Practical assessment of rotator cuff muscle volumes using shoulder MRI

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ABSTRACT Reliable quantitative assessment of rotator cuff (RC) muscle volumes can be done by reconstructing multiple MRI images of the entire shoulder. However, an equally reliable, but less time-consuming, method is needed for clinical practice. We compared the only method reported for estimation of volume with a new simple MRI technique. Both methods were validated by multiple MRI image reconstruction.

We performed MRI scans of 10 cadaver shoulders and determined the cross-sectional areas of RC muscles with two methods, using image analyzing software. In Method 1, the cross-sections were determined on a single image, previously described as a Y-shaped image. In Method 2, the cross-sections were calculated from two images: the Y-shaped and an image located medially, twice the distance from the glenoid articular surface compared to the Y-shaped image. We compared the results of these two methods with the volume of multiple MRI image reconstruction, which took into account all images consisting of RC cross-sections.

Pearson correlations for Method 1 were 0.96, 0.94 and 0.75, and for Method 2, 0.96, 0.97 and 0.93 for the supraspinatus, infraspinatus/teres minor and subscapularis muscle volumes when compared with the volumes determined by the multiple image reconstruction method. The Bland-Altman method showed better agreement with multiple MRI image reconstruction, using Method 2, to determine supraspinatus, infraspinatus, and subscapularis muscle volumes ($p < 0.001$ for each). The mean intra- and inter-observer variabilities of Method 1 was 3.9% and 2.9% and that of Method 2, 3.0% and 1.7%, respectively.

Both methods can be used for quantitative assessment of RC muscle volumes. However, Method 2, using two easily reproducible MRI images is more accurate for the evaluation of the supraspinatus and infraspinatus/teres minor muscles and particularly for the subscapularis muscle.

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Rotator cuff (RC) tears occur in more than half of the population above 60 years of age (Matsen et al. 1998). The chronic progression of RC tears is accompanied by RC muscle atrophy, fatty degeneration, retraction and loss of excursion (Bjorkenheim 1989, Matsen et al. 1998). A reduction in the volumes—the amount of atrophy and fatty infiltration—of the RC muscles is an important predictive factor for the outcome of surgery (Nakagaki et al. 1994, Matsen et al. 1998). MRI and CT have shown that the fatty infiltration and atrophy of the muscle belly correlate well with the extent of the RC tear (Goutallier et al. 1994, Nakagaki et al. 1994).

Although it has been found that multiple image reconstruction with MRI is accurate in the quantitative assessment of muscle volumes (Iannotti 1991, Hodler et al. 1992, Gusmer et al. 1997, Magee et al. 1997, Warner et al. 2001), clinical use of this method for RC muscles has hitherto been limited (Narici et al. 1992). Thomazeau et al. (1996) found changes in supraspinatus (SS) muscle cross-sections on sagittal MRI images at the most lateral

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image on which the spine of the scapula is in contact with the coracoid process (Y-shaped position). They found that reductions in SS cross-sections were related to the size of RC tears. Moreover, Zanetti et al. (1998) studied the infraspinatus/teres minor (IS/TM) and the subscapularis (SubS) muscles at the Y-shaped position. They could separate patients at various stages of RC tears by finding significant differences in RC muscle cross-sectional areas. However, the total volume of the RC muscles could not be determined in these studies and therefore no correlations of the cross-sections to real volumes were reported.

The aim of this investigation was to develop an easy reliable and reproducible method of measuring the volumes of the RC muscles from shoulder MRI images in clinical practice.

Material and methods

Specimens

10 fresh-frozen human cadaver shoulders (6 female) were stored at –20 °C. The specimens were thawed at room temperature 48 hours before MRI scanning. The mean age of the specimens was 76 (67–82) years. Radiographs were taken in anteroposterior and axillary planes to detect any bone abnormalities. Specimens with presence of previous proximal humeral fractures, other underlying bony pathology or surgical intervention were excluded from the study. 2 specimens had a full-thickness RC tear on MRI scans; these tears were confirmed later during dissection. In 1 specimen, only the SS muscle was affected, the second one had a tear in the SS muscle and a part of the IS muscle. The other specimens had an intact rotator cuff.

MRI scans

All MRI scans were performed on a GE Signa MRI 1.5T scanner (General Electric Medical Systems, Waukesha, WI, USA). A Linear Shoulder Array Coil (General Electric Medical Systems) was used. The shoulders were placed on the MRI table with the medial border of the scapula parallel to the long axis of the table and the proximal humerus in 10 degrees of abduction. The shoulder coil was fixed with tape on the ventral aspect of the shoulder.

A coronal scout scan parallel to the long axis of the scapula body was performed (repetition time: 100 ms, echo time: minimum, image matrix: 256 by 128, slice thickness: 5 mm, spacing: 5 mm, field of view: 26 × 26 cm). To ensure that the RC muscles were completely covered by the field of view (FOV), planning of sagittal MRI scans was done according to a coronal scout scan with a FOV of 18 × 18 cm, which always included the medial border of the scapula. Oblique sagittal T1-weighted spin-echo MR images were obtained perpendicular to the long axis of the scapula body and to the direction of the SS tendon (repetition time: 650 ms, echo time: 10 ms, image matrix: 512 by 224, slice thickness: 3 mm, spacing 0 mm). There was an average of 59 MRI images per shoulder, ranging from 50 to 65 images. Variations in the number of MRI images were due to differences in the shoulder size of the specimens.

MRI analysis

The contours of the SS, IS/TM and SubS muscles were traced by hand, using three-dimensional image analyzing software (“Alice”, Hayden Image Processing Group, Parexel Inc., Waltham, MA), which is routine in the Radiology Department of Massachusetts General Hospital and other hospitals (Figures 1 and 2). All contouring was done independently by 2 orthopedic surgeons. The IS and TM muscles were traced and evaluated as one muscle group (IS/TM), because the border between these muscles could not be clearly seen on all MRI images. This accords with previous studies that have also combined both of these muscles into one muscle group (Zanetti et al. 1998, Juul-Kristensen et. al. 2000).

In Method 1, described by Thomazeau et al. (1996), we traced the three muscle contours at the Y-shaped position/image, where scapular bony landmarks form a “Y”, because the spine of the scapula is in contact with the coracoid process (Figure 1). After the tracing, the software automatically calculated the result of each muscle. The site of the Y-shaped image was determined as the number of images medial to the glenoid articular surface.

In Method 2, we chose another, more medial image, in addition to the Y-shaped image, and the software summed up the two tracings from both

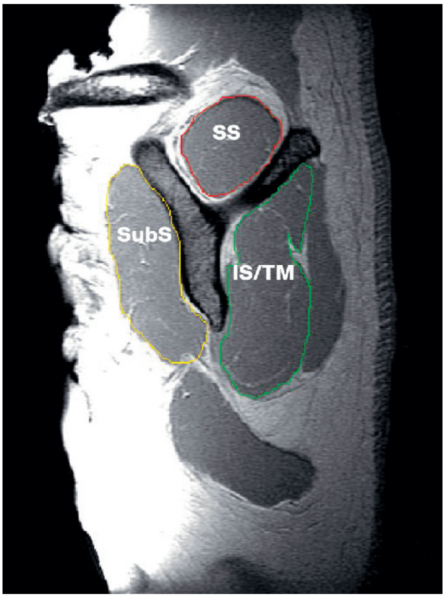

Figure 1. MRI scan of the left shoulder. The image is at the site of the Y-shaped position (Method 1). Rotator cuff muscles have been contoured, using three-dimensional image analysis software.

Figure 2. MRI scan of the left shoulder. The image is more medial from the Y-shaped image, and shows the subscapularis muscle belly better (2nd image, Method 2). Rotator cuff muscles have been contoured, using three-dimensional image analysis software.

images of each muscle (Figure 2). The previously-determined distance between the Y-shaped image and the articular surface of the glenoid was defined as the distance between the Y-shaped and this second, more medial image (Figure 3). The distance was counted as the number of images.

In the multiple image tracing, the muscle contours were outlined on each image proceeding from the Y-shaped position to the medial border of the scapula. Then this part of the muscle between the Y-shaped image and the insertion at the humeral head was traced. The muscles (SS, IS/TM, SubS) were traced one at a time. The software automatically calculated the volume of each muscle after the multiple image tracing.

The time required to trace the cross-sections using Methods 1, 2 and the multiple image tracing were recorded for each shoulder. All rotator cuff muscles were traced independently by 2 orthopedic surgeons. Methods 1 and 2 and the multiple image tracing were performed by each investigator 3 times on 3 days. The volumes (cm^3) of the SS, IS/TM and SubS muscles in Methods 1 and 2 and the multiple image tracing were automatically calculated, using the image analysis software, by taking into account the contoured area of each muscle and the thickness of each MRI slice. The volumes calculated with Methods 1 and 2 were compared with those from the multiple image tracing method for each muscle. The mean of the multiple image reconstruction method was used as the reference volume of each muscle.

Statistics

The Pearson product-moment correlation coefficient (r) was used to assess the linear relationship between the volume obtained with each method and the volume based on multiple image reconstruction for each RC muscle. Agreement between each method and the multiple image reconstruction gold standard was performed using Bland and Altman's method and the limits of agreement were constructed using 95% confidence intervals around the mean difference (Bland and Altman 1986). The Wilk-Shapiro test was used to assess whether the differences in agreement had a normal distribution (Gaussian). Paired t-tests were used to determine whether Methods 1 and 2 were significantly different as regards their agreement with the gold standard. The intra- and inter-observer variabilities of each method were calculated as the coefficient of variation (CV, %). The intra-observer variabil-

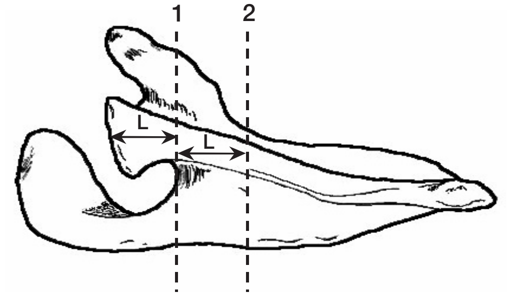

Figure 3. Infero-superior view of the right scapula showing the levels of the Y-shaped image (1) and a second more medially-located image (2) used for MRI assessment of the RC muscle volumes in this study. Distance (L) from the articular surface to the site of the Y-shaped image is equal to the distance (L) between the Y-shaped image and the other image used in Method 2.

ity of the study was calculated as the mean of the intra-observer variability of the two investigators. The data were analyzed with the SAS software package (version 6.12, SAS Institute, Cary, NC). A two-tailed value of $p < 0.05$ was used to indicate statistical significance.

Results

The average (SD) volumes of the SS, IS/TM and SubS muscles, calculated by multiple image tracing, were 36 (12), 96 (41) and 99 (33) cm^3, respectively.

The Pearson correlation between the total volume and the cross-section of Method 1 was $r = 0.96$ for the SS, $r = 0.94$ for the IS/TM, and $r = 0.75$ for the SubS muscles. As regards Method 2, the correlation between the total volume and the two cross-sections was $r = 0.96$ for the SS, $r = 0.97$ for the IS/TM, and $r = 0.93$ for the SubS muscles. These correlations were all statistically significant ($p < 0.01$ in each case). However, since the Pearson correlation measures the strength of a linear relationship between two variables rather than the agreement between them, a plot of the difference between the methods against their mean may be more informative. The Bland-Altman graphical technique allowed us to inspect the actual agreement between each method and the multiple image reconstruction as a plot depicting the mean difference and the limits of agreement which are approximately ± 2 standard deviations.

The Bland-Altman analysis illustrating the volume of all 10 specimens based on Method 1 and Method 2 compared to the MRI of the SS muscle, is shown in Figure 4A and 4B. The mean difference was smaller for Method 2 (27 cm^3 versus 32 cm^3), and a paired t-test indicated significantly closer agreement with the MRI for Method 2 ($p < 0.001$). Thus, the results indicate that both Methods 1 and 2 underestimate the true volume although, on the average, Method 2 comes closer.

The Bland-Altman analysis illustrating the volume of all 10 specimens, based on Method 1 and Method 2 compared to the MRI of the IS/TM muscle is shown in Figure 4C and 4D. The mean difference was slightly smaller with Method 2 (87 cm^3 versus 89 cm^3) and a paired t-test indicated significantly closer agreement with the MRI for Method 2 ($p < 0.001$).

The Bland-Altman analysis illustrating the volume of all 10 specimens based on Method 1 and Method 2 compared to the MRI of the SubS muscle, is shown in Figure 4E and 4F. The mean difference was smaller for Method 2 (80 cm^3 versus 91 cm^3), and a paired t-test indicated significantly closer agreement with the MRI for Method 2 ($p < 0.001$).

Although a superficial inspection of the Bland-Altman plots may suggest that the agreement with the MRI was similar for Methods 1 and 2, the results indicate that for each of the 10 specimens, agreement was closer to the MRI gold standard using Method 2 for all three RC muscles. There does appear to be a larger difference in agreement with increasing muscle volume, as shown by in each of the Bland-Altman plots.

The average time needed to complete the tracing of all three muscles with Methods 1 and 2 was 70 and 115 seconds, respectively, while the corresponding time to determine the muscle volumes of the entire shoulder by multiple image tracing was about a 1/2 hour.

The intra-observer variability with Method 1 was 4.2% for the SS, 3.0% for the IS/TM and 4.5% for the SubS muscles. The corresponding values with Method 2 were 3.3%, 2.3% and 3.5%, respectively (Table). The inter-observer variability with Method 1 was 1.6% for the SS, 2.7% for the IS/TM, and 4.4% for the SubS versus 1.6%, 1.0% and 2.6%, respectively, with Method 2 (Table).

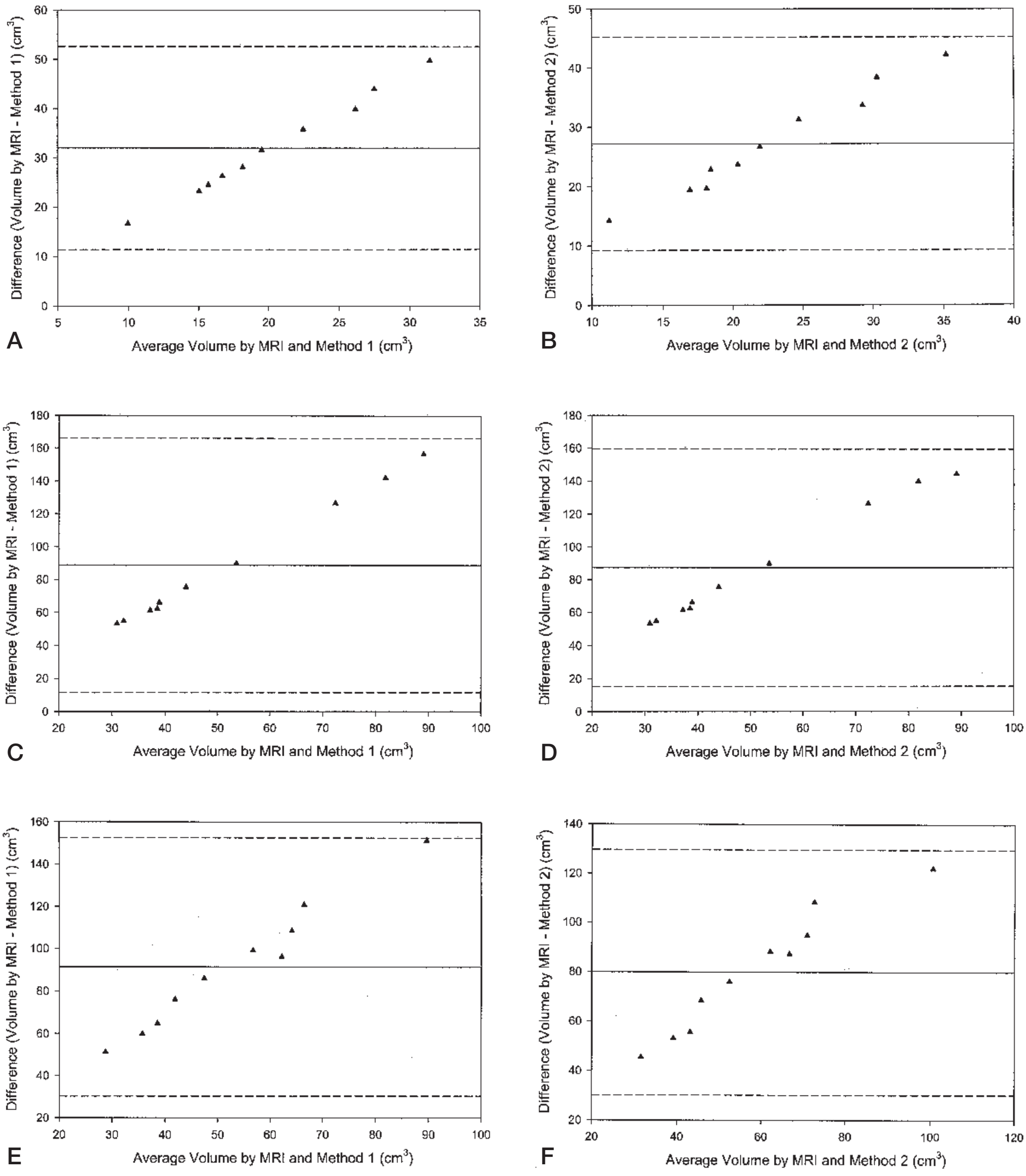

Figure 4. Bland-Altman analysis illustrating the volume, based on Method 1 and Method 2, compared to the MRI of the supraspinatus rotator cuff muscle (Figure 4A and 4B), infraspinatus/teres minor muscle (Figure 4C and Figure 4D), and the subscapularis muscle (Figure 4E and Figure 4F). The mean difference is denoted by the solid line and the limits of agreement by the dashed lines in each figure.

The locations of the images used for Methods 1 and 2 were determined as the number of images. The mean distance of the Y-shaped image was 7 images (range 6–9) medial from the articular surface of the glenoid. The corresponding mean distance of the second, more medial slice of Method 2 was twice this distance (average 14 images, range 12–18). The mean width of the scapulas was 41 images (range 34–46). The second image in Method 2 was always located on the lateral half of the scapula.

Correlation of the two MRI methods with the muscle volumes, determined by multiple image reconstruction, and intra- and inter-observer variabilities of both methods. Intra- and inter-observer variabilities are shown as coefficient of variation (CV, %)

	Method 1			Method 2		
Muscle [a]	Correlation	Intra-observer variability	Inter-observer variability	Correlation	Intra-observer variability	Inter-observer variability
SS	r = 0.96	4.2%	1.6%	r = 0.96	3.3%	1.6%
IS/TM	r = 0.94	3.0%	2.7%	r = 0.97	2.3%	1.0%
SubS	r = 0.75	4.5%	4.4%	r = 0.93	3.5%	2.6%

[a] SS = supraspinatus muscle, IS/TM = infraspinatus/teres minor muscle, SubS = Subscapularis muscle

Discussion

Muscle atrophy of the rotator cuff and fatty muscle degeneration are most often seen with chronic RC tears, even if there are some other pathologies (neurological or systemic diseases) which may be associated with RC muscle atrophy as well. These findings have been highlighted in the literature as an important predictor of patients' postoperative outcome after RC repair (Nakagaki et al. 1994, Matsen et al. 1998, Zanetti et al. 1998, Gerber et al. 2000). On the basis of these data, a simple method has been used to evaluate RC muscle volumes (Thomazeau et al. 1996, 1997, Zanetti et al. 1998, Gerber et al. 2000). However, the total volume of the muscles could not be determined in these studies and therefore the correlation of this method with the real muscle volume has not been reported. We tested both this previous application and another simple, easily reproducible method for clinical use to assess the RC muscle volumes from the shoulder MRI. The Method 1, which was developed by Thomazeau et al. (1996, 1997) and Zanetti et al. (1998), proved to be less accurate than Method 2 in evaluating the SS, IS/TM and SubS muscle volumes. Initially, Thomazeau and colleagues (1996, 1997) presented Method 1 only for the SS muscle and, in addition to tracing the cross-section of the muscle, they calculated a specific ratio concerning the relation of the SS muscle mass to the space available between the spine and upper plane of the scapula. In our study, the Y-shaped image (Method 1) proved to be representative of the whole SS muscle volume. However, the addition of the more medial image (Method 2) made it more accurate.

Zanetti et al. (1998) used this same Y-shaped MRI image to evaluate the other RC muscles. They found poor repeatability when separating the IS/TM muscles, and therefore treated these muscles as one muscle group. With this IS/TM, as with the SS, they found a reduction in the cross-sectional area that correlated with the increase in the size of the RC tear. However, with the SubS, the difference was not obvious and no statistical significance was found. Their conclusion was that it had not been shown that the cross-sectional image of the MRI used in the study was really representative of the total volume of each muscle. Furthermore, single image analysis might be limited since the results were strongly influenced by retraction of the musculo-tendinous junction, which is common in patients with chronic RC tears (Zanetti et al. 1998). However, in our study, the two full-thickness SS tears did not affect the accuracy of either method. On the basis of our results, this Y-shaped cross-section in Method 1 represents the SS, IS/TM and SubS muscle volumes quite well despite the presence of RC pathology, but we found that it was less accurate than method 2.

Method 2 is derived from Method 1, since the Y-shaped image had already been shown to be easily reproducible (Thomazeau et al. 1996, 1997, Zanetti et al. 1998). However, to delineate SS, IS/TM and, particularly, SubS better, a more medial image is essential, since most of the SubS muscle belly is located on the anterior wall of the scapula, medial to the glenoid neck (Matsen et. al 1998). The distance from the Y-shaped position to the articular surface of the glenoid was easily calculated by counting the number of images between the articular surface and the Y-shaped position. However, since the articular surface of the glenoid is curved, it was seen on 2 to 3 oblique sagittal images when using a slice thickness of 3 mm and a spacing of 0 mm. To determine the distance between the Y-shaped position and the glenoid, we always used the most medial image where the articular surface could be identified. The individual selection of these images proved very reproducible, as seen from the low intra- and inter-observer variabilities of our study. However, one image difference (3 mm) does not have much effect on the cross-sectional area, which may have kept the variation low. The addition of the second image to Method 2 seems to increase the reproducibility of the technique. Intra- and inter-observer values for every muscle were lower with the latter method introduced here.

The second image used for Method 2 was always located on the lateral half of the scapula, which is usually included in the shoulder MRI and therefore can be determined in clinical practice. When an axial scout scan is performed, we recommend inclusion of the lateral half of the scapula in the scan, to ensure of the RC muscle assessment. In this study we could correlate these simple Methods, 1 and 2, with the total muscle volumes, since we scanned the entire scapula for multiple image tracing. Current results suggest that studies with a larger material, including younger patients, would enable reliable estimation of normal variations in the muscle volumes based on gender and age (Zanetti et al. 1998).

The average age of the specimens used in our study was higher than the age of patients undergoing RC surgery. However, the aim of this methodological study was to compare two clinically applicable methods to estimate rotator cuff muscle volumes. For this purpose, we believe, the age of the specimens is of minor relevance.

In our study, it took about 1 minute to determine the cross-sectional areas for Method 1 and an overall time of less than 2 minutes for Method 2. This time seems to be reasonable also for busy clinical routines.

We showed that RC muscle volumes can be determined with a simple method from shoulder MRI scans with high reliability and reproducibility. In clinical practice, this will help to evaluate an optimal approach to the surgical treatment and to predict the postoperative outcomes. Moreover, this method can be useful in clinical studies when evaluating the pre- and postoperative status of the RC muscles. Future studies are needed to gain knowledge about RC muscle volume variations and to evaluate the importance of this method in making outcome measurements in clinical practice.

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No competing interests declared.

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