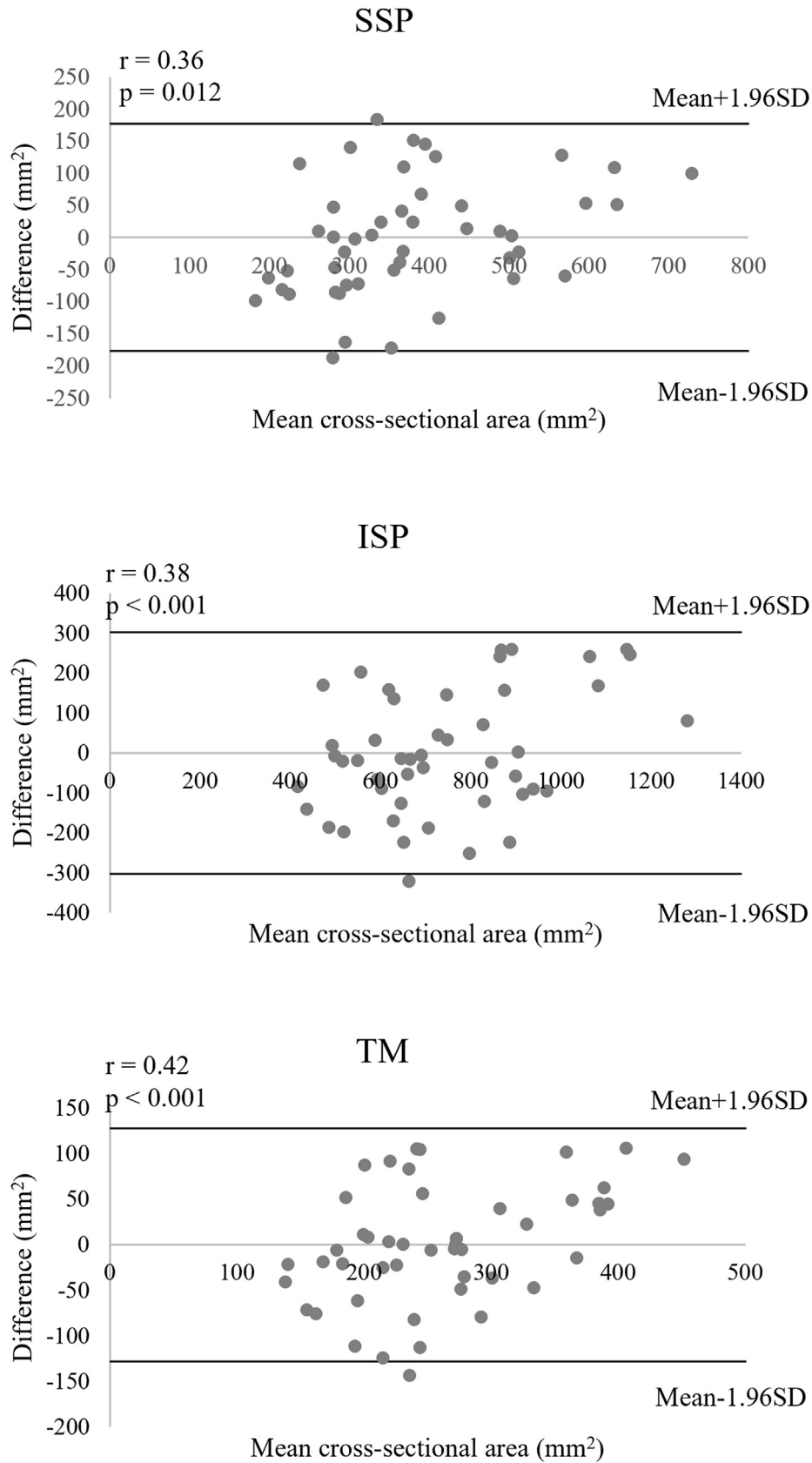
Fig. 5. Bland and Altman plots of the cross-sectional area between the measurement values by MRI and estimated values by US in rotator cuff muscles MRI, magnetic resonance imaging; US, ultrasonography, SSP, supraspinatus; ISP, infraspinatus; TM, teres minor; SD, standard deviation.

Funding/support statement

Declaration of competing interest

The authors have no conflict of interest relevant to this article.

Acknowledgments

References

1. Gladstone JN, Bishop JY, Lo IK, Flatow EL. Fatty infiltration and atrophy of the rotator cuff do not improve after rotator cuff repair and correlate with poor functional outcome. *Am J Sports Med*. 2007;35:719—728. https://doi.org/10.1177/0363546506297539.
2. Jo CH, Shin JS. Cross-sectional area of the supraspinatus muscle after rotator cuff repair: an anatomic measure of outcome. *J Bone Joint Surg Am*. 2013;95:1785—1791. https://doi.org/10.2106/JBJS.L.00938.
3. Kissenberth MJ, Rulewicz GJ, Hamilton SC, Bruch HE, Hawkins RJ. A positive tangent sign predicts the repairability of rotator cuff tears. *J Shoulder Elbow Surg*. 2014;23:1023—1027. https://doi.org/10.1016/j.jse.2014.02.014.
4. Liem D, Lichtenberg S, Magosch P, Habermeyer P. Magnetic resonance imaging of arthroscopic supraspinatus tendon repair. *J Bone Joint Surg Am*. 2007;89:1770—1776. https://doi.org/10.1684/mtp.2018.0650.
5. Tanaka M, Itoi E, Sato K, et al. Factors related to successful outcome of conservative treatment for rotator cuff tears. *Ups J Med Sci*. 2010;115:193—200. https://doi.org/10.3109/03009734.2010.493246.
6. Naimark M, Trinh T, Robbins C, et al. Effect of muscle quality on operative and nonoperative treatment of rotator cuff tears. *Orthop J Sports Med*. 2019;7(8):1—6. https://doi.org/10.1177/2325967119863010.
7. Melis B, Defranco MJ, Chuinard C, Walch G. Natural history of fatty infiltration and atrophy of the supraspinatus muscle in rotator cuff tears. *Clin Orthop*. 2010;468:1498—1505. https://doi.org/10.1007/s11999-009-1207-x.
8. Kikukawa K, Ide J, Kikuchi K, Morita M, Mizuta H, Ogata H. Hypertrophic changes of the teres minor muscle in rotator cuff tears: quantitative evaluation by magnetic resonance imaging. *J Shoulder Elbow Surg*. 2014;23:1800—1805. https://doi.org/10.1016/j.jse.2014.03.014.
9. Kikukawa K, Ide J, Terakawa Y, et al. Hypertrophic teres minor restores shoulder strength and range of external rotation in posterosuperior rotator cuff tears. *J Shoulder Elbow Surg*. 2016;25:1882—1888. https://doi.org/10.1016/j.jse.2016.04.016.
10. Zanetti M, Gerber C, Hodler J. Quantitative assessment of the muscles of the rotator cuff with magnetic resonance imaging. *Invest Radiol*. 1998;33:163—170. https://doi.org/10.1097/00004424-199803000-00006.
11. Maman E, Harris C, White L, Tomlinson G, Shashank M, Boynton E. Outcome of nonoperative treatment of symptomatic rotator cuff tears monitored by magnetic resonance imaging. *J Bone Joint Surg Am*. 2009;91(8):1898—1906. https://doi.org/10.2106/JBJS.G.01335.
12. Moosmayer S, Gärtner AV, Tariq R. The natural course of nonoperatively treated rotator cuff tears: an 8.8-year follow-up of tear anatomy and clinical outcome in 49 patients. *J Shoulder Elbow Surg*. 2017;26(4):627—634. https://doi.org/10.1016/j.jse.2016.10.002.
13. Pfalzer F, Huth J, Stürmer E, Endele D, Kniesel B, Mauch F. Serial clinical and MRI examinations after arthroscopic rotator cuff reconstruction using double-row technique. *Knee Surg Sports Traumatol Arthrosc*. 2017;25(7):2174—2181. https://doi.org/10.1007/s00167-017-4437-6.
14. Roy JS, BraÄn C, Leblond J, et al. Diagnostic accuracy of ultrasonography, MRI and MR arthrography in the characterisation of rotator cuff disorders: a systematic review and meta-analysis. *Br J Sports Med*. 2015;49:1316—1328. https://doi.org/10.1136/bjsports-2014-094148.
15. Juul-Kristensen B, Bojsen-Moller F, Finsen L, Ekkdahl C. Comparison of muscle sizes and moment arms of rotator cuff muscles measured by ultra sound sonography and magnetic resonance imaging. *Eur J Ultrasound*. 2000;11:161—173. https://doi.org/10.1016/s0929-8266(00)00084-7.
16. Schneebeli A, Egloff M, Giampietro A, Clijsen R, Barbero M. Rehabilitative ultrasound imaging of the supraspinatus muscle: intra- and interrater reliability of thickness and cross-sectional area. *J Bodyw Mov Ther*. 2014;18:266—272. https://doi.org/10.1016/j.jbmt.2013.09.009.
17. Khoury V, Cardinal E, Brassard. Atrophy and fatty infiltration of the supraspinatus muscle: sonography versus MRI. *AJR Am J Roentgenol*. 2008;190(4):1105—1111. https://doi.org/10.2214/AJR.07.2835.
18. Okoroha KR, Mehran N, Duncan J, et al. Characterization of rotator cuff tears: ultrasound versus magnetic resonance imaging. *Orthopaedics*. 2017;40(1):124—130. https://doi.org/10.3928/01477447-20161013-04.
19. Kretic D, Turk T, Rotim T, Saric G. Reliability of ultrasound measurement of muscle thickness in patients with supraspinatus tendon pathology. *Acta Clin Croat*. 2018;57(2):335—341. https://doi.org/10.20471/acc.2018.57.02.15.
20. Kim YS, Heo NY, Kim MW. The test-retest reliability of supraspinatus cross-sectional area measurement by sonography. *Ann Rehabil Med*. 2011;35(4):524—528. https://doi.org/10.5535/arm.2011.35.4.524.
21. Yi TI, Han IC, Kim JS, Jin JR, Han JS. Reliability of the supraspinatus muscle thickness measurement by ultrasonography. *Ann Rehabil Med*. 2012;36(4):488—495. https://doi.org/10.5535/arm.2012.36.4.488.
22. Yanagisawa O, Okumura K, Torii S. Comparison of the morphology of the rotator cuff muscles across age groups. *Clin Anat*. 2014;27(3):365—369. https://doi.org/10.1002/ca.22306.
23. Goutallier D, Postel JM, Bernageau J, Lavau L, Voisin MC. Fatty muscle degeneration in cuff ruptures. Pre- and postoperative evaluation by CT scan. *Clin Orthop*. 1994;304:78—83.
24. Patte D. Classification of rotator cuff lesions. *Clin Orthop*. 1990;254:81—86.
25. Gerber C, Fuchs B, Hodler J. The results of repair of massive tears of the rotator cuff. *J Bone Joint Surg Am*. 2000;82:505—515. https://doi.org/10.2106/00004623-200004000-00006.
26. O'Sullivan C, Meaney J, Boyle G, Gormley J, Stokes M. The validity of rehabilitative ultrasound imaging for measurement of trapezius muscle thickness. *Man Ther*. 2009;14:572—578. https://doi.org/10.1016/j.math.2008.12.005.
27. Ferri M, Finlay K, Popowich T, Stamp G, Schuringa P, Friedman L. Sonography of full-thickness supraspinatus tears: comparison of patient positioning technique with surgical correlation. *AJR Am J Roentgenol*. 2005;184:180—184. https://doi.org/10.2214/ajr.184.1.01840180.
28. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet*. 1986;1:307—310.
29. Takai Y, Katsumata Y, Kawakami Y, Kanehisa H, Fukunaga T. Ultrasound method for estimating the cross-sectional area of the psoas major muscle. *Med Sci Sports Exerc*. 2011;43:2000—2004. https://doi.org/10.1249/MSS.0b013e31821994cb.
30. Fukuta S, Tsutsui T, Amari R, Wada K, Sairyo K. Tendon retraction with rotator cuff tear causes a decrease in cross-sectional area of the supraspinatus muscle on magnetic resonance imaging. *J Shoulder Elbow Surg*. 2016;25:1069—1075. https://doi.org/10.1016/j.jse.2015.11.008.