Shoulder ultrasound: Diagnostic accuracy for impingement syndrome, rotator cuff tear, and biceps tendon pathology

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We sought to determine the accuracy of ultrasound for the preoperative evaluation of shoulder impingement syndrome, rotator cuff tear, and abnormalities of the long head of the biceps tendon. The findings in 42 consecutive surgical cases were compared with the preoperative sonographic readings. Ultrasound detected all of the 10 full-thickness cuff tears identified at surgery (sensitivity 1.0, specificity 0.97) but detected only 6 of 13 partial-thickness cuff tears (sensitivity 0.46, specificity 0.97). A full-thickness tear was falsely diagnosed in one case of severe cuff abrasion. Dynamic scan criteria correctly diagnosed impingement in 27 of 34 cases (sensitivity 0.79, positive predictive value 0.96). Abnormalities of the long head of the biceps were accurately diagnosed with the exception of low-grade tendinitis and the superior labral tear, anterior to posterior, lesion. We concluded that ultrasound is a sensitive and accurate method of identifying patients with full-thickness tears of the rotator cuff, extracapsular biceps tendon pathology, or both. Dynamic ultrasound can help confirm, but not exclude, a clinical diagnosis of impingement. (J Shoulder Elbow Surg 1998;7:264-71.)

Disorders of the rotator cuff are common. An effective treatment plan first requires an accurate diagnosis. Although a careful history and physical examination are important, clinically differentiating full-thickness cuff tear (FTT) from partial-thickness tear (PTT) or impingement-related tendinitis can be difficult. This is the goal of imaging. The key orthopaedic question is usually does a full-thickness rotator cuff tear exist, but there is currently no consensus about which technique is best for this purpose. A variety of tests are being used: single-contrast arthrography, double-contrast arthrography, computed tomographic arthrography, ultrasound, and magnetic resonance imaging (MRI).

Ultrasound is attractive as an imaging test because it is fast, safe, inexpensive, widely available, well-tolerated, and noninvasive. It is not restricted by patient size, positioning, cooperation, and the special contraindications that pertain to MRI. However, doubts have been raised about the accuracy and reproducibility of ultrasound.* In addition, it is believed that many operators do not have the skills required to achieve good results. Such attitudes can be challenged on several grounds:

1. There are now many reports confirming the accuracy of ultrasound.
2. Inadequate operator skills indicate poor training rather than a poor test. Poor training can be corrected.
3. Recent technologic improvements have reduced equipment dependence.
4. Cost-containment issues are increasingly important.

We therefore decided to assess the accuracy of our own shoulder ultrasound technique and diagnostic criteria. Our study design specifically tested the hypothesis that preoperative ultrasound was an adequate and reliable guide to the selection of surgical approach. Data were also collected on the value of dynamic sonography for the diagnosis of subacromial impingement.

METHODS

From May 1993 to October 1994, a consecutive series of arthroscopic or open shoulder operations were performed in 42 patients in whom rotator cuff or long...
head biceps tendon disease had been diagnosed and for whom surgery was indicated. A preoperative shoulder sonogram was obtained in every case, and the subsequent operative findings were correlated with the ultrasound reading. The patients had acute or chronic shoulder pain (more common) and their ages ranged from 19 to 70 years (mean 44 years). The time that elapsed between ultrasound and surgery ranged from 1 to 11 months (mean 8.8 weeks). All preoperative clinical assessments and operative procedures were performed by Mark Perko. A clinical diagnosis of Neer stage II or III impingement was based on the site of pain, limitation of functional activities, and night ache. Physical examination demonstrated a positive impingement sign, greater tuberosity tenderness with or without subacromial crepitus, and rotator cuff weakness. A test injection of subacromial lignocaine (lidocaine) was usually not given.

Although the ultrasound results were available to the surgeon preoperatively and were generally used to diagnose and plan the treatment, surgery was always undertaken on the basis of clinical data, after an appropriate trial of conservative therapy had failed, except when acute injury warranted early intervention. Whenever a FIT was suspected, an open procedure was performed; arthroscopic surgery was used in all other cases. Operative findings were used to establish the gold standard of impingement diagnosis: anterior acromial spurring; thickening of the subacromial-subdeltoid bursa caused by inflammation; abrasive changes (fraying, or distinct erythema, or both) along the bursal side of the greater tuberosity of the humerus. To maintain visualization of these same landmarks in real time throughout abduction, the abduction arc was in the plane of the transducer. Abduction was active rather than passive (reproducing the functional setting of a painful arc). Several trials of abduction were performed at each site.

**Sonographic criteria.** A FTT was diagnosed if the tendon was completely absent (Figure 1, B), or there was a deep focal contour defect in the surface of the cuff regardless of loss of underlying normal tendon echotexture at this point (Figure 1, C). Using imaging in two orthogonal planes, a PTT was diagnosed if a thin, bright, nonshadowing echogenic band was consistently seen within the substance of the cuff or if a fluid-filled cleft was unambiguously present within the cuff and did not extend from one surface to the other (Figure 1, D). Partial tears could be entirely intrasubstance or extend to either the articular or bursal surfaces of the cuff. Two additional but less specific ultrasound findings of rotator cuff tear were used in this study: (1) a "small" tear, not otherwise specified, was diagnosed when there was a shallow focal contour defect in the surface of the cuff (Figure 1, E) that was not clearly associated with an alteration of underlying tendon echotexture (i.e., focal volume loss was indicative of tear but differentiation of FTT from PTT was not attempted); (2) a partial tear was suspected if a localized tender hypoechoic swelling (suggestive of hematoma) could be seen within the cuff in a clinical setting of acute trauma.

Rotator cuff tendinitis was diagnosed if tendon calcification was present, or there was global swelling and tenderness of one or more cuff segments. Bicipital tendinitis was diagnosed if a diffusely enlarged tendon was detected (i.e., if the tendon was centered within but bulging beyond its humeral groove or if >1 mm in cross-sectional diameter could be seen between sides). Rupture of the long head of the biceps was diagnosed if there was a gap in tendon fibril continuity or if the tendon was absent (after medial tendon dislocation was excluded). Subluxation or dislocation of the long head of the biceps was diagnosed if the tendon was located beyond its bony groove on static or dynamic imaging. Most importantly, presence of the biceps tendon in the bicipital groove could not be confirmed unless characteristic fibrillar echotexture was identified on long-axis scanning.

Active subacromial impingement was diagnosed whenever a mechanical compression of the subdeltoid
Figure 1  A, Normal left supraspinatus tendon. The tendon surface (arrow) is smooth and convex, paralleling the subjacent articular surface of humeral head. Normal tendon echotexture can be appreciated only where fibril orientation is perpendicular to the ultrasound beam (beneath arrow). The tendon inserts at the greater humeral tuberosity (gr tub). B, Full thickness rotator cuff tear. Long axis view shows complete absence of the distal end of left supraspinatus tendon (between Xs), and replacement by a very thin hypoechoic layer of bursal thickening, fluid, or both (arrow). C, Full thickness rotator cuff tear. Long axis view shows marked volume loss and concave surface contour (arrow) at the distal end of left supraspinatus tendon (between Xs). There is complete absence of normal underlying tendon echotexture at this point. Note the subtle echoes indicating tendon proximal to calipers. D, Partial thickness tear of the rotator cuff. Long axis view shows a thin bright echogenic line (arrow) extending into the distal substance of left supraspinatus tendon from its articular surface. The abnormality does not reach the bursal side of the tendon. E, Small rotator cuff tear not otherwise specified. Long axis view shows localized concavity in the distal surface contour of the left supraspinatus tendon (arrow) with no apparent loss of underlying tendon echotexture (gr tub).

bursa or supraspinatus tendon could be seen during shoulder abduction. The specific sonographic signs were distention of the SB from the adducted position\(^\text{6}\) (Figure 2) and bunching of the supraspinatus tendon.\(^\text{4, 43}\) For objective diagnosis of these signs a fixed visual reference point (e.g., the outer tip of the greater humeral tuberosity) and a hard-copy or “snapshot” of the abnormal finding, which was capable of independent verification, were required.

Blocking was also noted if present. Blocking involves an abrupt loss of relative motion between the humerus and acromion during abduction and failure of the cuff to pass fully beneath the acromion. Further elevation of the arm is then achieved by rotation of the entire shoulder.
girdle as a single unit. When objective ultrasound findings were absent, a subjective report of pain during shoulder abduction was excluded as a sonographic sign of impingement.

RESULTS

The overall results are summarized in Table I. Ultrasound detected all 10 FTTs that were identified during surgery. Of these tears, 9 involved the supraspinatus tendon and 1 involved the subscapularis tendon. There were 2 small, 6 moderate, and 2 large tears. Ultrasound accurately graded the small and moderate tears but underestimated the size of the 2 large tears. In one case of small tear (5 mm), the sonographic finding of focal concavity in the distal surface contour of supraspinatus tendon correctly identified the size and site of tear but did not allow differentiation of PTT from FTT. There was one false-positive diagnosis of small complete tear in a patient with severe abrasive changes on the bursal side of the cuff. (An open acromioplasty was performed but the articular side of rotator cuff was not inspected.) There was an overall high sensitivity (1.0), specificity (0.97), and accuracy (0.98) for the diagnosis of full-thickness cuff tear.

Ultrasound detected only 6 of 13 PTTs that were identified at surgery (sensitivity, 0.46). Of the 7 cases with false-negative scans, all but 1 tear (a small intrasubstance lesion) involved the articular side of the cuff and consisted of either superficial fraying (3 patients) or a discrete rent of <7 mm (3 patients). Of the 6 patients in whom partial tears were detected, the sonogram only specified that 4 were partial-thickness lesions. The remaining 2 cases of true-positive diagnosis were both perceived as shallow concavities ≤8 mm long in the bursal side contour of the rotator cuff, and were therefore reported as small tears with no attempt at partial versus complete differentiation. There was one false-positive diagnosis of incomplete tearing. Ultrasound detected a shallow 7 mm concavity in the bursal side contour of the cuff, but only abrasive changes indicative of impingement were found during the operation.

Although an ultrasound diagnosis of cuff tendinitis was made in 15 cases, surgical correlation was difficult because there was no satisfactory way to assess cuff swelling or tenderness during the operation, and there was typically a significant delay between sonography and operation in these patients (mean 14.7 weeks). The sonographic findings were tendon calcification (3) and global supraspinatus tendon swelling with associated tenderness (12). In the 12 cases with cuff swelling, abrasive changes of subacromial impingement were found in 9, partial tears in 2, and complete tears were found in 1 patient during the operations. However, there were many other cases where the same operative findings were present but the preoperative sonogram did not suggest cuff tendinitis.

Of 34 patients with subacromial impingement found at operation, the ultrasound findings were true positive in 27 and false negative in 7 (sensitivity 0.79). In the false-negative scans the operation findings of impingement comprised anterior acromial prominence or spur with impingement on the greater tuberosity of humerus during passive abduction under anesthesia, and abrasive changes along the coracoacromial ligament or acromion process. Bursal thickening was found in only two of these cases (one was minimal). One false-positive diagnosis of impingement (found at operation) was recorded by study criteria in a patient with signs of only mild bicipital tendinitis at operation. Despite this finding, the sonographic diagnosis at the time was probably correct because there was clinical agreement, the sonographic findings were dramatic (severe tendon bunching and blocking), and there was enough time for an episode of acute impingement to...
Table I Summary of results

<table>
<thead>
<tr>
<th>Ultrasound diagnosis</th>
<th>True Positive</th>
<th>True Negative</th>
<th>False Positive</th>
<th>False Negative</th>
<th>Accuracy*</th>
<th>Sensitivity†</th>
<th>Specificity*</th>
<th>Positive Predictive Value§</th>
<th>Negative Predictive Value‖</th>
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<tr>
<td>Full-thickness tear</td>
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<td>31</td>
<td>1</td>
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<td>0.98</td>
<td>1.0</td>
<td>0.97</td>
<td>0.91</td>
<td>1.0</td>
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<tr>
<td>Partial-thickness tear</td>
<td>6</td>
<td>28</td>
<td>1</td>
<td>7</td>
<td>0.81</td>
<td>0.46</td>
<td>0.97</td>
<td>0.86</td>
<td>0.8</td>
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<td>32</td>
<td>0</td>
<td>2</td>
<td>0.95</td>
<td>0.8</td>
<td>1.0</td>
<td>1.0</td>
<td>0.94</td>
</tr>
<tr>
<td>Longhead biceps dislocation</td>
<td>2</td>
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<td>0</td>
<td>0</td>
<td>1.0</td>
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<td>1.0</td>
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</tr>
<tr>
<td>Longhead biceps rupture</td>
<td>3</td>
<td>38</td>
<td>0</td>
<td>1</td>
<td>0.98</td>
<td>0.75</td>
<td>1.0</td>
<td>1.0</td>
<td>0.97</td>
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<td>Impingement</td>
<td>27</td>
<td>7</td>
<td>1</td>
<td>7</td>
<td>0.81</td>
<td>0.79</td>
<td>0.88</td>
<td>0.96</td>
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<tr>
<td>Clinical diagnosis</td>
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<td>5</td>
<td>3</td>
<td>1</td>
<td>0.9</td>
<td>0.97</td>
<td>0.63</td>
<td>0.92</td>
<td>0.83</td>
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</table>

TN, True-negative; TP, true-positive.

*TN + TP/total.
†TP/TP + FN.
‡TN/TN + FN.
§TP/TP + FP.
‖TN/TN + FN.

resolve during the 10 months before surgery. The overall positive predictive value was 0.96 for impingement. In the same group of patients a clinical diagnosis of impingement was more sensitive but less specific (Table I). Using our specified operative criteria as the standard, there were four cases of false-positive and one case of false-negative clinical diagnosis for impingement. Thus clinical evaluation, which did not include a test injection of subacromial lignocaine, had a lower positive predictive value (0.89) than ultrasound.

Bicipital tendonitis was correctly detected in 8 of 9 cases, and correctly excluded in 32 cases (sensitivity 0.8, accuracy 0.95). Two patients with low-grade bicipital tendinitis had false-negative sonograms (although a potentially significant delay to surgery of 3.5 and 10 months, respectively, occurred in both cases, and one patient had a false-positive sonogram [mild biceps tendon swelling was reported, and the delay to surgery was 2 months]). Biceps tendon rupture was correctly detected in 3 of 4 cases, and correctly excluded in 38 (sensitivity 0.75, accuracy 0.98). Of the three tears detected, one was an acute detachment from the glenoid margin that occurred in a young swimmer, and two had chronic attrition ruptures (one was a partial tear that involved 25% of the tendon fibers). Although one false-negative diagnosis of biceps tendon rupture was recorded on both clinical and imaging grounds, the tear may have occurred during the 4½ months before surgery. Biceps tendon subluxation was detected by ultrasound in 2 of 2 cases (sensitivity 1.0, accuracy 1.0). SLAP lesions were missed in 3 of 3 cases.

DISCUSSION

Shoulder ultrasound has been a controversial subject1, 11, 25, 38 and MRI has been suggested as a better noninvasive test of rotator cuff integrity.3, 32 In addition MRI can examine the glenoid labrum at the same examination.32 However, in a recent comprehensive review of the literature, Stiles and Otte34 concluded that the role of conventional MRI in both rotator cuff tear and glenohumeral instability was unclear. Standard MRI cannot differentiate some full-thickness cuff tears from partial tears,30 detect incomplete tears,34 correctly identify the cuff surface that is involved,34 differentiate partial tears from tendon degeneration,14, 28, 38 and adequately resolve the capsule and labrum.38 In fact, the reported sensitivity (0.80 to 0.97) and specificity (0.93 to 0.94) of conventional MRI for complete tears is not superior to
ultrasound results obtained by experienced operators. For these reasons there has been a trend toward MRI arthrography with the attendant problem of even higher cost. Furthermore, MRI has no cost-benefit advantage over computed tomography arthrography, which gives similar information.

The aim of our study was to assess the diagnostic accuracy of ultrasound for impingement syndrome, rotator cuff tear, and biceps tendon pathology. A basic limitation of the study design was that only patients who proceeded to surgery were selected for analysis. This selection was sufficient to study the hypothesis that sonography could be used to choose the operative approach, but did not assess the accuracy of ultrasound in diagnosing those patients who were treated conservatively. No patient was excluded from our study based on age or technical difficulty. Although the radiologist was aware of the provisional clinical diagnosis and x-ray findings in most cases, no sonographic abnormality was reported without including objective photographic evidence that was capable of providing independent verification.

The type of equipment, examination technique, and sonographic criteria all potentially affect the diagnostic accuracy of ultrasound. Very high frequency transducers improve the display of tissue texture, anatomic detail, and diagnostic confidence. Broad-band 7.5 MHz linear array probes with electronic focusing in the imaging plane and mechanical focusing set at about 1.5 cm in the elevation plane (the average depth of the rotator cuff) are preferable for scanning the shoulder. Operator dependence is generally regarded as a limitation but is also significant in MRI; differences in scanning techniques and diagnostic criteria are cited as major factors. There is also confusion about which sonographic criteria to use and how these criteria are defined. Brandt et al. found the literature “both conflicting and confusing” in regard to criteria and further noted that there was “little agreement as to what are reliable signs.”

Nevertheless, sonography was very accurate (0.98) for the diagnosis of FTT in our study. These results are in accord with the studies of Mack (0.94-0.98), Weitner (0.95), Weitner (0.95), Hodler (0.92), Brenneke (0.91), and Middleton (0.87-0.91). Thus, the accuracy for diagnosing complete tears would appear to be equivalent to, or better than, the reported accuracy of MRI arthrography without fat suppression (0.84). Only MRI arthrography with fat suppression (1.0) may be more accurate.

The diagnostic value of ultrasound for PTT in our study was not impressive (sensitivity 0.46, accuracy 0.81), and closely mirrors the experience of Brenneke and Morgan. This may be partly the result of a conservative reporting philosophy aimed at avoiding false-positive results (specificity 0.97), and the use of diagnostic criteria that were narrowly defined. By way of contrast, Weiner and Seitz achieved a sensitivity of 0.94 and van Holsbeeck et al. achieved a sensitivity of 0.93 for PTT. Certain observations arise from our results: Virtually all of the missed partial tears involved the articular side of the cuff, some partial tears produced neither distinct textural features nor definite focal volume loss, and differentiation from very small complete tears was not always possible.

The accuracy of ultrasound for the diagnosis of noncalcific rotator cuff tendinitis could not be usefully assessed in our study because of the lack of an adequate operative standard and the long interval to surgery in many cases. Although the apparent sonographic signs of soft tissue swelling (i.e., thickened supraspinatus tendon, subacromial-subdeltoid bursa, or both) and localized tenderness would intuitively suggest a diagnosis of tendinitis, or bursitis, no biopsies were performed.

Biceps tendon abnormalities were generally well defined by ultrasound with a high degree of diagnostic accuracy found for biceps tendon dislocation (1.0), biceps tendon rupture (0.98), and bicipital tendinitis (0.95). Of potential diagnostic value as an indicator of possible cuff pathology, there was an association between bicipital tendinitis and either partial- or full-thickness cuff tear in 6 of 10 (60%) cases.

Despite the well-recognized ability of ultrasound to show moving rotator cuff tissues, there has been little work published on the accuracy of dynamic scan findings for the diagnosis of subacromial impingement. Farin et al. reported an overall sensitivity of 0.81, specificity of 0.95, and positive predictive value of 0.91 for impingement, using fluid distention of the subacromial bursa during elevation of the arm as the only sonographic criterion and bursal thickening as the operative standard. Our protocol produced a comparable sensitivity (0.79), lower specificity (0.88), and higher positive predictive value (0.96). A clinical diagnosis of impingement in this same group of patients was more sensitive (0.97) but, because of...
a larger number of false-positive results, less specific (0.63) and slightly less predictive (0.92).

Bunching of bursal or tendon tissue during abduction would seem to indicate mechanical compression by the overlying coracoacromial arch and was the criterion used to diagnose impingement in our study. Bursal bunching was the most frequently observed sign of impingement, but may not be present in the absence of active bursitis. Although bunching may be related to bursal fluid entrapment alone, chronic impingement bursitis frequently appears as nothing more than a line of synovial thickening that blends subtly with the surface of the rotator cuff without accompanying effusion. This may be difficult to appreciate until the thickened bursa is compressed during abduction. Blocking can be a feature of high-grade impingement, but capsulitis commonly has the same effect. This sign, therefore, cannot alone be regarded as diagnostic for impingement.

There are a number of difficulties with the dynamic ultrasound diagnosis of impingement. The examination process is complicated. It can be hard to maintain simultaneous visualization of the chosen sonographic landmarks throughout the process of abduction because the transducer may slip, the patient may not abduct exactly within the desired plane, and skin creases that interfere with transducer contact may sometimes form at high angles of abduction. Sonographic signs of impingement can be intermittent because the phenomenon of cuff or bursal compression or both may occur in one particular plane of elevation only, and patients with abduction pain may quickly learn to avoid the provocative maneuver. One important observation does not appear in the results of our surgically correlated series: ultrasound signs of impingement were frequently found on the contralateral side where symptoms were absent or minimal.

The clinical role of dynamic ultrasound in the diagnosis and management of impingement remains unclear. Critics might argue that a positive impingement test is essentially diagnostic, false-negative rates as high as 18% nullify the value of a normal scan; the technique may not be easily reproducible; and clinical management would not be affected. Others could choose to emphasize the fallibility and invasive nature of the impingement test because false-negative diagnosis can occur with injection into the wrong space, and false-positive diagnosis can occur when pain derived from calcium deposits or arthritis is blocked. Therefore, ultrasound may be useful as a complement to the physical examination, reducing the need for subacromial injection and improving overall diagnostic accuracy.

In summary, there are now many studies that support the accuracy and reproducibility of ultrasound for the diagnosis of FTT of the rotator cuff. However, the type of equipment, exact diagnostic criteria used, and level of operator training remain important issues in achieving reliable results. With the exception of very low-grade bicipital tendinitis, ultrasound is also an accurate means of evaluating abnormalities of the extraarticular segment of the biceps tendon. Using carefully defined methods, a positive sonographic finding of subacromial impingement is diagnostic but a negative scan result is of limited value.

REFERENCES


43. Welber H. Ultrasound of the shoulder in impingement syndrome [abstract]. The 20th Annual Scientific Meeting of the Australasian Society for Ultrasound in Medicine; September 1990; Adelaide, Australia.