Atrophy and Fatty Infiltration of the Supraspinatus Muscle: Sonography Versus MRI

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Keywords: atrophy, fatty degeneration, fatty infiltration, MRI, rotator cuff muscles, shoulder, sonography

OBJECTIVE. The objective of our study was to compare sonography with MRI for the evaluation of supraspinatus muscle atrophy and fatty infiltration.

SUBJECTS AND METHODS. Forty-five shoulders in 39 patients who had undergone shoulder MRI for the assessment of rotator cuff disease were evaluated blindly with sonography. Supraspinatus muscle atrophy was quantitatively assessed by calculating the occupation ratio (cross-sectional surface area of the supraspinatus muscle belly divided by that of its fossa). This was done by reproducing on sonography the equivalent of the "Y" view on MRI. Fatty infiltration was assessed by evaluating supraspinatus muscle echogenicity compared with that of the trapezius muscle and pennate pattern. The occupation ratio and fatty infiltration of the supraspinatus muscle on sonography were compared with these findings on MRI.

RESULTS. Occupation ratios calculated on sonography images ranged from 0.07 (severe atrophy) to 0.81 (normal) and correlated with the ratios calculated on MRI (R = 0.90; 95% CI, 0.83–0.95). All 20 shoulders with no fatty infiltration on MRI had normal echogenicity and a pennate pattern on sonography. Eight of the 10 shoulders with mild fatty infiltration on MRI had an effaced pennate pattern and mild hyperechogenicity on sonography. In 13 of the 15 shoulders with moderate to severe fatty infiltration on MRI, the pennate pattern was absent and marked hyperechogenicity was present on sonography.

CONCLUSION. Our study suggests that there is a good correlation between sonography and MRI for the assessment of supraspinatus muscle atrophy and fatty infiltration.

Complete tears of the rotator cuff tendons may be accompanied by muscle atrophy and fatty infiltration that are progressive and are probably irreversible [1–4]. These modifications are known to be important negative prognostic factors for the anatomic and functional results after both tendon repair and shoulder arthroplasty [5–9]. The assessment of muscle quality using imaging is therefore a crucial element in evaluating surgical indications and postoperative prognosis. However, few studies in the radiology literature have addressed the evaluation of rotator cuff muscles.

A classification system of fatty infiltration was established by Goutallier et al. [6]. Although it is widely used in the orthopedics literature [7, 10–12] and is highly reproducible, it is based on CT, whereas currently sonography and MRI are the imaging techniques most used for the assessment of rotator cuff abnormalities. MRI has been shown to be a valuable method for the evaluation of supraspinatus muscle atrophy by assessing muscle size [4, 13]. Sonography has also been shown to be useful for assessing rotator cuff muscle atrophy [9]. There is, however, no sonography quantitative method or grading system for evaluation of muscle atrophy and fatty degeneration, and MRI remains the standard of reference for the assessment of these changes in routine clinical practice [4, 9, 14–16]. Studies that compare the performance of sonography with MRI for the evaluation of supraspinatus muscle atrophy are rare [17].

The purpose of our study was to compare sonography with MRI for the evaluation of supraspinatus muscle atrophy and fatty infiltration and to establish a quantitative method for the sonographic assessment of muscle atrophy.

Subjects and Methods
Forty-five shoulders in 39 patients who had undergone shoulder MRI were included in this study. A musculoskeletal radiologist reviewed all shoulder MRI examinations in the PACS database of our institution and selected study cases. Patients included in the study had undergone an MRI...
examination for rotator cuff disease (evaluation of tendinopathy or tear). Patients who had a history of shoulder surgery, who had a poor-quality MR study (motion artifacts, poor “Y” view delineation), or who could not undergo sonography within 3 months of MRI were excluded. The mean age of the 19 men and 20 women was 61 years (range, 44–77 years). There were 28 right and 17 left shoulders. Included were 13 shoulders with no or mild supraspinatus atrophy on MRI, 13 with moderate atrophy, and 19 with severe atrophy.

Muscle atrophy was defined by calculating the occupation ratio according to the method of Thomazeau et al. [18]. The occupation ratio is the ratio between the cross section of the muscle belly and that of its fossa on the Y view. The Y view is the oblique sagittal plane that crosses the scapula through the medial border of the coracoid process, where the supraspinatus fossa is mostly limited by bone. When the ratio is between 1.00 and 0.60 (stage I), the muscle is considered normal or slightly atrophied; between 0.60 and 0.40 (stage II), moderately atrophied; and below 0.40 (stage III), severely atrophied.

Patients were evaluated using sonography by a musculoskeletal radiologist who was blinded to the MRI findings. Both radiologists have been fellowship-trained: the MRI reader had 4 years of MRI experience at the time of the study and the fellowship-trained: the MRI reader had 4 years of fellowship training. The MRI findings were reviewed subjectively by examining the proportion of fat in the muscle on the sagittal and coronal T1-weighted images. Fatty infiltration was graded according to the method of Goutallier et al. [2]. According to that method, normal muscle that contains no fatty streaks is grade 0. In mild muscle fatty infiltration (grade 1), there are a few fatty streaks; in moderate muscle fatty infiltration (grade 2), there are about equal amounts of muscle and fat; and in severe muscle fatty infiltration (grade 3), there is more fat than muscle (Fig. 2).

MRI Assessment of Muscle Atrophy

MRI was performed on one of two 1.5-T scanners (LightSpeed, GE Healthcare; or Avento, Siemens Medical Solutions). The shoulder was placed in a dedicated receive-only shoulder coil (GE unit) or in a large surface flex coil (Siemens unit). The arm was placed alongside the body in a neutral position. Complete MRI examinations included a sagittal oblique (parallel to the glenoid fossa) T1-weighted turbo spin-echo sequence (TR range/TE range, 525–535/10–15; 15–17 slices; field of view, 18 cm; image matrix, 512 × 192 [GE unit] or 208 × 320 [Siemens unit]; section thickness, 4 mm) and a coronal oblique T1-weighted turbo spin-echo sequence (600–620/10–14; 16–18 slices; image matrix, 512 × 256; section thickness, 4 mm).

Supraspinatus muscle atrophy was measured by calculating the occupation ratio of the supraspinatus fossa according to the method of Thomazeau et al. [18] as described earlier. On the sagittal T1-weighted sequence, the cross-sectional surface area of the supraspinatus muscle was divided by that of its fossa. The sagittal image used for the measurement was selected, according to Thomazeau et al. [18], where a Y view is formed by the bone landmarks of the scapular spine, the coracoid process of scapula, and the distal clavicle. On the PACS workstation, the boundary of the supraspinatus muscle was drawn by tracing a line as close as possible to its outer edge, the boundary of the supraspinatus fossa was drawn along the inner bone margins of the Y, and the superior limits of the supraspinatus fossa were the distal clavicle and a line drawn between the distal clavicle anteriorly and the scapular spine posteriorly (Figs. 1A and 1C).

A modified method of occupation ratio calculation was also performed in which the cross-sectional area of the muscle and fossa was estimated by drawing the best circle or ellipse around each muscle and using the “ellipse” tool provided by the PACS manufacturer (Figs. 1B and 1D).

MRI Assessment of Fatty Replacement

Supraspinatus fatty infiltration was evaluated subjectively by examining the proportion of fat in the muscle on the sagittal and coronal T1-weighted images. Fatty infiltration was graded according to the method of Goutallier et al. [2]. According to that method, normal muscle that contains no fatty streaks is grade 0. In mild muscle fatty infiltration (grade 1), there are a few fatty streaks; in moderate muscle fatty infiltration (grade 2), there are about equal amounts of muscle and fat; and in severe muscle fatty infiltration (grade 3), there is more fat than muscle (Fig. 2).

Fig. 1—Calculation of occupation ratio by MRI in two shoulders. Two methods were used in each shoulder: using either lines (A and C) or ellipse tool (B and D) on PACS console to outline contours of supraspinatus muscle and those of its fossa, as shown on these sagittal oblique T1-weighted images.

A, Normal supraspinatus muscle (no atrophy) in 56-year-old woman. Using lines, occupation ratio is 3.45/5.61 cm² = 0.61.
B, Using ellipse method in same shoulder as in A, occupation ratio is 3.41/5.72 cm² = 0.60.
C, Supraspinatus with severe atrophy in 68-year-old woman. Using lines, occupation ratio is 2.04/5.53 cm² = 0.37.
D, Using ellipse method in same shoulder as in C, occupation ratio is 2.11/6.08 cm² = 0.35.
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Sonography Assessment of Fatty Replacement

Supraspinatus muscle fatty infiltration was assessed by evaluating its echogenicity and echostucture. The echogenicity of the supraspinatus muscle was compared with that of the trapezius muscle to determine whether the supraspinatus muscle was isoechoic, mildly hyperechoic, or markedly hyperechoic. The echostucture of the supraspinatus muscle or pennate pattern of the muscle was evaluated as normal (homogeneously distributed well-defined hyperechoic streaks), effaced (slight loss of pennate pattern with blurring of the margins of hyperechoic streaks), or absent (loss of pennate pattern with very poor or no visibility of the streaks).

Results

Occupation Ratio of Supraspinatus Muscle: MRI Versus Sonography

For the 45 shoulders, the occupation ratio of the supraspinatus muscle on sonography ranged from 0.07 to 0.81, compared with 0.11 to 0.87 on MRI, using the ellipse tool to outline the areas of muscle and fossa for both techniques. The correlation coefficient was 0.90 (95% CI, 0.83–0.95).

Echogenicity and Pennate Pattern of Supraspinatus Muscles

All 20 shoulders without fatty infiltration on MRI had normal echogenicity and a normal pennate pattern on sonography. Eight of the 10 shoulders with mild fatty infiltration on MRI had an effaced pennate pattern and mild hyper-echogenicity on sonography (Figs. 4A–4D). Thirteen of 15 shoulders with moderate to severe fatty infiltration on MRI had absence of...
the pennate pattern and marked hyperechogenicity on sonography (Figs. 4E and 4F). Two shoulders that were found to have severe atrophy and fatty infiltration on MRI were assessed as having a less severe grade on sonography; both had a full-thickness tear of the supraspinatus tendon that was retracted approximately 4 cm. Two other shoulders showed discordance between the two sonography features of fatty infiltration: one with moderate fatty infiltration on MRI had an effaced pennate pattern but marked hyperechogenicity on sonography. For these two shoulders, there was severe atrophy and tendon retraction of >2 cm. The relationship between atrophy and echogenicity and pennate pattern is shown in Figure 5.

Discussion

Sonography is a widely used and accurate technique in the evaluation of rotator cuff tendon tears [19, 20]. However, sonography is sometimes viewed as insufficient compared with MRI for preoperative evaluation of the rotator cuff because rotator cuff musculature quality, an important prognostic element, is generally not routinely assessable on sonography [21, 22].

Two distinct muscle abnormalities may be seen with rotator cuff tears: atrophy (reduced cross-sectional area of muscle or reduced muscle bulk) [3, 4, 13–16, 19, 23] and fatty infiltration or “degeneration” (replacement of muscle fibers by fat) [2, 6, 8, 14, 24]. Although these two muscle modifications associated with rotator cuff disease are closely interdependent [13, 24], they are not perfectly correlated [25]. The two phenomena are likely different manifestations of the same disease, although it is currently not known exactly how the two are related. For this reason, atrophy and fatty infiltration were evaluated separately in our study.

To our knowledge, only two studies have assessed sonography in the evaluation of rotator cuff muscle quality. Sofka et al. [26] used increased echogenicity and decreased muscle bulk as indicators of muscle atrophy. A limitation of their study was the lack of a standard of reference. In addition, the degree of muscle atrophy (mild, moderate, or severe) was not quantified. Strobel et al. [17] reported that sonography is only moderately accurate in grading fatty infiltration of the supraspinatus and infraspinatus muscles. However, a limitation of their study was the use of static images for interpretation by the examiners instead of a prospective examination of patients, as in our study, based on dynamic scanning in multiple planes, which likely gives a more global and thus more accurate assessment of muscle echogenicity and bulk. In addition, Strobel and colleagues used four parameters (visibility of outer contour, of central tendon, and of pennate pattern, and echogenicity) to assess both atrophy and fatty infiltration simultaneously, whereas quantification of the degree of muscle atrophy (muscle size) was not performed.

Fatty Infiltration

On sonography, fat replacement of skeletal muscles is generally hyperechoic and is the main cause of hyperechogenicity of skeletal muscle [27]. Fatty infiltration should not be regarded as a true degenerative process, but rather as a rearrangement of the tissue after macroarchitectural changes caused by musculotendinous retraction [28]. Rotator cuff muscle fatty infiltration is considered quite specific for tendon tears [2]. In the elderly population, fatty infiltration may occur but is generally not more than mild and generally homogeneous among different muscles of the shoulder [23]. Therefore, the use of the trapezius muscle as a standard of reference, as was done in our study, appears reasonable.

Our study shows that two sonography features—echogenicity and pennate pattern—correlate in most cases with the degree of fatty infiltration on MRI. Using both echogenicity and pennate pattern to evaluate the degree of fatty infiltration gives the operator increased confidence in grading this parameter because both of these sonography features are interdependent. Sonography has an advantage over MRI in that sonography can be used to assess the internal architecture of muscle and its pennate pattern [29]. On longitudinal scanning, the hyperechoic fibroadipose septa of the perimysium surrounding hypoechoic muscle bundles are responsible for the pennate pattern, appearing as multiple parallel lines forming oblique angles with the echogenic myotendinous junction [30]. With increased muscle echogenicity, the sharp contrast between muscle tissue and its striations becomes less distinct, leading first to the effacement and then to the disappearance of the pennate pattern. These sonography features correlate with the MRI appearance of increasing fatty infiltration. Recent studies have shown the utility of sonography in measuring the angles of the pennate pattern of muscle [31]. However, as other authors have noted, visualization of the pennate angle becomes more difficult with increasing atrophy [17].

We found that when muscle has fatty infiltration and shows increased hyperechogenicity, it can be difficult to distinguish from the surrounding fat in the supraspinatus fossa with similar echogenicity. Although delineating the
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contours of muscle was more challenging in such cases, it became easier with practice. Muscle contours were more easily assessed on sonography first in the coronal plane.

By grading echogenicity as either mild or marked and the pennate pattern as either effaced or lost, we could not distinguish moderate from severe fatty infiltration using sonography because marked hyperechogenicity and a lost pennate pattern correlated with both moderate and severe fatty infiltration on MRI. This distinction between moderate and severe infiltration may not be as important clinically as distinguishing mild infiltration from moderate or severe infiltration because many studies state that the likelihood of a recurrent tear is the same when fatty infiltration is greater than mild, or Goutallier grade 2 [6–8].

A sonography grading system for the evaluation of supraspinatus muscle fatty infiltration may be used as follows: In the absence of fatty infiltration (Goutallier grade 0), echogenicity is normal and the pennate pattern is preserved. With mild fatty infiltration (Goutallier grades 1 and 2), there is mild hyperechogenicity and an effaced pennate pattern. With moderate to severe fatty infiltration (Goutallier grades 3 and 4), there is marked hyperechogenicity and an absent pennate pattern. Fatty infiltration and atrophy should be assessed independently during sonographic evaluation of the supraspinatus muscle at shoulder evaluation for rotator cuff disease.

Because MRI has replaced CT and CT–arthrography for the assessment rotator cuff disease, it was not practical for our study to correlate sonography with CT. Given that there is no standardized MRI grading system for the assessment of fatty infiltration, we adapted the Goutallier system. One study found that the correlation between MRI and CT was not satisfactory [24]. Among the possible reasons hypothesized were the use of different planes (sagittal for MRI and transverse for CT) and the inability of CT to distinguish between fibrous tissue and muscle. However, interobserver variability using each technique individually was found to be good to excellent.

Muscle Atrophy

Several methods have been proposed to evaluate muscle bulk on MRI [16, 25], although the method of Thomazeau et al. [18] is probably the most widely used. Because the Y view in this method uses osseous (scapular) landmarks, we found that it could be easily reproduced on a sonography study. We first showed on MRI that it is as accurate to use the ellipse (modified Thomazeau method) as it is to draw lines as originally described by Thomazeau et al. [18]. Our study shows that there is excellent correlation between the occupation ratios measured on MRI and on sonography using the modified...
Stage II (moderate atrophy); stage I (normal to mild atrophy); 0.40–0.60, that this learning curve applies to measuring musculoskeletal sonography, and we believe however, there is a learning curve with all examinations. Another potential limitation is that an experienced musculoskeletal radiologist—occupation ratio of > 0.60, stage I (normal to mild atrophy); 0.40–0.60, stage II (moderate atrophy); < 0.40, stage I (severe atrophy).

A limitation of our study is that reproducibility was not tested; it would have been impractical and difficult and to justify having each patient return for a second sonography examination. Another potential limitation is that an experienced musculoskeletal radiologist performed the sonography examinations. However, there is a learning curve with all musculoskeletal sonography, and we believe that this learning curve applies to measuring the occupation ratio of the supraspinatus muscle and classifying echogenicity and the appearance of the pennate pattern.

In conclusion, our study suggests that there is good correlation between sonography and MRI for the assessment of both supraspinatus muscle atrophy and fatty infiltration.

Acknowledgment

We thank Assia Belblidia for her assistance.

References


Thomazeau method. The task of measuring cross-sectional areas is made easier today by the availability of elliptical measuring tools on PACS consoles for MRI and sonography images and directly on sonography units. We chose to use the ellipse around each area of muscle and fossa because this method can be applied reasonably quickly in a busy clinical practice. We may conclude therefore that the Thomazeau classification of supraspinatus muscle atrophy can be transposed to sonography—occupation ratio of > 0.60, stage I (normal to mild atrophy); 0.40–0.60, stage II (moderate atrophy); < 0.40, stage I (severe atrophy).
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**Sonography Versus MRI of the Shoulder**