The use of in-office, orthopaedist-performed ultrasound of the shoulder to evaluate and manage rotator cuff disorders

Dean W. Ziegler, MD, *Milwaukee, WI*

This study presents the use of in-office ultrasound, performed by an attending orthopaedic surgeon, as a means of evaluating the integrity of the rotator cuff. The results of 282 shoulder sonograms in patients ultimately treated surgically were included. Findings at surgery were recorded and compared with those documented during the ultrasound examination. Ultrasound findings included 118 full-thickness and 143 partial-thickness rotator cuff tears and 6 intact cuffs confirmed at surgery. One patient with a partial supraspinatus tear on ultrasound was intact at surgery, nine with complete supraspinatus tears had partial-thickness tears at surgery, one with an intact supraspinatus had a full-thickness tear at surgery, and four with partial-thickness supraspinatus tears had full-thickness tears at surgery. The sensitivity, specificity, positive predictive value, and negative predictive value were 94.1%, 96.1%, 96.6%, and 93.2%, respectively, for partial-thickness tears; 95.9%, 94.3%, 92.9%, and 96.8%, respectively, for full-thickness tears; and 99.6%, 85.7%, 99.6%, and 85.7%, respectively, when the rotator cuff was evaluated for damage (either partial- or full-thickness tears). This series documents the ability of an orthopaedic surgeon to image the rotator cuff effectively using portable ultrasound in the clinic setting, allowing for a more efficient implementation of the management plan. (J Shoulder Elbow Surg 2004; 13:291–7.)

Shoulder disorders and dysfunction are severely debilitating to both the patient and society.[7] Although many shoulder problems respond readily to nonoperative treatment, those that require more invasive management do best if the management plan can be implemented as efficiently and effectively as possible. Plain radiographs can provide hints as to the presence of complete or partial-thickness tears of the rotator cuff as well as recurrent instability of the shoulder but cannot definitively diagnose these entities. Therefore, a method is needed to evaluate the soft tissues of the shoulder definitively and efficiently, especially the rotator cuff.

Arthrography and magnetic resonance imaging (MRI) are presently the most commonly used methods to evaluate the soft tissues of the shoulder.[1] Although good results have been reported with the use of these modalities to diagnose rotator cuff tears, each has significant drawbacks.[8,17] These include invasiveness, discomfort, expense, inconvenience, and variability of results.

Diagnostic ultrasound can fulfill the required conditions for imaging the soft tissues of the shoulder, especially the rotator cuff. It is noninvasive and cost- and time-efficient, has virtually no side effects, and allows for a dynamic, functional evaluation of the shoulder. Most importantly, diagnostic ultrasound has the potential to be performed in the setting of the orthopaedic clinic. This has been demonstrated in large series elsewhere[11] but in only limited series in the United States.[26]

This study presents the use of in-office ultrasound examination, performed by an orthopaedic surgeon during the patient's clinic visit, as a means of evaluating the integrity of the rotator cuff.

MATERIALS AND METHODS

Four hundred fifty-one consecutive bilateral shoulder sonograms in four hundred six patients were obtained over a 3-year period. Of these, 282 shoulders were treated surgically in 262 patients. The findings of these 282 ultrasounds, for which the results were verified at surgery, were included in the study. There were 173 shoulders in men and 109 shoulders in women with a mean age of 50.4 years (range, 15-84 years).

A single orthopaedic surgeon in a busy clinic performed all of the ultrasound examinations using portable linear scanning ultrasound with a 7.5-MHz probe. Before each ultrasound, a thorough history was obtained followed by physical examination of the shoulders. In each case, bilateral examinations were performed beginning with the asymptomatic shoulder. Plain radiographs of the involved shoulder were obtained and reviewed. Indications for an ultrasound examination included objective findings of rotator cuff pathology on physical examination in patients in

From Blount Orthopaedic Clinic, Ltd.

Reprint requests: Dean W. Ziegler, MD, Blount Orthopaedic Clinic, Ltd, 625 E Saint Paul Ave, Milwaukee, WI 53202 (E-mail: *dziegler@pol.net*).

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Figure 1 Position of patient and examiner during shoulder ultrasound examination.

whom proper nonoperative management of their shoulder dysfunction had failed. Bilateral shoulder ultrasounds were obtained in all cases. The asymptomatic shoulder was initially evaluated to define the patient's shoulder anatomy. It also allowed the patient to experience the examination of an asymptomatic shoulder in order to give a better indication of relative tenderness during examination of the involved shoulder. In addition, it provided an opportunity to educate the patient regarding the anatomy of the shoulder. A standard shoulder ultrasound protocol was followed for each examination with the results and interpretations recorded.

All examinations were performed within the normal flow of the clinic day. Once it was determined that ultrasound was to be performed, an assistant set up the portable unit. During this time, the surgeon was able to see several other patients. Ultrasound was then performed, with the bilateral examination taking approximately 10 minutes. This included discussion of the examination findings; however, it did not include the post-examination discussion of further shoulder management. The examination was billed under the code for upper extremity ultrasound (76880) with a total cost of $474.00 for a bilateral examination. Total payment varied based on previously negotiated contracts with third-party payers. However, there was never a problem obtaining reimbursement. As mentioned previously, all scans were performed with portable linear scanning ultrasound with a 7.5-MHz probe. These units ranged in cost from $9,000 to $20,000.

Ultrasound examination technique

The technique of shoulder ultrasound performed was a modification of that described by Mack et al.[15,16] They emphasized a dynamic examination of the shoulder in 6 planes, using active muscle contraction against resistance to better accentuate rotator cuff defects. In this series the examiner and patient were both positioned on rolling, rotating stools. The examiner and patient were seated in an angled position, allowing both to see the ultrasound monitor and providing the examiner access to the patient's shoulder (Figure 1). Positions were switched when the opposite shoulder was examined. The specific order of shoulder imaging used in this series included the following: transverse view of the biceps tendon; longitudinal view of the subscapularis tendon (recording tendon thickness and evaluating dynamic movement of the tendon under the coracoid process); transverse view of the supraspinatus tendon (recording tendon thickness); longitudinal view of the infraspinatus tendon (recording tendon thickness), posterior glenoid, and labrum; longitudinal view of the infraspinatus muscle (recording muscle belly thickness and evaluating muscle contractility), longitudinal view of the biceps tendon; transverse view of the subscapularis tendon attachment; longitudinal view of the supraspinatus tendon both static and dynamic with elevation (evaluating the ability of the greater tuberosity to clear under the acromion during passive and active elevation); longitudinal view of the supraspinatus muscle (recording muscle belly thickness and evaluating muscle contractility); longitudinal view of the supraspinatus with the arm in internal rotation and extension (Figure 2); and transverse view of the supraspinatus with the arm in internal rotation and extension (recording tendon thickness). Tenderness when imaging over a particular structure was noted and compared with that in the asymptomatic shoulder.

Criteria for diagnosing rotator cuff tears

Disruptions of the rotator cuff tendons presented themselves in several different ways during ultrasonography. The criteria for making the diagnosis of both partial- and full-thickness rotator cuff tears have been documented in multiple studies.*

In this series a full-thickness tear was diagnosed if any of the following criteria were present: focal thinning of a rotator cuff tendon, complete nonvisualization of a rotator cuff tendon, focal discontinuity in the homogenous echogenicity of the rotator cuff without focal thinning (Figure 3), or inversion of the superficial bursal contour and/or hyperechoic material in the location of the tendon that fails to move with the humeral head during real-time dynamic imaging. Another criterion used specifically in this series was the limitation of further active glenohumeral elevation due to abutment of the greater tuberosity on the acromion, visualized during longitudinally imaging of the supraspinatus.

Criteria used for diagnosing a partial-thickness rotator cuff tear in this series included the following: a hypoechoic discontinuity in the rotator cuff tendon in which the lesion involved either the bursal or articular side of the tendon or a mixed hyperechoic and hypoechoic region within the tendon, which is thought to be due to a separation of the torn edge from the rest of the tendon, resulting in a new interface within the tendon. It was also considered important if the patient had tenderness when imaging over mixed hyperechoic and hypoechoic regions was performed. The diagnosis of a partial-thickness rotator cuff tear was supported if tenderness could be elicited when these regions were imaged in different shoulder and transducer positions. This finding was only considered to be supportive of rotator cuff pathology if no tenderness was elicited when the same structure was imaged in the asymptomatic shoulder.

In this series the two-criteria model[11] was used to improve results. In this model a defect is only diagnosed if a criterion is reproducible in either different joint positions or

*References 6, 8, 11, 15, 20, 22, 27, 30, 33.

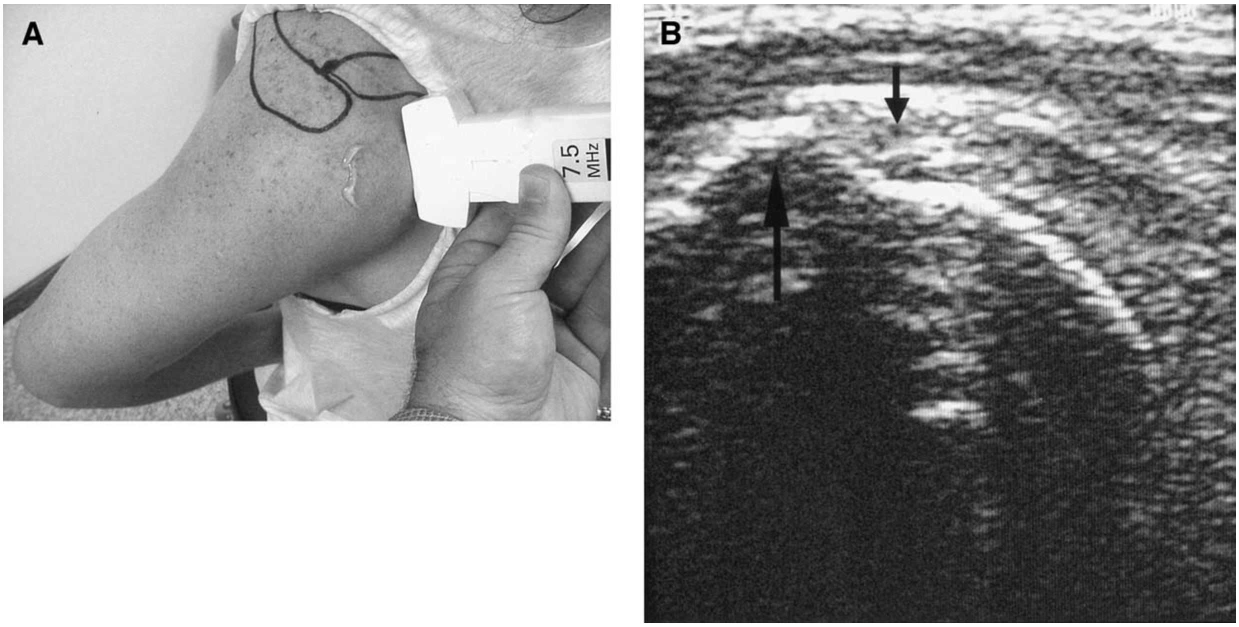

Figure 2 A, Transducer position for longitudinal imaging of the supraspinatus tendon with the shoulder in internal rotation and extension. **B**, Longitudinal ultrasonic image of the supraspinatus tendon (*short arrow*) with the shoulder in internal rotation/extension including the supraspinatus attachment to the greater tuberosity (*long arrow*).

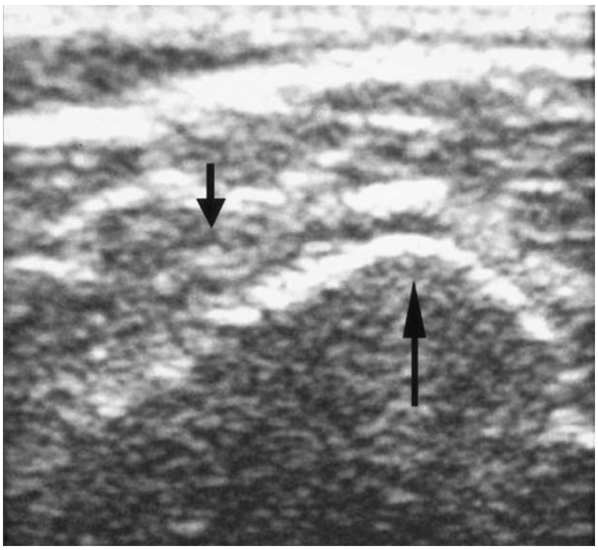

Figure 3 Longitudinal view of the supraspinatus tendon with the arm in internal rotation and extension demonstrating the greater tuberosity (*long arrow*) but complete nonvisualization of the tendon (*short arrow*), indicating a complete tear of the supraspinatus with retraction.

transducer positions or if a second criterion (eg, static along with dynamic criterion) is present in different positions.

At surgery, a full-thickness rotator cuff tear was diagnosed if there was a complete defect in the integrity of the tendon from the deep to the superficial surface. A full-thickness tear was still considered to be present if there was capsular or bursal tissue intact but no tendon fibers attached to the tuberosity. A partial-thickness tear was diagnosed if there was any defect in the tendon attachment that did not extend from the deep to the superficial surface.

A relational database was used to record the findings of the ultrasound as well as the overall impression. Surgical results were also recorded in a similar database, and the databases were merged. Findings from the ultrasounds were then compared with those at surgery.

RESULTS

Ultrasound findings in the 282 surgical cases included 104 full-thickness supraspinatus tears, 148 partial-thickness supraspinatus tears, 14 full-thickness subscapularis tears, 9 full-thickness tears of the supraspinatus and subscapularis, and 7 intact rotator cuffs. At surgery, 95 full-thickness supraspinatus tendon tears were confirmed, as were 143 partial-thickness tears, all 14 subscapularis tears, all 9 combined supraspinatus and subscapularis tears, and 6 intact rotator cuffs. One patient with a partial-thickness supraspinatus tear on ultrasound was found to have an intact rotator cuff at surgery. Nine patients with full-thickness supraspinatus tears detected on ultrasound were found to have partial-thickness tears at surgery, and four with partial-thickness supraspinatus tears on ultrasound were found to have full-thickness tears at surgery. One patient with an intact supraspinatus on ultrasound was found to have a full-thickness tear at surgery. For partial-thickness rotator cuff tears, the ultrasound demonstrated a sensitivity of 94.1%, a specificity of 96.1%, a positive predictive value of 96.6%, and a negative predictive value of 93.3%. For full-thickness rotator cuff tears, the ultrasound demonstrated a sensitivity of 95.9%, a specificity of 94.3%, a positive predictive value of 92.9%, and a negative predictive value of 96.8%. Finally, when the rotator cuff was evaluated for damage (either full or partial thickness), the ultrasound demonstrated a sensitivity of 99.6%, a specificity of 85.7%, a positive predictive value of 99.6%, and a negative predictive value of 85.7%.

Data regarding the limitation of further active glenohumeral elevation due to abutment of the greater tuberosity onto the acromion were available in 258 shoulders. These included 99 with full-thickness supraspinatus tears, 134 with partial-thickness supraspinatus tears, and 25 with intact supraspinatus tendons, all verified at surgery. Of the 99 shoulders with full-thickness supraspinatus tears, 41 demonstrated abutment of the greater tuberosity onto the acromion limiting further active elevation. Abutment also limited further elevation in 24 of the patients with partial-thickness rotator cuff tears and in 2 shoulders with intact supraspinatus tendons. Therefore, using the criterion of greater tuberosity abutment on the acromion limiting active elevation for diagnosing a full-thickness supraspinatus tear demonstrated a sensitivity of 41.4%, a specificity of 87%, a positive predictive value of 61.2%, and a negative predictive value of 70%.

DISCUSSION

In the early 20th century, Codman[7] recognized the devastating effects that rotator cuff tears have on the individual patient and society in general. He believed that suboptimal results were due primarily to the fact that patients rarely presented at the early stages of disease. Today, early recognition as well as management of rotator cuff tears remains important. This includes documentation of the tear, which is often required by the patient, surgeon, and third-party payer before planning and approving surgical intervention.

Shoulder arthrography has traditionally been the primary method of documenting tears of the rotator cuff.[17] Although excellent results have been reported for detection of complete tears, deep-surface partial-thickness tears are difficult to evaluate and superficial partial-thickness tears cannot be diagnosed. Other disadvantages of arthrography include the invasiveness of the technique and the possibility of neurovascular injury, infection, allergic reaction to dye injection, and pain.[8,17]

MRI is presently a common method used to document pathology in the soft tissues of the shoulder.[17] It is reported to have excellent results in the diagnosis of full-thickness tears of the rotator cuff and is potentially an improvement over arthrography in evaluating partial-thickness tears, especially those involving the superficial surface. Although MRI is presented as a noninvasive modality, many patients find lying for extended periods of time in the MRI scanner to be very uncomfortable and, for some, intolerable. Furthermore, invasive techniques such as arthrography or injection MRI have become increasingly more common. In addition, MRI examination is quite time-consuming, expensive, and variable in quality depending on the type of MRI scanner used and the performing MRI technician.

One of the biggest drawbacks of both shoulder arthrography and MRI is the fact that these diagnostic tests must be scheduled and performed outside the orthopaedic surgeon's office at a time separate from the initial clinical evaluation. An additional office visit may need to be scheduled to educate the patient regarding the results of these tests and to discuss further management of the problem. Diagnostic ultrasound provides another option for the evaluation of the soft tissues of the shoulder and the documentation of rotator cuff tears and has the potential to be performed by an orthopaedic surgeon in the office setting.

The first publication documenting the use of ultrasound in the shoulder was by Mayer[13] in 1977. In 1983, at the annual meeting of the American Academy of Orthopaedic Surgeons, Farrar et al[10] presented the use of dynamic sonography to evaluate the shoulder in 48 patients. They found a sensitivity of 91% and a specificity of 76% for diagnosing complete rotator cuff tears. Middleton et al[19–21] described the normal ultrasonic anatomy of the shoulder in 1984, the criteria for diagnosing tears of the rotator cuff in 1985, and the pitfalls of sonography that may lead to poor results in 1986. In 1985 Mack et al[15] described a technique for examination stressing the use of dynamic sonographic evaluation of the shoulder.

There have been multiple studies presenting the results of ultrasound in diagnosing rotator cuff tears (Table I).† Although many of these series report excellent sensitivity and specificity,‡ there are also several studies that report less than satisfactory results.[1,3,4,9,14,23,25,32] Regardless of the findings, these series and others stress the operator dependence of the procedure, which leads to the variability in results.[11,12,18,28,29] It has been this variability that has deterred many physicians from using ultrasound more frequently. Although technique is highly operator-dependent, results can be markedly improved if a

†References 1, 3, 4, 6, 8-11, 14, 15, 20, 22, 23, 25-27, 30-33.
‡References 6, 8, 10, 11, 15, 20, 22, 26, 27, 30, 31, 33.

Table I Summary of sensitivity and specificity in multiple series

Author	Year	No. of patients	Verification	Full-thickness tears	Partial-thickness tears
Farrar et al[10]	1983	48		91%, 76%	
Mack et al[15]	1985	72	Arthrography	93%, 97%	
Mack et al[15]	1985	47	Surgery	91%, 100%	
Middleton et al[20]	1985	39	Arthrography	93%, 83%	
Middleton et al[21]	1986	106	Arthrography	91%, 91%	
Brandt et al[3]	1989	62	Arthrography	68%, 90%	
Brandt et al[3]	1989	38	Surgery	57%, 76%	
Soble et al[27]	1989	75	Arthrography	92%, 84%	
Soble et al[27]	1989	30	Surgery	93%, 73%	
Miller et al[23]	1989	57		58%, 93%	
Burk et al[4]	1989	10	Surgery	63%, 50%	
Vick and Bell[32]	1990	81	Arthrography (79), surgery (2)	67%, 93%	
Drakeford et al[8]	1990	50	Arthrography	92%, 95%	
Kurol et al[14]	1991	58	Surgery	67%, 74%	
Hedtmann and Fett[11]	1995	1227	Surgery	97.3%, 94.6%	91%, 94.6%
van Holsbeeck et al[30]	1995	52	Surgery		93%, 94%
van Moppes et al[31]	1995	41	Arthrography and surgery	86%, 91%	
Chiou et al[6]	1996	157	Arthrography	92%, 97.2%	
Alasaarela et al[1]	1998	20	Surgery	83%, 57%	
Read and Perko[25]	1998	42	Surgery	100%, 97%	46%, 97%
Fabis and Synder[9]	1999	74	Surgery	98.2%, 90%	50%, 96.3%
Roberts et al[26]	2001	24	Surgery	80%, 100%	71%, 100%

specific protocol is followed and certain errors of interpretation are avoided.[5,11,21,24]

One of the most common errors in sonography of the shoulder is a misinterpretation of normal anatomy. For example, the echogenicity of the rotator cuff, specifically the supraspinatus, can be similar to that of the overlying deltoid. This is uncommon but does occur in older patients. Furthermore, the normal ultrasonic appearance of thinning of the posterior supraspinatus and infraspinatus as seen on the transverse view and other mild inhomogeneities of the rotator cuff tendons are often misinterpreted as representing rotator cuff pathology. These potential misinterpretations can be avoided by comparing the findings with those in the asymptomatic shoulder.

Other potential errors of shoulder sonography occur as a result of soft-tissue or bony abnormalities. Calcific nodules within the rotator cuff tendon (ie, calcific tendinitis), greater tuberosity fractures, and inferior subluxations of the glenohumeral joint are examples of such abnormalities. Errors resulting from abnormalities of bone or soft tissue can be avoided by evaluating radiographs of the shoulder before performing ultrasonography.

Technical limitations of ultrasound can also lead to errors in interpretation of the examination. An example of such a limitation is the inability to image a portion of the supraspinatus tendon because of the overlying acromion. This can easily be corrected by positioning the arm in internal rotation and extension to improve exposure of the supraspinatus tendon.

The ability to control potential pitfalls may be the greatest limitation for the orthopaedic surgeon who is considering use of ultrasound as a diagnostic tool in his or her practice. The best way to eliminate errors may be for the surgeon to perform the examination. Orthopaedists who have studied the shoulder and who perform shoulder surgery regularly have an excellent 3-dimensional conception of shoulder anatomy which is essential for ultrasound image reading.[2] With experience, they can develop a proficiency in the use of ultrasound and learn to avoid the aforementioned pitfalls of shoulder sonography. Hedtmann and Fett[11] have demonstrated this in a large series of patients in Germany. For 4,588 shoulder ultrasounds, 1,227 verified at surgery, they reported an overall sensitivity of 95.3% (97.3% for complete tears and 91.0% for partial tears) and an overall accuracy of 94.9%. They stress the importance of experience, noting that better results tend to be reported in larger series of patients. Large series such as this have not been commonly reported in the United States. Roberts et al[26] presented their results using ultrasound to evaluate the shoulder in a limited series. In 24 patients they reported a sensitivity and specificity of 80% and 100%, respectively, for diagnosing full-thickness rotator cuff tears and 71% and 100%, respectively, for partial-thickness tears.

Presented here is a series of 282 shoulder ultrasounds with results verified at surgery, performed by a single orthopaedic surgeon over a 3-year period. All ultrasounds were performed during the patient's office visit, and the results are comparable to those reported by Hedtmann and Fett.[11] Sonographic experience and the large number of patients allowed for a rapid improvement in ultrasound proficiency and accuracy. Bilateral ultrasound was performed in all cases, with the asymptomatic shoulder being evaluated first. Multiple shoulder and transducer positions were used to avoid technical limitations. Static and dynamic images were evaluated to maximize the effectiveness of the examination. Another criterion used specifically in this series was the abutment of the greater tuberosity onto the acromion limiting further active elevation. This finding combined with other previously described criteria helped document the integrity of the supraspinatus tendon. Having the same individual perform the physical examination, ultrasound, and surgery allows for an improved understanding of the 3-dimensional anatomy and pathology of the patient's shoulder. The surgeon also receives firsthand feedback with regard to the ultrasound findings at the time of surgery. Performance of the examination at the time of the clinic visit eliminated the need to schedule further tests or follow-up visits. In-office ultrasound, therefore, allows for a cost-and-time efficient method for evaluating the rotator cuff, documenting rotator cuff pathology, and implementing a definitive management plan.

Multiple limitations are inherent in this study. Because the same individual performed the physical examination, ultrasound, and surgery, there is the potential of interpretation bias. Interpretations of the ultrasound may be biased by physical examination findings, and surgical findings may be influenced by the results of physical examination and ultrasound. However, the goal of this study was not to prove the efficacy of ultrasound in diagnosing tears of the rotator cuff. Rather, the goal was to evaluate the ability of a practicing orthopaedic surgeon to reproduce the previously presented successful results of using shoulder ultrasound for diagnosis of rotator cuff pathology. In fact, because the same individual performed the physical examination, ultrasound, and surgery, it was anticipated that the predictive value of the ultrasound and overall surgical management should be improved. In this sense, the ultrasound is viewed as an extension of the physical examination. Another limitation of the study is that only a small number of intact rotator cuffs were imaged and evaluated at surgery. The numbers could have been increased if all shoulders in the practice were evaluated with ultrasound before surgery regardless of diagnosis. However, in an attempt avoid overutilization of the technology, ultrasound was only performed on patients who were considered to have the proper indications.

Diagnostic ultrasound provides a superb method for evaluating the rotator cuff and other soft tissues of the shoulder. It is noninvasive and cost- and time-efficient and allows for static, dynamic, and functional imaging of the shoulder. It is also an educational tool for patients, giving them an opportunity to participate in the evaluation and management of their shoulder disorder.[2]

REFERENCES

1. Alasaarela E, Leppilahti J, Hakala M. Ultrasound and operative evaluation of arthritic shoulder joints. Ann Rheum Dis 1998;57: 357-60.
2. Balogh B, Fruhwald F, Neuhold A, Wicke L, Firbas W. Sonoanatomy of the shoulder. Acta Anat (Basel) 1986;126:132-5.
3. Brandt TD, Cardone BW, Grant TH, Post M, Weiss CA. Rotator cuff sonography: a reassessment. Radiology 1989; 173:323-7.
4. Burk DL, Karasick D, Kurtz AB, et al. Rotator cuff tears: prospective comparison of MR imaging with arthrography, sonography, and surgery. AJR Am J Roentgenol 1989;153:87-92.
5. Casser HR, Sulimma H, Straub A, Paus R. Sources of error in sonographic diagnosis of the rotator cuff [in German]. Ultraschall Med 1991;12:256-62.
6. Chiou HJ, Hsu CC, Chou YH, et al. Sonographic signs of complete rotator cuff tears. Zhonghua Yi Xue Za Zhi (Taipei) 1996;58:428-34.
7. Codman EA. The shoulder: rupture of the supraspinatus tendon and other lesions in or about the subacromial bursa. Boston: Thomas Todd; 1934.
8. Drakeford MK, Quinn MJ, Simpson SL, Pettine KA. A comparative study of ultrasonography and arthrography in evaluation of the rotator cuff. Clin Orthop 1990;253:118-22.
9. Fabis J, Synder M. The sensitivity and specificity of sonographic examination in detection of rotator cuff [in Polish]. Chir Narzadow Ruchu Ortop Pol 1999;64:19-23.
10. Farrar EL, Matsen FA, Rogers JV, Hirsch J, Kilcoyne RF. Dynamic sonographic study of lesion of the rotator cuff [abstract]. Presented at the American Academy of Orthopaedic Surgeons 50th Annual Meeting; Atlanta, GA: March 10-15, 1983. p. 49.
11. Hedtmann A, Fett H. Sonography of the shoulder in subacromial syndromes with diseases and injuries of the rotator cuff. Orthopade 1995;24:498-508.
12. Helweg G, Moriggl B, Sperner G, et al. Ultrasound diagnosis of the shoulder [in German]. Radiologe 1996;36:971-80.
13. Katthagen B-D. Ultrasonography of the shoulder. New York: Thieme Medical Publishers, Inc; 1990.
14. Kurol M, Rahme H, Jilding S. Sonography for diagnosis of rotator cuff tear. Acta Orthop Scand 1991;62:465-7.
15. Mack LA, Matsen FA, Kilcoyne RF, Davies PK, Sickler ME. US evaluation of the rotator cuff. Radiology 1985;157:205-9.
16. Mack LA, Nyberg DA, Matsen FA III. Sonographic evaluation of the rotator cuff. Radiol Clin North Am 1988;26:161-77.
17. Matsen FA, Arntz CT, Lippitt SB. Rotator cuff. In: Rockwood CA, Matsen FA, editors. The shoulder. 2nd ed. Philadelphia: Saunders; 1998. p. 789-91.
18. Mellerowicz H, Kefenbaum A, Stelling E. Soft tissue diagnosis of the shoulder joint using sonography, computerized tomography and magnetic resonance tomography (MRT) [in German]. Zentralbl Chir 1989;114:209-21.
19. Middleton WD, Edelstein G, Reinus WR, Melson GL, Murphy WA. Ultrasonography of the rotator cuff: technique and normal anatomy. J Ultrasound Med 1984;3:549-51.
20. Middleton WD, Edelstein G, Reinus WR, et al. Sonographic detection of rotator cuff tears. AJR Am J Roentgenol 1985;144: 349-53.
21. Middleton WD, Reinus WR, Melson CL, Totty WG, Murphy WA. Pitfalls of rotator cuff sonography. AJR Am J Roentgenol 1986; 146:555-60.
22. Middleton WD, Reinus WR, Totty WG, Melson CL, Murphy WA.

Ultrasonic evaluation of the rotator cuff and biceps tendon. J Bone Joint Surg Am 1986;68:440-50.
23. Miller CL, Karasick D, Kurtz AB, Fenlin JM Jr. Limited sensitivity of ultrasound for the detection of rotator cuff tears. Skeletal Radiol 1989;18:179-83.
24. Ptasznik R. Sonography of the shoulder. In: van Holsbeeck MT, Introcaso JH, editors. Musculoskeletal ultrasound. 2nd ed. St Louis: Mosby; 2001. p. 463-516.
25. Read JW, Perko M. Shoulder ultrasound: diagnostic accuracy for impingement syndrome, rotator cuff tear, and biceps tendon pathology. J Shoulder Elbow Surg 1998;7:264-71.
26. Roberts CS, Walker JA, Seligson D. Diagnostic capabilities of shoulder ultrasonography in the detection of complete and partial rotator cuff tears. Am J Orthop 2001;10:159-62.
27. Soble MG, Kaye AD, Guay RC. Rotator cuff tear: clinical experience with sonographic detection. Radiology 1989;173:319-21.
28. Sonnabend DH, Hughes JS, Giuffre BM, Farrell R. The clinical role of shoulder ultrasound. Aust N Z J Surg 1997;67:630-3.
29. Tallroth K. Shoulder imaging. A review. Ann Chir Gynaecol 1996;85:95-103.
30. van Holsbeeck MT, Kolowich PA, Eyler WR, et al. US depiction of partial-thickness tear of the rotator cuff. Radiology 1995;197:443-6.
31. van Moppes FI, Veldkamp O, Roorda J. Role of shoulder ultrasonography in the evaluation of the painful shoulder. Eur J Radiol 1995;19:142-6.
32. Vick CW, Bell SA. Rotator cuff tears: diagnosis with sonography. AJR Am J Roentgenol 1990;154:121-3.
33. Wiener SN, Seitz WH. Sonography of the shoulder in patients with tears of the rotator cuff: accuracy and value for selecting surgical options. AJR Am J Roentgenol 1993;160:103-7.