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Increased postoperative deltoid signal seen after suprapectoral biceps tenodesis: potential risk to the anterior branch of the axillary nerve

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Background: Arthroscopic suprapectoral biceps tenodesis is a common procedure for lesions of the long head of the biceps in the setting of anterior shoulder pain. However, the distal portal poses a theoretical risk to the terminal branches of the axillary nerve as the nerve travels from posterior to anterior to innervate the anterior deltoid. The purpose of this retrospective cohort study was to assess for axillary nerve branch injury, identified by deltoid signal change in postoperative magnetic resonance imaging (MRI) in patients who underwent an arthroscopic suprapectoral biceps tenodesis.

Methods: Patients who underwent rotator cuff repair with a concomitant arthroscopic suprapectoral biceps tenodesis had a postoperative MRI, and at least 1 year of follow-up was included. The incidence of increased deltoid signal consistent with injury to an anterior branch of the axillary nerve on proton density fat-saturated sequences was collected. Age, sex, body mass index (BMI), and patient-reported outcome measures (PROMs), including the American Shoulder and Elbow Surgeons Shoulder (ASES) score, patient-reported outcomes measurement information system pain, physical function, and upper extremity scores, and single assessment numeric evaluation score were compared in patients with and without increased deltoid signal on postoperative MRI. $P < .05$ was used for significance.

Results: Twenty-four patients were eligible for inclusion (9 female, average age 59.0 ± 10.1, BMI 27.6 ± 6.7). Edema-like signals within the anterior deltoid musculature was observed in 9 patients on postoperative MRI. Two patients had a second follow-up MRI performed, which demonstrated resolution of signal, and one patient required a second surgery for release of adhesions. Patients with increased deltoid signal had higher BMI ($P = .03$). There was no difference in any other demographic or post-operative patient-reported outcome measure between patients with increased signal and those without at any follow-up time point. No patient demonstrated persistent weakness or numbness in the axillary nerve distribution at final follow-up.

Discussion: Over one third of patients in our cohort had MRI evidence of axillary nerve branch injury as seen on proton density fat-saturated MRI sequences postoperatively. The distal arthroscopic portal for a suprapectoral biceps tenodesis may place anterior terminal branches of the axillary nerve at risk for injury. Additional investigation and strategies for avoidance of nerve injury in this area should be pursued.

Lesions of the long head of the biceps brachii tendon (LHBT) are a common source of anterior shoulder pain, and the incidence of LHBT pathology is rising as patients continue to be active as they age.[4,19] If patients fail a trial of nonoperative management, surgery generally consists of a LHBT tenotomy or tenodesis. There is a lack of consensus regarding the preferred treatment option, as several systematic reviews have failed to show the superiority of one technique over the other.[21] However, tenodesis provides improved cosmetic appearance and may be preferred in the active population

This study was carried out in accordance with the ethical standards of the Mayo Clinic Institutional Review Board (IRB), with the 1964 Helsinki Declaration and its later amendments, and in compliance with relevant regulations of the US Health Insurance Portability and Accountability Act (HIPAA). The IRB application number for this manuscript is 23-012828.

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due to improvement of deformity, decreased muscle cramping, and less early fatigue.[2,3]

Both open and arthroscopic approaches for performing biceps tenodesis have been described, each with a variety of fixation techniques.[1] The arthroscopic suprapectoral biceps tenodesis is a well-accepted technique, which has been reported to have excellent clinical results and the potential advantage of removing all diseased tissue of the proximal biceps from the intertubercular groove. This technique utilizes the falciform ligament of the pectoralis major tendon as a landmark for docking the biceps tendon.[8] This technique has not been reported to present any higher risk to surrounding anatomic structures compared to other techniques, but due to its distal positioning, there is a theoretical risk to the anterior terminal branches of the axillary nerve as they travel from posterior to anterior to innervate the anterior deltoid.

Iatrogenic axillary nerve damage has been described in the radiology literature as a potential postoperative complication after biceps tenodesis.[9] It is unknown if this represents a clinically significant risk, and advanced imaging following biceps tenodesis is not routinely ordered in the absence of unexpected clinical findings or a suspected complication. However, if present, such an injury would not be visible on plain film imaging. Magnetic resonance imaging (MRI) is often considered the advanced imaging modality of choice for evaluating soft tissues, and certain sequences can also improve localization to answer specific clinical questions. The denervation of muscle suggestive of nerve injury can in particular be seen in fluid-sensitive proton density fat-saturated sequences and manifests as diffusely increased signal intensity in the known anatomic distribution of a nerve.[18] This sequence has been used to reliably identify both nerve and muscle injury in the upper extremity (UE).[7,13]

The purpose of this retrospective cohort study was to assess for axillary nerve branch injury, identified by deltoid signal change in postoperative MRI in patients who underwent an arthroscopic suprapectoral biceps tenodesis. We hypothesized that there would be signal change evident in proton density fat-saturated MRI sequences in most patients, but these imaging changes would not influence clinical outcomes.

Materials and methods

Patient population

Patients who consecutively underwent rotator cuff repair with arthroscopic suprapectoral biceps tenodesis and biceps tendon autograft augmentation at a single, tertiary care academic hospital were eligible for inclusion. All patients had a postoperative MRI performed within 6 months of surgery and at least 1 year of follow-up either in-person or by telecommunication. Age, sex, and body mass index (BMI) were obtained. Patient-reported outcome measures (PROMs) were collected preoperatively and postoperatively at 3, 6, and 12 months after surgery.

Surgical technique

All patients underwent arthroscopic rotator cuff repair with a single sports fellowship-trained orthopedic surgeon. Patients were placed in a lateral decubitus position, and standard posterior, lateral, and anterior portals were established. The biceps tendon was identified intra-articularly and cut at its origin using arthroscopic scissors. The rotator cuff was biologically prepared, and a standard repair was performed using suture anchors. A reverse field view was obtained by directing the arthroscope distally along the humeral shaft in the subdeltoid space through the lateral portal. An additional outside-in portal was made approximately 1 centimeter (cm) superior to the falciform ligament of the pectoralis major, and an 8 millimeter (mm) cannula (Arthrex, Naples, FL, USA) was established in this portal.[8] This allowed for biologic preparation of the intertubercular groove to facilitate tenodesis healing and anchor placement perpendicular to the bone at this level. The LHBT was exposed in the subdeltoid space just above the falciform ligament, and a tenodesis was performed just superior to the falciform ligament using a single all-suture knotless suture anchor (1.8 mm knotless Fibertak; Arthrex, Naples, FL, USA) fixed to the LHBT with a locking figure of eight stitch. The remainder of the tendon was cut and removed and then compressed on the back table and used to augment the rotator cuff repair. Postoperatively, patients were placed into a sling and followed a standard postoperative rotator cuff repair protocol. Patients started a passive range of motion with physical therapy at two weeks and active motion at six weeks following surgery. Strengthening commenced at three months postoperatively, and return to full activity was achieved by six months postoperatively.

MRI

All patients undergoing biceps augmentation of the rotator cuff repair underwent an MRI as standard of care to evaluate the incorporation of the graft within 6 months of surgery. As such, this created a consecutive series of patients who had undergone a suprapectoral biceps tenodesis with a postoperative MRI, and these patients formed the basis of this study. MRI was performed using a 1.5 Tesla Siemens Sola, 3T Siemens Vida, or 3T Siemens Skyra machines (Siemens Healthineers, Issaquah, WA, USA). Patients were positioned supine with the operative arm held in a neutral position. A T1 sagittal sequence was run using a standard protocol, and proton density axial, sagittal, and coronal sequences with and without fat saturation were completed. All sequences included the deltoid from its origin to the mid humerus as well as the shoulder joint in its entirety with 3-5 mm slices. Fluid in the deltoid was best seen on proton density fat-saturated sequences in the axial cuts. All images were interpreted by a fellowship-trained musculoskeletal radiologist. The incidence of increased anterior deltoid signal consistent with muscle edema on proton density fat-saturated MRI sequences was collected.

Outcomes

The primary outcome was the incidence of imaging findings suggestive of axillary nerve branch injury, such as fatty infiltration, edema, or atrophy. Secondary outcomes were the American Shoulder and Elbow Surgeons Shoulder (ASES) score, patient-reported outcomes measurement information system (PROMIS) pain, physical function (PF), and UE scores, and single assessment numeric evaluation (SANE) score. Information on any return to the operating room was collected. Patients who did not meet the follow-up criteria or did not have a postoperative MRI were excluded.

Statistics

The baseline demographics and PROMs of patients who had increased deltoid signal were compared to patients without increased signal. Due to small sample sizes, Mann Whitney U-tests were completed for all continuous variables, and Fisher's exact tests were completed for categorical variables. Significance was set at $P < .05$, and all data were presented as mean and standard deviation.

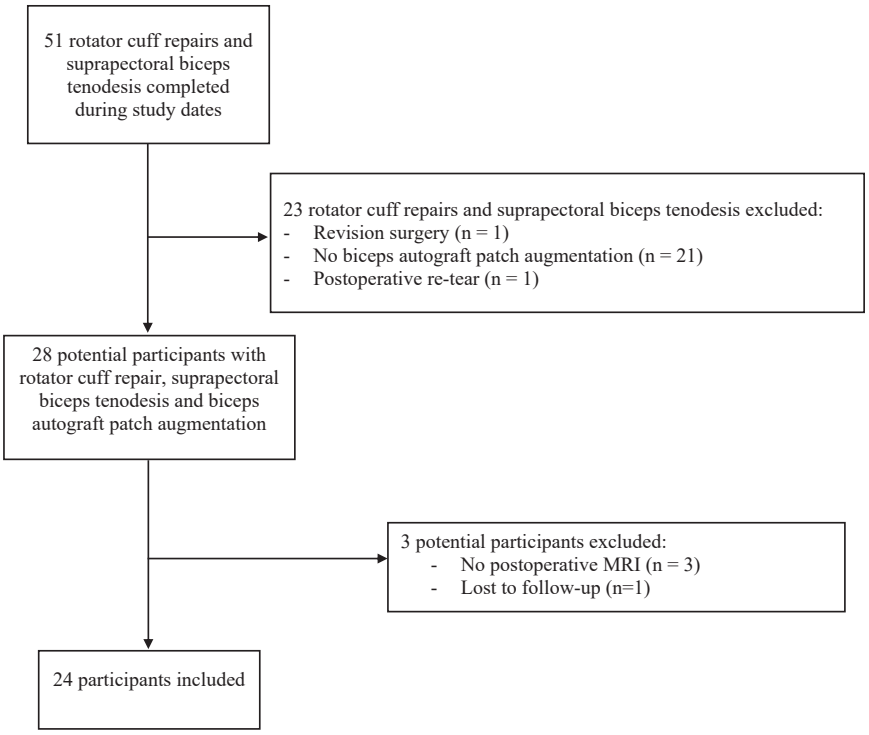

Figure 1 Consolidated Standard of Reporting Trials (CONSORT) flow diagram. *MRI*, magnetic resonance imaging.

Results

MRI findings

Twenty-four consecutive patients were eligible for inclusion (Fig. 1). Nine were female, the average age was 59.0 ± 10.1 years, and the average BMI was 27.6 ± 6.7. The average time between surgery and MRI was 4.17 ± 1.72 months. Thirteen patients completed their MRI within 3 months postoperatively, and the remainder completed their MRI within 6 months.

Nine patients exhibited increased edema-like signal within the anterior deltoid on MRI, of which 7 were male (Fig. 2, Table I). There were no instances of fatty infiltration or atrophy observed. Patients with positive signal had an increased BMI ($P = .03$). There was no difference between sex, age, or time between surgery and MRI with respect to the presence or absence of signal abnormality. Two patients with increased signal had a second follow-up MRI performed, which demonstrated complete resolution of deltoid signal abnormality.

One patient reported painful popping and catching in the shoulder with abduction and adduction three months postoperatively. MRI revealed mild edema along the anterior portion of the deltoid without any evidence of recurrent rotator cuff tear. At six months postoperatively, the patient continued to exhibit asymmetry in active range of motion with 140° overheard abduction, 45° external rotation at the side, 50° external rotation in the abducted position, and 140° forward elevation compared to 190°/90°/100°/190°, respectively, on the contralateral side. The patient did not exhibit any muscle weakness clinically. A second MRI was completed, which demonstrated resolution of the abnormal deltoid signal and no evidence of recurrent cuff tear. An electromyography test was also ordered, which did not reveal any signs of nerve compression or injury. Thus, the patient's limitation in range of motion was attributed to postoperative stiffness, and they were subsequently taken back to the operating room for repeat arthroscopy, with capsular release and subacromial decompression. Postoperatively, they successfully regained a full and symmetric shoulder arc of motion.

PROMs

There was no difference in preoperative PROMIS pain, PF, and UE scores for patients with increased postoperative deltoid signal and those without (Fig. 3). There was also no difference in preoperative global pain scores, ASES, SANE, or contralateral SANE scores. Starting at three months postoperatively, patients with positive signal on postoperative MRI did not experience a significant improvement in any PROMIS score postoperatively, although they did have significantly improved global pain, ASES, and SANE scores ($P = .034$, $P < .01$, $P = .04$, respectively). These results persisted at all follow-up points (3 months, 6 months, and 1 year). Patients without increased signal on postoperative MRI exhibited significant improvement in all PROMs postoperatively at all follow-up time points ($P < .01$). There was no difference in any postoperative PROM between patients with and without increased deltoid signal at any follow-up point, including at 1-year follow-up. Full values for 1-year PROMs are available in Table II.

Discussion

In this retrospective cohort study of 24 patients who underwent arthroscopic rotator cuff repair with suprapectoral biceps tenodesis, we found that 38% of patients demonstrated increased postoperative anterior deltoid signal seen on proton density fat-saturated sequence MRI, consistent with muscular edema secondary to neurogenic injury. This did not appear to be correlated with a difference in clinical outcomes between patients with increased signal and those without, although patients with increased signal did not demonstrate postoperative improvement in their PROMIS scores. To our knowledge, this finding has not been

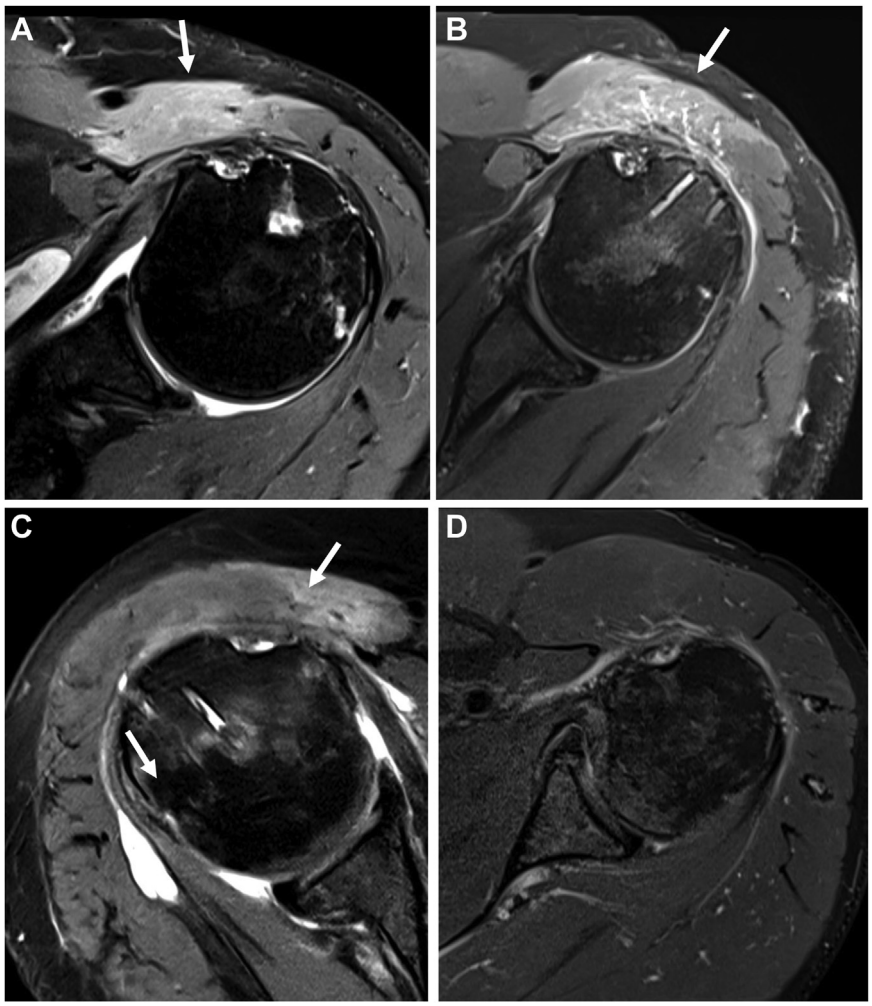

Figure 2 Deltoid signal in postoperative magnetic resonance imaging. (**A-C**) Proton density fat saturated MRI axial sequences of the shoulder demonstrating increased signal in the anterior deltoid musculature (*white arrows*). (**D**) Normal deltoid musculature for comparison. *MRI*, magnetic resonance imaging.

Table I
Demographic and MRI results.

	Increased postoperative deltoid signal	No increased signal	*P* value
N	9	15	
Age (years)	55 ± 14.1	62 ± 6.0	.21
Sex			.23
Female, N (%)	2 (22.2)	8 (53.3)	
Male, N (%)	7 (77.8)	7 (46.7)	
BMI	31.0 ± 3.9	26 ± 7.3	.03
Time between surgery and MRI (months)	4.17 ± 1.84	4.18 ± 1.77	.99

BMI, body mass index; *MRI*, magnetic resonance imaging.
Table describing demographic variables for patients in this study, including the number of patients, age, sex, body mass index, and time between surgery and MRI. Patients were separated into two cohorts based on presence or absence of increased postoperative deltoid signal on magnetic resonance imaging.

previously described, and the incidence of this imaging finding in a larger population is unknown as advanced imaging following arthroscopic biceps tenodesis is not routinely obtained in the absence of a suspected complication.

Previous studies have assessed the risk of axillary nerve injury associated with biceps tenodesis, but these focused on older techniques where fixation was obtained with bicortical drilling of the humerus and the risk was posterior. Pinedo et al described in a study of 10 cadaveric shoulders that a bicortical drilling technique in suprapectoral biceps tenodesis did not present a risk to the axillary nerve.[11] Sethi et al also reported penetration of the posterior cortex resulted in direct penetration of the axillary nerve in 20% of specimens.[15] Filho et al obtained an MRI in 31 shoulders after rotator cuff repair with biceps tenodesis vs. tenotomy to examine signs of fatty infiltration in the biceps muscle, but focused on the anterior compartment of the arm and did not report on the deltoid.[17] Similar to our results, they did not find any changes in muscle mass or signs of fatty infiltration, although they looked at the biceps and did not comment on the deltoid. It is important to note that these studies did not use a distal suprapectoral portal to perform the tenodesis. Our study utilized a well-described suprapectoral portal to perform an arthroscopic biceps tenodesis using a suture anchor that does not violate the posterior cortex, thus our findings represent the first study we are aware of to report on possible injury to the deltoid anteriorly in this procedure. Because postoperative MRIs are not routinely ordered, it is unknown how these advanced imaging findings compare to the results of other surgeons who perform this procedure.

In every patient with increased deltoid signal on postoperative MRI, the increased signal was localized to the anterior deltoid anterior to the position of the cannula and in the distribution of the axillary nerve. This suggests that the anterior terminal branches of

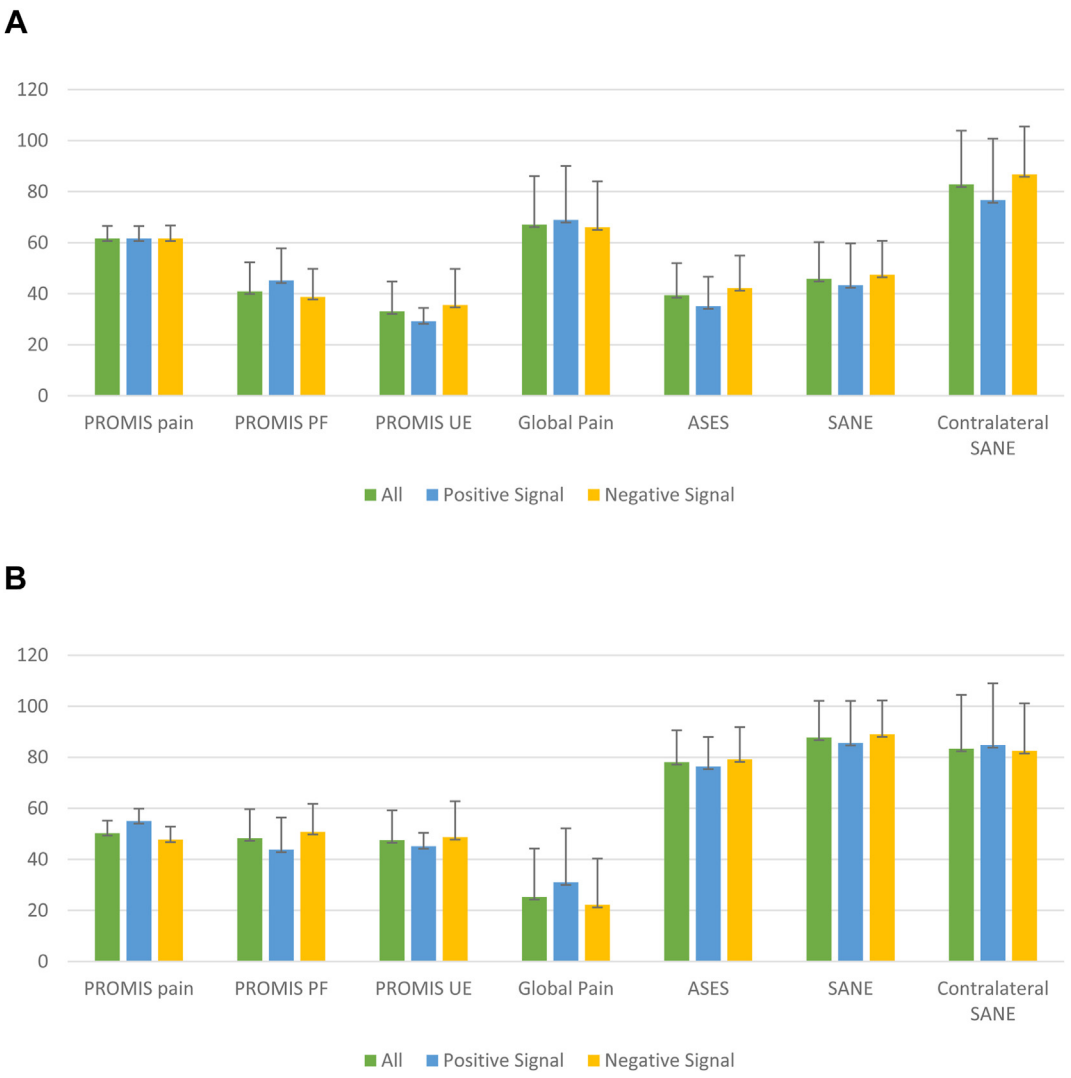

Figure 3 Preoperative and postoperative patient-reported outcome measures (PROMs). Bar chart demonstrating preoperative and postoperative PROMs with standard deviation in patients with and without signal. Each score has 3 bars, the first showing all patients, the second showing patients with increased deltoid signal, and third showing patients without increased deltoid signal. (**A**) Preoperative PROMs. (**B**) Postoperative PROMs. *ASES*, American Shoulder and Elbow Surgeons Shoulder Score; *PF*, physical function; *PROMIS*, Patient-Reported Outcomes Measurement Information System; *SANE*, Single Assessment Numeric Evaluation; *UE*, upper extremity.

the axillary nerve are potentially at risk when creating and working through the distal portal for a suprapectoral biceps tenodesis. This portal may be near the anterior terminal branches of the axillary nerve as it travels from posterior to anterior along the deep surface of the deltoid. There are several papers that detail the course of the axillary nerve. Apaydin et al dissected out the axillary nerve in 50 cadaveric specimens and described its branching relationship on the deep surface of the deltoid and reported that the anterior branch had the longest average length of 5.5 cm. Rastogi et al, in a study of 23 cadavers, found that the anterior division of the axillary nerve supplies the majority of the deltoid by weight.[12] However, the location of the most anterior portion of the nerve as it travels to the anterior deltoid has not been well-described. Lastly, Shiu et al described a relationship between the anterior branch of the axillary nerve and the insertion of the pectoralis major tendon and found that the nerve was on average 3.2 mm distal to the tendon.[16] This would suggest that a "safe zone" for portal placement in arthroscopic biceps tenodesis would be anywhere proximal to the pectoralis tendon, and in fact, the placements of the arthroscopic portals in the current study were always placed proximal to the pectoralis tendon in line with the standard arthroscopic suprapectoral biceps tenodesis technique. However, the findings reported in this paper would suggest that the anterior branch of the nerve may have a more proximal or variable course than was reported by Shiu. The deltoid edema seen on the MRIs in this study was always seen in the anterior portion of the deltoid, but the signal was diffused and it was not possible to obtain a reliable measurement between the nerve and the portal. Therefore, a better anatomic understanding of the location of the terminal nerve branches in proximity to the portal may help surgeons performing this procedure avoid iatrogenic injury in the future. A cadaveric study that examines the relationship between the anterior branch of the axillary nerve and anatomic landmarks, such as the pectoralis tendon, as well as the proximity of the nerve to a planned portal incision, would help shed light on this important question.

All the patients included in this study had overall improvement in their PROMs at 1 year. We found no evidence of cuff re-tear or rupture at 1 year. Interestingly, the patients who had increased deltoid signal did not have significant improvement at any follow-up point with respect to their PROMIS scores but did in every other PROM. In contrast, patients without deltoid signal achieved significant improvement in all PROMs starting at 3 months. These

Table II
Preoperative and postoperative PROMs in patients with and without increased deltoid signal.

	Preoperative	Postoperative	*P* value
Positive signal			
PROMIS			
Pain	61.7 ± 4.8	55.0 ± 10.9	.22
PF	45.3 ± 12.6	43.8 ± 11.0	.90
UE	29.2 ± 5.3	45.2 ± 16.7	.07
Global pain	68.9 ± 21.2	31.0 ± 34.1	.03
ASES	35.1 ± 11.6	76.4 ± 26.2	<.01
SANE	43.4 ± 16.4	85.7 ± 18.4	<.01
Contralateral SANE	76.7 ± 24.1	84.8 ± 23.3	.50
Negative			
PROMIS			
Pain	61.7 ± 5.1	47.8 ± 8.3	<.01
PF	38.8 ± 11.0	50.8 ± 9.9	.01
UE	35.6 ± 14.1	48.7 ± 10.9	<.01
Global pain	66.0 ± 18.0	22.2 ± 25.7	<.01
ASES	42.3 ± 12.7	79.2 ± 17.2	<.01
SANE	47.5 ± 13.3	89.0 ± 14.5	<.01
Contralateral SANE	86.8 ± 18.7	82.5 ± 23.0	.90

PROM, patient-reported outcome measures; *PROMIS*, Patient-Reported Outcomes Measurement Information System; *ASES*, American Shoulder and Elbow Surgeons Shoulder; *SANE*, Single Assessment Numeric Evaluation; *PF*, physical function; *UE*, upper extremity.
Table reporting the exact values for patient reported outcome measures (PROMs) in patients with and without increased deltoid signal. *P* values from student t-tests are reported with <.05 being considered significant.

results were counter to our hypothesis. With respect to the PROMIS UE score, it has been reported that patients should achieve most functional milestones within 1-5 months after rotator cuff repair.[20] Thus, it is possible that our results suggest that patients with increased deltoid signal have some functional deficit not seen in cohort without deltoid signal ie, being captured by the PROMIS UE score but not by the other outcome scores. However, this was a secondary outcome in our study, and it is unclear if PROMIS scores can be used solely to predict or draw conclusions about the clinical implications of the increased deltoid signal seen in this cohort. The correlation between PROMIS scores and ASES and SANE is also still debated.[14] Patterson et al suggested that PROMIS pain, PF, and UE demonstrated weak to moderate correlations with ASES scores.[10] Other papers have suggested that PROMIS UE scores correlate well with ASES scores at 1-year postoperatively but may have less utility at earlier time points.[5] Further research may assess the relationship between PROMs, the imaging findings we reported in this study, and any associated clinical significance.

There are several limitations to this study. First, the cohort was only 24 patients and may have been underpowered to demonstrate true significant changes. It is certainly possible that a higher number of patients in this study would have allowed us to identify a larger cohort of patients with increased deltoid signal, and that tracking these patients over time would have showed that they do in fact achieve significant improvement in PROMs. Routine postoperative MRIs were only performed in the setting of patch augmentation and thus represented only a small percentage of the total suprapectoral biceps tenodeses performed. However, the MRIs were completed in consecutive patients, which minimized the risk of selection bias. While all surgeries were performed by the senior surgeon using a standard technique, the suprapectoral portal placement was based on arthroscopic landmarks, specifically the junction of the lateral border of the LHBT and 1 cm superior to the proximal border of the pectoralis major tendon. Therefore, the portal incision and cannula placement through the deltoid was likely slightly variable. Third, we did not obtain a postoperative MRI for patients who underwent standard rotator cuff repair without a suprapectoral tenodesis (eg, in cases with previous biceps rupture), and thus it is possible that this deltoid edema pattern could be present with standard portals. This is unlikely however, as the edema pattern was consistent with the level and position of this portal extending anteriorly.[6] Although all MRIs included in this study were interpreted by a musculoskeletal fellowship-trained radiologist, it is also possible that the signal seen may represent another injury mechanism to the deltoid muscle, as we did not obtain routine follow-up electromyographies to assess the axillary nerve specifically nor did we find any clinical evidence of axillary nerve injury. However, notably, no MRI demonstrated any evidence of deltoid injury in the area of the standard lateral portal, which also involves an incision through the deltoid. Finally, our follow-up was limited to 1 year, so long-term outcomes were not assessed. However, the outcome of interest was MRI findings in the acute postoperative period, rather than long-term results related to cuff repair. Thus, our finding of increased deltoid signal may serve as an important caution to surgeons performing this technique, as it may suggest that iatrogenic damage to a branch of the axillary nerve may occur at the time of surgery.

The clinical significance of the study findings is unclear. There was no difference in PROMs between patients with edema compared to those without, except that patients with edema did not show significant postoperative improvement in all PROMIS scores. Two patients had a subsequent MRI of the same shoulder, one at 4 months from the index surgery for suspected adhesive capsulitis and the other at 5 months for continued shoulder pain. Both patients demonstrated complete resolution of the edema. This study provides the first evidence that placement of a suprapectoral portal for biceps tenodesis may place the terminal anterior branches of the axillary nerve at risk for at least temporary injury. Further study is warranted to determine methods for alternative placement to avoid this potential injury.

Conclusions

In patients undergoing arthroscopic rotator cuff repair with suprapectoral biceps tenodesis, the creation and use of the distal arthroscopic portal may put the terminal anterior branches of the axillary nerve at risk for at least a temporary injury. These results warrant additional investigation into the impact on clinical outcomes and strategies for avoidance of the nerve in this area.

Disclaimers:

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Conflicts of interest: Dr. Tokish is a board member of the Arthroscopy Association of North America, Presidential line and reports a relationship with Arthrex Inc. and DePuy Synthes Mitek Sports Medicine that includes consulting or advisory. All the other authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

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