The validity and reliability of ultrasound on identifying supraspinatus tears during passive external rotation from 0° to 30°: a pilot project

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Abstract

Background: Controversy exists regarding how much external rotation should be allowed following rotator cuff repair. Clinicians may use ultrasound imaging (USI) to visualize the supraspinatus (SSp) tendon during passive external rotation. However, the validity and reliability of USI used to assess supraspinatus tendon gap formation during external rotation needs to be established prior to using this technique in patient cohorts.

Methods: Ten subjects with magnetic resonance imaging (MRI) confirmation of full-thickness SSp tears were matched to 10 control subjects. Images of the SSp were obtained at 0°, 10°, 20° and 30° of external rotation by a blinded tester on two occasions to establish both validity and reliability of the measure.

Results: Validity was established as 70% agreement between the USI and MRI confirmed SSp tear group; reliability was established at greater than 0.90 at all positions of external rotation measured.

Conclusions: USI may be used to detect SSp tears with 70% validity, and the technique is reliable in all positions of external rotation.

Keywords

external rotation, rotator cuff, supraspinatus, ultrasound imaging

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Introduction

Rotator cuff tear is a very common disability affecting 20% of the population, and 35% of people older than 65 years, with the prevalence of tear increasing with age.¹ The most common tendon of the rotator cuff muscle group to tear is the supraspinatus (SSp).² A frequently employed treatment solution for the torn SSp tendon is to have an arthroscopic repair that restores the tendon footprint to the greater tuberosity of the humerus.³ Failure to heal or re-rupture of the repaired tendon is unfortunately common, with reports of repair disruption in up to 80% of massive and large tears.⁴ Failure to fully heal or to re-rupture a repair is attributed to tear size, patient age, muscle degeneration with fatty infiltration, environmental factors, medical comorbidities and rehabilitation protocol. The only postoperative variable that is within the control of the

surgeon and rehabilitation specialist and has an impact on the success of the tendon healing is an appropriate rehabilitation protocol. There is controversy about what the optimal rehabilitation protocol should entail, ranging from complete immobilization for 6 weeks,⁵

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early aggressive passive and active motion⁶ or staged passive motion.⁷⁻⁹ A method of assessing the SSp tendon during commonly utilized rehabilitation exercises, such as passive external rotation, could be beneficial in resolving this controversy.

Following rotator cuff repair, patients are immobilized in a sling with the surgical arm supported in internal rotation, which may create adaptive shortening of the capsuloligamentous structures and muscles on the anterior side of the shoulder joint. Consequently during the early phase of healing following rotator cuff repair, passive external rotation (ER) exercises are often prescribed to counteract the potentially deleterious effects of the immobilization. Several studies have published rehabilitation guidelines that suggest that passive external rotation up to 30° is safe during the first 6 weeks following rotator cuff repair.⁷⁻⁹ In contradiction of this assumption, Park et al. reported that external rotation from 0° to 30° in cadaveric specimens created gap formation in the anterior fibres of a SSp repair.¹⁰ This gap formation extended into the thick intramuscular cord that is a critical anatomic structure to remain intact for a successful outcome following SSp tendon repair.¹¹ As a result of this study, Park et al. suggested that external rotation may be deleterious to optimal restoration of the repaired rotator cuff footprint therefore clinicians should limit postoperative external rotation.¹⁰ Several studies have corroborated the assertion by Park et al.¹⁰ by demonstrating that delaying external rotation for 3 weeks to 6 weeks results in a similar outcome with improved healing rates at the site of the tendon repair.^{5,8,12}

The contradictory evidence in the literature between early versus delayed movement to optimize healing of the SSp tendon can render a clinician conflicted regarding how much external rotation is safe following SSp tendon repair. Musculoskeletal ultrasound imaging (USI) may allow clinicians to observe the effect of external rotation on SSp tendon footprint integrity, which would assist in decision-making regarding these concerns. Ultrasound has been reported to be a useful imaging tool for the detection of rotator cuff tear in the pre- and postoperative setting, with an accuracy of between 90% and 100%.¹³⁻¹⁵ The current method for exposing the SSp footprint for ultrasound assessment of tendon integrity is to have the patient place the arm in slight extension and internal rotation (hand behind the hip) so that the greater tuberosity is exposed anterior the acromion.^{14,16} In this position, the footprint is assessed for the presence of a gap along the anterior to posterior (longitudinal or long axis) and medial to lateral (transverse or short axis) directions. Although this static position measurement provides useful information about SSp footprint integrity, it does not provide information about the effect of movement, specifically

external rotation, on footprint integrity during the movement. USI at intervals of external rotation may be a good tool for studying the effect of this movement on the presence of gap formation at the footprint of a SSp repair; however, the validity and reliability of this assessment have not been reported.

The purpose of the present study is to establish the validity and reliability of using musculoskeletal USI to identify the presence of a rotator cuff tear during passive external rotation from 0° to 30°. If this technique proves to be valid and reliable, then future studies can be attempted to assess the effect of external rotation from neutral to 30° on SSp tendon integrity following rotator cuff repair using this method. The hypothesis of this study is that musculoskeletal USI will prove to be a valid and reliable tool for establishing gap formation in the SSp at 10° intervals from neutral to 30° of passive external rotation.

Materials and Methods

Subjects

All subjects signed an informed consent form that had been approved by the medical center's institutional review board prior to study initiation. Five males [mean (SD) 65.6 (15.8) years of age] and five females [66.6 (7.9) years of age] with magnetic resonance imaging (MRI) confirmed full thickness SSp tears were recruited from their treating orthopaedic surgeons, physician assistants or physical therapists. Ten sex- and age-matched subjects (five males [62.8 (14.1) years of age] and five females [64.8 (11.0) years of age]) were recruited by word of mouth to participate in the control group which served to blind the ultrasonographer to the presence of an MRI confirmed tear. Descriptive statistics, including laterality of tear and body mass index (BMI) of each group, are summarized in Table 1.

To be included in the SSp group, subjects had a documented full thickness SSp tear by MRI. Other pathologies such as a tear in other rotator cuff tendons, biceps long head, labrum or acromioclavicular arthrosis were considered acceptable concomitant pathologies because these additional diagnoses would not be expected to impact the visibility of the SSp tendon on USI. Subjects in this group were excluded if diagnosed with concomitant proximal humeral fracture, cuff tear arthropathy with humeral head migration to acromion and loss of joint space. Subjects were included in the control group if they demonstrated full active range of motion in the shoulder for elevation, ER and internal rotation bilaterally symmetrical without pain; 5/5 manual muscle test bilaterally symmetrical for ER in neutral position (with the arm at the side) and scaption

Table 1. Descriptive statistics of subjects taking part in the supraspinatus (SSp) tear and Control Groups, including laterality of tear and body mass index (BMI).

Group	Age (years)		Laterality of tear		BMI
	Male	Female	Left	Right	
SSp tear	65.6 (15.8)	66.6 (7.9)	2	8	29.7
Control	62.8 (14.1)	64.8 (11.0)	NA	NA	30.3

NA, not applicable. Data are the mean (SD).

at 30° without pain. These criteria were selected for the control group because prior research demonstrated specificity of 98% for rotator cuff tear presence in a population with a painful shoulder when the following three clinical tests were positive: ER weakness, SSp weakness and impingement with internal or ER.¹⁷ Subjects were excluded from the control group if they had pain with active range of motion testing in any plane for the extremity selected for USI; or pain or weakness with resisted contraction for ER or scapulation at 30°.

Procedure

All included subjects had ultrasound images of the SSp tendon taken across an arc of ER. To capture these images, a diagnostic ultrasound unit (A General Electric 121-RS Linear Array Transducer; GE Medical Systems Co., Ltd, Jiangsu, China; ref # 5393485, serial number 190678wx3) was utilized to capture data with a frequency of 5 Hz to 13 Hz and a 42 mm × 7 mm footprint. Two ultrasonographers were used to complete data collection in the present study with the test and retest images captured by the same ultrasonographer. Both ultrasonographers were blinded to subject group assignment (SSp group or control group). A barrier was placed so that the tester was not able to see the participant, and only the involved upper extremity was exposed. The subject was seated with the arm in neutral position along the side of the body, and the elbow in 90° of flexion (Fig. 1a). An ultrasound image was obtained of the SSp tendon footprint at 10° intervals from 0° to 30° of ER (Fig. 1b). The assistant used a standard goniometer to indicate positions to capture the images at each incremental position. The images were assessed at each position to determine whether there was a visible rotator cuff tear at any of the positions and, if so, the length and width of the tear in the longitudinal and transverse axes were measured and recorded. This procedure was repeated three times within this trial, and then the subject returned in 1

Figure 1. Positioning for ultrasound imaging procedure with subject positioned at 0° (a) and 30° external rotation (b); curtain blinds the ultrasonographer from full view of the subject.

hour for a second trial. The mean of the three measures of the longitudinal and transverse images of the tear was calculated for each trial to use for reliability comparison between the two trials. A minimum of three subjects were assessed by ultrasound at each testing session, and the order of receiving ultrasound was randomized by picking a number to control for the test/retest expectation from the ultrasonographer which might impact the reliability measure. Figure 2 illustrates ultrasound images for both intact and torn SSp tendons at 20° of ER shown in both long axis and short axis views. Subject age and body weight were recorded, with BMI calculated so that potential effect of BMI on the validity of the US image could be considered.

Statistical analysis

The validity of the dynamic ultrasound method was calculated as the percentage of agreement between the presence of SSp tear identified by MRI and the presence of SSp tear identified by ultrasound. In addition, comparisons were made between the observed USI in the control group and the assumption that there was no tear based on clinical exam findings. Intra-tester reliability was assessed by comparing the mean of the three measures of the longitudinal and transverse tear images for the test–retest data. Weighted kappa statistics were utilized to calculate the percent agreement and intra-class correlation coefficients (ICC) were utilized to calculate the reliability of the tear measures (SPSS, version 21; IBM Corp, Raleigh, NC, USA).

Results

All 20 subjects completed both trials of ultrasound testing, which was required for reliability testing. Each

Figure 2. Ultrasound images of the supraspinatus tendon in 20° of external rotation. (a) Image of supraspinatus in long axis shows intact tendon (open arrows). (b) Image of supraspinatus tendon in long axis showing a full thickness tear of the tendon with retracted tendon (arrowheads). (c) Image of supraspinatus in short axis shows intact tendon (open arrows). (d) Image of supraspinatus tendon in short axis showing a tear of the tendon (arrowheads). a, shadow of acromion process. H, humeral head. T, greater tuberosity.

Table 2. Summary of percentage of agreement between the magnetic resonance imaging (MRI) documented supraspinatus (SSp) tear and ultrasound imaging (USI) identified SSp tear, as well as a summary of percentage of agreement of control group subjects presumed to have no SSp tear with USI identified SSp tear.

Group	MRI positive	USI positive	USI negative
SSp tear	10	7	3
Control	Not applicable	2 (single trial)	2 (both trials) 6

subject was able to tolerate having the ultrasound performed at the multiple arm positions: 0°, 10°, 20° and 30° of ER.

Validity

Ultrasound images were compared with the MRI to confirm full-thickness SSp tears, and the percentage agreement is summarized in Table 2. Seven of the ten subjects with SSp tear were successfully identified as

having the tear at all angles of ER measured (0°, 10°, 20° and 30°), which resulted in 70% agreeability between the MRI and USI. Among the 10 subjects in the control group who were presumed to have no SSp tear as a result of having full active range of motion (AROM) with normal mechanics for elevation without pain, as well as strong and painless resisted contractions for ER and scaption, there were positive findings suggestive of SSp tear at all angles in both test trials for two subjects, and in one test trial for two subjects. The mean measure of gap formation (cm), for those subjects who were identified as having a SSp tear, is shown in Table 3.

Reliability

Reliability of the USI measures on the observed tears was measured over two sessions on the same day. There was a high level of reliability between the means of the trial 1 and trial 2 values for all angles of ER measured in the SSp group (range 0.90 to 0.98). The reliability is strong in neutral position (0.94 on the longitudinal axis and 0.96 along the transverse axis), as well as at the 30°

Table 3. Mean (SD) deviation of gap formation (cm) on the longitudinal and transverse axes at each angle of external rotation (0°, 10°, 20° and 30°).

	0°	10°	20°	30°
Long axis trial 1	1.03 (0.72)	0.96 (0.72)	0.97 (0.72)	1.00 (0.74)
Long axis trial 2	1.23 (0.78)	1.24 (0.71)	1.14 (0.66)	1.14 (0.66)
Transverse axis trial 1	0.78 (0.46)	0.79 (0.51)	0.80 (0.49)	0.81 (0.57)
Transverse axis trial 2	0.85 (0.39)	0.87 (0.38)	0.89 (0.36)	0.85 (0.39)

Table 4. Reliability with 95% confidence intervals in parenthesis of repeated measures of supraspinatus tear measured on ultrasound imaging along the longitudinal and transverse axes at all angles of external rotation studied (0°, 10°, 20° and 30° reported as an intra-class correlation coefficient).

Orientation	0°	10°	20°	30°
Longitudinal	0.94 (0.75 to 0.98)	0.93 (0.72 to 0.98)	0.98 (0.91 to 0.99)	0.96 (0.83 to 0.99)
Transverse	0.96 (0.86 to 0.99)	0.90 (0.58 to 0.97)	0.93 (0.72 to 0.98)	0.94 (0.76 to 0.98)

ER position (0.96 and 0.94 for longitudinal and transverse axes, respectively). This measure of test–retest reliability is reported using intraclass correlation coefficients presented in Table 4 for each angle of ER studied in this project (0°, 10°, 20° and 30°).

Discussion

USI was used in an attempt to identify SSsp tears at 10° intervals of shoulder ER from 0° to 30°, and was found to be valid for this measure in 70% of the cases evaluated in this case–control series. This method of obtaining USI of the rotator cuff could be useful in a postoperative cohort investigation aiming to assess whether gap formation of the SSsp tendon occurs during passive ER from neutral to 30°. Clinicians would find this information useful when designing safe postoperative rehabilitation guidelines. To date, no other study has reported on the validity or reliability of imaging the SSsp tendon in the neutral position or at intervals of ER. Prior studies examining the validity of USI to determine SSsp tendon tears in the standard position (hand behind the hip) compared to arthroscopic or MRI documentation of SSsp tears have demonstrated an accuracy ranging from 89% to 96%.^{13–15}

Although the primary purpose of the control group was to provide a means to blind the sonographer to the presence of a SSsp tear, the four cases where the USI did show a SSsp tear should be addressed. There was no MRI on record to refute the presence of a tear; therefore, it is unknown whether these are true false positive cases. The assumption was made with the control group

that, if there was full AROM for elevation with good mechanics and no pain, and strong and painless resisted ER and scaption tested in full can position, that the subject did not have a SSsp tear. One control group subject who was identified by USI as having a SSsp tear was an 80-year-old female and another had a history of playing many years of volleyball. The current literature suggests that the incidence of rotator cuff tear increases with age and also with repeated participation in overhead sports.^{1,18} Many individuals who have rotator cuff tears are ‘copers’ with no symptoms, particularly if there is only a single tendon tear in the SSsp and the remainder of the cuff is intact. Therefore, it is very possible that the 80-year-old female and the overhead athlete did meet the control group criteria yet do have some degree of SSsp tendonopathy. The remaining two subjects in the control group who exhibited one trial of USI positive for SSsp tear, and one trial negative for SSsp tear, were over 63 years of age, and so it is possible that they also had some level of tendon pathology given their advanced age. Each of these subjects did have one trial that reflected an intact SSsp tendon with the USI; therefore, tendonopathy may have been misread as tendon tearing on one of the trials.

There were three cases who did not show SSsp tear on USI yet had positive MRI confirmation of full-thickness tears. Two of these three were subjects with a BMI over 36%, which falls into the obese category.¹⁹ The literature does support the idea that scan quality is diminished in obese patients and that unsatisfactory image quality often occurs.²⁰ Prior studies investigating the use of USI for identification of rotator cuff tear in

the postoperative setting also found a greater error with obese subjects.¹³ Therefore, if USI is to be used to assist when addressing the question of the appropriate amount of ER following SSp repair, studies should refrain from utilizing subjects with a BMI of greater than 35%. The third subject who did not show the SSp tear on USI yet had confirmation of tear by MRI was the first subject enrolled in the data collection. This project posed a novel method of imaging the SSp, and prior research on the standard position for SSp imaging (hand behind the hip) reports that technician reliability is optimized after 100 images are taken.²¹ There were 96 images obtained for each subject considering all of the trials involved, and therefore the technician rapidly improved in skill and reliability. It is possible that the discrepancy between the USI and MRI regarding the SSp tear may have been avoided if the technician had practiced the technique at least 100 times prior to beginning data collection.

The reliability of the measure of the tendon tear in the SSp group was very strong, with an ICC ranging from 0.90 to 0.98 in the transverse and longitudinal axes of the SSp at 0°, 10°, 20° and 30° of ER. This high level of reliability is similar to that reported in prior studies for USI of SSp tears in a standard position (hand behind the hip).^{13–15} The reliability reported in the present study included measures of the two different sonographers combined. The repeatability of the measure at each angle suggests that dynamic ultrasound is a reliable method for assessing SSp tendon tear through this range of motion.

The limitations of the present study include the small sample size, the assumption that the control group subjects had no SSp tear based on the findings of a physical examination without MRI confirmation, and the use of two different ultrasonographers for data collection. The small sample size was selected so that this project could serve as a pilot, and the promising results warrant further exploration in a larger pool of subjects. The assumption that the control group had no SSp tear appeared to be appropriate based on the selected clinical tests demonstrating high specificity (98%) in the literature¹⁷, and allowed this project to proceed with a blinded design without the expense of MRI studies for the control group. The use of two different ultrasonographers was an unanticipated circumstance and, given the high volume of ultrasounds performed, with research showing good reliability after 100 ultrasounds²¹, the assumption was made that the change in technicians would not decrease the merit of the present study.

In summary, this case-control pilot series was completed to determine whether USI can be effective in assessing SSp tendon tear at intervals of ER from 0° to 30° with the arm at the side because this range of

motion is frequently part of a rehabilitation effort during the healing phase following rotator cuff repair. The hypothesis that the method was valid was found to be true in 70% of the cases studied with documented MRI findings of tear. This validity may be improved for future studies if subjects with a BMI of greater than 35% are excluded, and all ultrasounds are conducted by an experienced technician who practices the technique at least 100 times prior to beginning data collection. The reliability of the measure was strong at all positions of ER for SSp tear subjects with a documented tear on the ultrasound images.

Conclusions

Ultrasound imaging of the SSp tendon footprint from 0° to 30° of ER with the arm at the side may provide a method of assessing the safety of passive ER after repair of this tendon. Additional study of this method with a larger pool of subjects is warranted to strengthen the power of these results prior to use in patient cohorts.

Declaration of Conflicting Interests

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References

1. Yamamoto A, Takagishi K, Osawa T, et al. Prevalence and risk factors of a rotator cuff tear in the general population. *J Shoulder Elbow Surg* 2010; 19: 116–20.
2. Ianotti JP. Lesions of the rotator cuff: pathology and pathogenesis. In: Matsen FA, Fu FA, Hawkins RJ, eds. *The shoulder: a balance of mobility and stability*. Rosemont, IL, American Academy of Orthopaedic Surgeons, 1993.
3. Colvin AC, Egorova N, Harrison AK, Moskowitz A and Flatow E.L. National trends in rotator cuff repair. *J Bone Joint Surg Am* 2012; 94: 227–33.
4. Galatz L, Ball C, Teefor S, Middleton WD and Yamaguchi K. The outcome and repair integrity of completely arthroscopically ruptured large and massive rotator cuff tears. *J Bone Joint Surgery* 2004; 86: 219–24.
5. Parsons BO, Gruson KI, Chen DD, Harrison AK, Gladstone J and Flatow E. Does slower rehabilitation after arthroscopic rotator cuff repair lead to long-term stiffness? *J Shoulder Elbow Surgery* 2010; 19: 1034–9.
6. Dunzgun I, Baltaci G and Atay OA. Comparison of slow and accelerated rehabilitation protocol after arthroscopic rotator cuff repair: pain and functional activity. *Acta Orthop Trauma Turcica* 2011; 45: 23–33.

7. Cuff DJ and Pupello DR. Prospective randomized study of arthroscopic rotator cuff repair using an early versus delayed postoperative physical therapy protocol. *J Shoulder Elbow Surgery* 2012; 21: 1450–5.
8. Lee BG, Cho NS and Rhee YG. Effect of two rehabilitation protocols on range of motion and healing rates after arthroscopic rotator cuff repair: aggressive versus limited early passive exercises. *J Arthroscopic Rel Surgery* 2012; 28: 34–42.
9. Millett PJ, Wilcox R, O'Holloran J and Warner JP. Rehabilitation of the rotator cuff: an evaluation-based approach. *J Acad Orthop Surg* 2006; 14: 599–609.
10. Park MC, Idjadi JA, ElAttrache NS, Tibone JE, McGarry MH and Lee TQ. The effect of dynamic external rotation comparing 2 footprint-restoring rotator cuff repair techniques. *Am J Sports Med* 2008; 36: 893–901.
11. Roh M, Wang V, April E, Pollock RG, Bigliani L and Flatow E. Anterior and posterior musculotendinous anatomy of the supraspinatus. *J Shoulder Elbow Surgery* 2000; 9: 436–40.
12. Riboh JC and Garrigues GE. Early passive motion versus immobilization after arthroscopic rotator cuff repair. *Arthroscopy* 2014; 30: 997–1005.
13. Prickett WD, Teefey SA, Galatz LM, Calfee RP, Middleton WD and Yamaguchi K. Accuracy of ultrasound imaging of the rotator cuff in shoulders that are painful postoperatively. *J Bone Joint Surgery* 2003; 85A: 1084–9.
14. Teefey S, Hasan A, Middleton W, Patel M, Wright R and Yamaguchi K. Ultrasonography of the rotator cuff: a comparison of ultrasonographic and arthroscopic findings in one hundred consecutive cases. *J Bone Joint Surgery* 2000; 82A: 498–504.
15. Teefey SA, Rubin DA, Middleton WD, Hildebold CF, Leibold RA and Yamaguchi K. Detection and quantification of rotator cuff tears: comparison of ultrasonographic, magnetic resonance imaging, and arthroscopic findings in seventy-one consecutive cases. *J Bone Joint Surgery* 2004; 86A: 708–16.
16. Fealy S, Adler RS, Drakos MC, Kelly A, Allen A, Cordasco A, et al. Patterns of vascular and anatomical response after rotator cuff repair. *Am J Sports Med* 2006; 34: 120–7.
17. Murrell GA and Walston J. Diagnosis of rotator cuff tears. *Lancet* 2001; 357: 769–70.
18. Emonds EW and Dengerink DD. Common conditions in the overhead athlete. *Am Fam Physician* 2014; 89: 537–41.
19. National Institute of Health; Department of Health and Human Services. http://www.nhlbi.nih.gov/health/educational/lose_wt/BMI/bmicalc.htm (accessed 1 November 2014).
20. Monnington S, Dodd-Hughes K, Milnes E, Ahmad Y. Risk management of musculoskeletal disorders in sonography work. Health and Safety Executive. March 2012. <http://www.hse.gov.uk/healthservices/management-of-musculoskeletal-disorders-in-sonography-work.pdf> (accessed 1 November 2014).
21. Alavekios DA, Dionysian E, Sodi J, Contreras R, Cho Y and Yian EH. Longitudinal analysis of effects of operator experience on accuracy for ultrasound detection of supraspinatus tears. *J Shoulder Elbow Surgery* 2013; 3: 375–80.