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Patterns of Vascular and Anatomical Response After Rotator Cuff Repair

Stephen Fealy,* MD, Ronald S. Adler, PhD, MD, Mark C. Drakos, MD, Anne M. Kelly, MD, Answorth A. Allen, MD, Frank A. Cordasco, MD, Russell F. Warren, MD, and Stephen J. O'Brien, MD

From the Department of Sports Medicine & Shoulder Service, Hospital for Special Surgery, New York, New York

Background: It has been assumed that a robust vascular response at the tendon to bone interface during rotator cuff repairs is an integral part to the healing process. There are few studies that have explored this in an in-vivo prospective fashion.

Purpose: To prospectively characterize vascular and anatomical patterns in repaired rotator cuff tendons using Power Doppler sonography in a double-blinded fashion.

Study Design: Case control study; Level of evidence, 3.

Methods: Fifty patients undergoing rotator cuff repair were enrolled: 28 mini-open, 14 open, and 8 arthroscopic repairs; 20 patients were controls. Patients underwent Power Doppler sonography at 6 weeks, 3 months, and 6 months postoperatively. Power Doppler sonography analysis examined 6 areas of the rotator cuff repair: discretely marginated intrasubstance, partial-thickness defects, full-thickness defects, focal thinning of repair, presence of bursal or joint fluid, and location of anchors. A subjective scoring system assessed blood flow in each region.

Results: There was a predictable, significant decrease in vascular scores after rotator cuff repair over time. The mean vascular score was 11.6 at 6 weeks, 8.3 at 3 months, 7.0 at 6 months, and 2.4 for controls. There was a significant difference ($P < .05$) in vascular recruitment scores between each time period, with the most robust flow at the peritendinous region. The lowest vascular score was at the anchor site or cancellous trough. Forty-eight percent of the patients had a rotator cuff repair defect postoperatively. These findings did not correlate with functional assessment and outcome at 6 months. There was no significant difference in vascular scores between the defect and no-defect groups. Mean University of California, Los Angeles; L'Insalata; and American Shoulder and Elbow Surgeons scores at 6 months were 28.6, 86.3, and 81.5, respectively. Thirty-three percent of asymptomatic controls had a rotator cuff tear that averaged 7.6×7.1 mm.

Conclusion: The robust vascular response dropped with time, which is not seen in asymptomatic shoulders. Nearly half of the patients demonstrated persistent rotator cuff defects after rotator cuff repair that did not correlate with functional outcome and physical findings at 6 months.

Keywords: rotator cuff; ultrasound; outcome; vascularity

Ultrasound has given clinicians another diagnostic tool to accurately detect certain soft tissue injuries. Recent studies have shown that ultrasound is a proven and reliable modality for diagnosing rotator cuff tears and recurrent postoperative rotator cuff defects. Teefey et al[30,31] reported a sensitivity of 100%, a specificity of 85%, and an overall accuracy of 96% in a study comparing sonographic evaluation of rotator cuff defects to arthroscopic findings in 100 consecutive shoulders. Brenneke and Morgan[3] reported a sensitivity of 95% and a specificity of 93% for the detection of full-thickness rotator cuff tears. Other studies have corroborated these data with similar results.[7,15,16,20-22,34,35] Despite these findings, ultrasound has yet to gain the popularity in the United States that it has in Europe. Many clinicians in the United States continue to favor MRI as the radiographic diagnostic modality of choice for evaluation of rotator cuff abnormalities.[10,18,19]

Nevertheless, the data have prompted some authors to conduct studies using ultrasound to correlate clinical findings.[14,17] Crass et al[7] used sonography to evaluate postoperative rotator cuff repairs with mixed results. They found that high-resolution real-time sonography was an accurate

*Address correspondence to Stephen Fealy, MD, Hospital for Special Surgery, 535 East 70th Street, New York, NY 10021 (e-mail: Fealys@hss.edu).

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noninvasive method for the diagnosis of rotator cuff tears. However, in postoperative analysis, it was determined that criteria for diagnosis of retear must be different from those used in detecting new tears in a nonoperated cuff. Wulker et al[37] reexamined 97 shoulders with rotator cuff lesions that were repaired at a mean of 37 months postoperatively. They reported a poor correlation between clinical and ultrasound evaluations. Although 70% had a good or excellent clinical result, only 37 of 97 had a normal-appearing rotator cuff with ultrasound evaluation. Harryman et al[13] evaluated 105 rotator cuff repairs and found that ultrasound evaluation of the repaired tendon correlated with clinical function only 55% of the time. They found that at the time of the most recent follow-up, most of the patients were comfortable and satisfied with the result of the repair, even when they had sonographic evidence of a recurrent defect. They also reported that 20% of rotator cuff tears involving the supraspinatus tendon had a recurrent defect, whereas 50% of rotator cuff repairs involving more than the supraspinatus tendon had a recurrent defect.

Galatz et al[11] reported a 92% rate of recurrent tears at 2 years postoperatively in patients with a massive rotator cuff tear, despite favorable clinical outcomes using established metrics. Gazielly et al[12] used ultrasound and clinical evaluations to assess the functional and anatomical results of rotator cuff repairs at a mean of 4 years' follow-up. They reported a close correlation between the anatomical condition of the cuff and the clinical score preoperatively. Postoperatively, ultrasound evaluation revealed that 65% of rotator cuffs were intact, 11% were intact but thinned, and 24% were recurrent defects. The functional evaluation correlated more closely with anatomical condition of the repaired cuff at follow-up than with the tear size at surgery. Recurrent defects were associated with the size of the rotator cuff tear to be repaired, the age of the patient, and the degree of occupational use. However, none of these studies attempted to illuminate the reasons these patients had good functional scores with a poor anatomical condition evaluated via ultrasound.

Power Doppler sonography can accurately assess and differentiate between arterial and venous flow patterns.[30] It can also depict moving blood in soft tissues, inflammation, and abnormal fluid or synovium, and it can assess acromial impingement on the supraspinatus tendon.[1,2,4-6,21,28] Brockis[4] provided the first detailed accounts of intratendinous vascularity. These findings were subsequently confirmed by Moseley and Goldie[23]; they called it the *critical zone*. They believed that this critical zone was an area of vascular anastomosis. Rothman and Parke[28] examined this area and associated it with advancing age rather than with rotator cuff damage. This area has been determined to be approximately 1 cm medial to the insertion of the supraspinatus tendon, and it has been implicated in the origin of certain rotator cuff tears.

The purpose of the current study was to prospectively characterize the anatomical and vascular patterns in repaired rotator cuff tendons after a rotator cuff repair procedure using Power Doppler sonography in a double-blinded fashion. These findings were then correlated with clinical data in the immediate postoperative period.

MATERIALS AND METHODS

After institutional review board approval was obtained, 50 consecutive patients (33 men, 17 women; mean age, 57 years; range, 34-71 years) undergoing rotator cuff repair from 11 different orthopaedic attending physicians at our institution were enrolled in this study to evaluate the integrity of rotator cuff repairs at 3 time points postoperatively. The study was prospective and double-blinded. Both the surgeon and the patient were blinded to the results of their postoperative ultrasound findings. It was essential that the surgeons remained blinded because negative results may have altered their normal postoperative rehabilitation protocols. The ultrasonographer was blinded as to the type of procedure the patient had and the findings of prior ultrasounds. Twenty patients with clinically asymptomatic shoulders and no previous history of shoulder injury served as controls.

There were 28 mini-open, 14 open, and 8 arthroscopic rotator cuff repairs studied. Patients were evaluated, on average, at 6 weeks (time #1), 3 months (time #2), and 6 months (time #3) postoperatively. At the 6-month postoperative visit, patients underwent an ultrasound scan of the rotator cuff repair and a physical examination, and they answered the University of California, Los Angeles (UCLA); L'Insalata; and American Shoulder and Elbow Surgeons (ASES) outcomes questionnaires. To assess both the vascular response and the anatomical status of the rotator cuff repair, Power Doppler sonography was used. Rotator cuff integrity was graded according to the Harryman classification,[13] whereby a score of 0 indicates no tear, a score of 1A indicates 1 tendon involvement partially, a score of 1B is a full-thickness tear involving 1 tendon, and a score of 2 involves 2 tendons.

Statistical Analysis

The L'Insalata questionnaire was scored according to the weighted system described. On completion of the physical examination, the American Shoulder and Elbow Surgeons questionnaire and the UCLA shoulder examination were scored. The data were then analyzed using standard methods. The data for the clinical evaluation, which was quantified by using the aforementioned questionnaires, were examined using the Student *t* test. Analysis of variance tests were used to establish significance between the different techniques and outcomes. Furthermore, this test was also used to evaluate the vascular response at the different time periods, the vascular response and the location of the rotator cuff studied, and the vascular recruitment score and the clinical score compared with the size of the rotator cuff defect. The correlation of the social and medical histories of the patients was also analyzed using this test. The data for the persistent rotator cuff defects were analyzed by utilizing the χ^2 and Fisher exact tests.

Power Doppler Sonography

Power Doppler sonography is a relatively new technique that depicts moving blood volume within tissues. It effectively

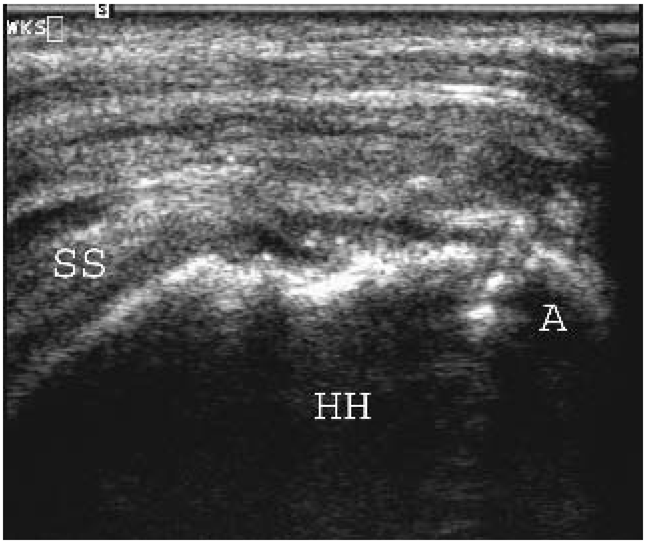

Figure 1. Postoperative ultrasound demonstrating an intact repair of the supraspinatus tendon in which the tendon (SS) can be seen attaching directly to the humeral head (HH). Note the presence of a metallic suture anchor (A).

Figure 2. Postoperative ultrasound demonstrating a full-thickness defect.

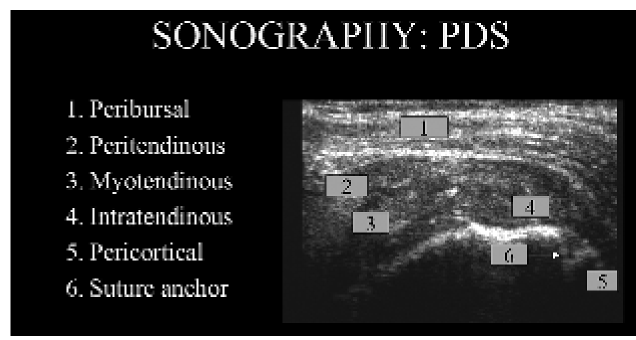

Figure 3. Power Doppler analysis consisted of examining several portions of the repair. The peribursal (1), peritendinous (2), musculotendinous (3), intratendinous (4), pericortical (5), and site of the suture anchor (6) were visualized for all patients at each time point postoperatively.

extends the dynamic range over that of conventional color Doppler imaging.[8,9,24,25] Recently, the ability to quantitate moving blood volume with Power Doppler sonography has become possible. Power Doppler sonography supplements the gray-scale ultrasound evaluation of the musculoskeletal system by depicting vascularity in and/or adjacent to tendons, bursae, muscle, and fluid collections. Spectral Doppler traces were used to assess the nature of vessels (artery or vein).

Shoulder ultrasounds were performed by 1 of 2 examiners experienced in performing musculoskeletal ultrasound. Scans were performed using a broadband linear 7.5-MHz transducer operating in tissue harmonic mode and a Siemens Elegra scanner (Siemens, Issaquah, Wash). Power Doppler imaging was performed using the scanner's low-flow sensitivity settings, which were maintained throughout the study for all patients. The arm was placed in an internally rotated position and minimally hyperextended to ensure patient comfort. The supraspinatus repair was then examined in long and short axes. All images were stored digitally on the scanner hard drive and subsequently transferred as digital imaging and communications in medicine images to a prodigy workstation (ALI) for subsequent review. One of the authors (R.S.A.), an experienced musculoskeletal radiologist and ultrasonographer with more than 16 years' experience, classified the studies according to the criteria below without knowledge of the clinical examination or the results of prior ultrasound scans.

The presence of a continuous band of tissue extending to the suture anchor was considered an intact repair (Figure 1). The following gray-scale features were documented:

1. The presence of discretely marginated hypoechoic defects according to size and whether they were intrasubstance, partial-thickness (bursal or articular surface), or full-thickness (Figure 2)
2. The presence and location of focal thinning of the repair
3. The presence of bursal or joint fluid
4. The location of the suture anchors

When possible, assessment of the composition of the defects was ascertained as being soft tissue or fluid. The latter could generally be compressed with redistribution of the echoes in real time, whereas the latter generally demonstrated blood flow on Power Doppler imaging.

Power Doppler analysis consisted of examining several portions of the repair (Figure 3). These portions were designated as follows:

1. Peribursal—above the peribursal fat stripe
2. Peritendinous—along the periphery of the repair and deep to the fat stripe
3. Musculotendinous—within the repair and proximal to the anatomical neck of the humerus
4. Intratendinous—within the repair and distal to the anatomical neck of the humerus

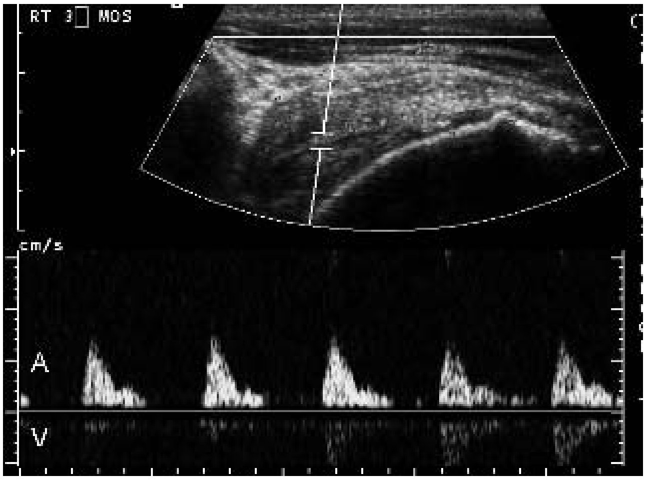

Figure 4. Spectral Doppler tracing differentiating between arterial (A) vasculature and venous (V) flow in the setting of an intact rotator cuff repair at 3 months after surgery.

5. Pericortical—along the cortical margin, distal to the surgical trough
6. Suture anchor site—along the cortical trough, including the anchor sites

A subjective scoring system was employed to assess blood flow in each region as being absent (0), sparse (1), moderate (2), or prominent (3). Namely, sparse blood flow was characterized as the presence of a few scattered vessels. Moderate blood flow was determined to be thin (<2 mm in width), long segments (>5 mm) of vessels that were not engorged. Prominent vascular findings were characterized by the presence of larger vessels in continuity or the presence of a frank blush. Sporadic spectral Doppler traces were obtained in each patient to assess the nature of the vessels as being arterial or venous as well as to eliminate the possibility of artifactual flow (ie, attributable to noise or patient motion) contributing to Power Doppler assessment (Figure 4). A maximum vascular score of 18 was possible, as 6 distinct regions were observed. Scores are described here as a cumulative score of a total potential of 18 points.

Evaluation of the contralateral asymptomatic shoulder was performed to assess the supraspinatus tendon in 20 patients. Tendon inhomonogeneity and indistinctness of either articular or bursal margins were documented and classified as tendinosis. The presence of bursal fluid was likewise documented. An identical vascular assessment of the asymptomatic side was then performed, with all anatomical landmarks being evaluated (with the exception of the suture anchor, which was not applicable).

Vascular Assessment

Patients underwent Power Doppler sonography of the affected shoulder at 6 weeks (time #1), 3 months (time #2), and 6 months (time #3) after surgery. The ultrasonographer then scored the examination of 6 separate areas based on the criteria above. The results were blinded to patient and surgeon. The ultrasonographer was blinded to previous results. Each vascular assessment was later reread, with the reader having no knowledge of the score from the first reading to ensure validity and reproducibility of the scoring. On reevaluation of the original subjective scoring, there was no divergence of scoring, and the original score was allowed to remain.

Anatomical Assessment

The documented gray-scale features were discretely marginated intrasubstance, partial-thickness or full-thickness defects, focal thinning of repair, presence of bursal or joint fluid, and location of anchors. The composition of defects was ascertained as soft tissue or fluid. The portions of the repair that were examined corresponded to those assessed for vascular response: peribursal, peritendinous, musculotendinous, intratendinous, pericortical, and along the cortical trough, including the suture anchor site. For purposes of analysis, defects were categorized according to the Harryman classification.[13]

RESULTS

There was no statistical trend noted between clinical outcome and surgeon. The profile of patients who had a defect in their rotator cuff repair was not consistent. A mean of 3.5 anchors was used in the entire group of patients. It is interesting to note that a mean of 2 anchors was used for all arthroscopic rotator cuff repairs, more than 3.2 were used for the mini-open cohort, and 5 anchors were used for the all-open repairs. The majority of rotator cuff tears (72%) involved an isolated supraspinatus tear. Sixteen percent of the group had a tear involving both the supraspinatus and the infraspinatus; 8% had a tear involving the supraspinatus, the infraspinatus, and the subscapularis. Only 2 patients (4%) had a rotator cuff tear involving all 4 rotator cuff tendons. We were unable to consistently determine the true size and tissue quality characteristics of each rotator cuff tear, thereby making comparison of outcome as a function of tear size impossible. Unfortunately, the dimensions of the tear size were not adequately dictated in each operative finding. Furthermore, tear size was sporadically documented in MRI reports, which were obtained preoperatively. Each MRI report and operative report was reviewed by one author (S.F.).

Vascular

The peritendinous region had the most robust vascular response at each time point postoperatively (Figures 5 and 6). Surprisingly, the site of the bleeding bony bed into which the tendon was repaired had consistently low vascular scores. Although pulsatile, arterial blood could be seen originating from the anchor site, the blood in the region of the decorticated trough was often sparse. There was a significant and predictable decrease in vascular flow

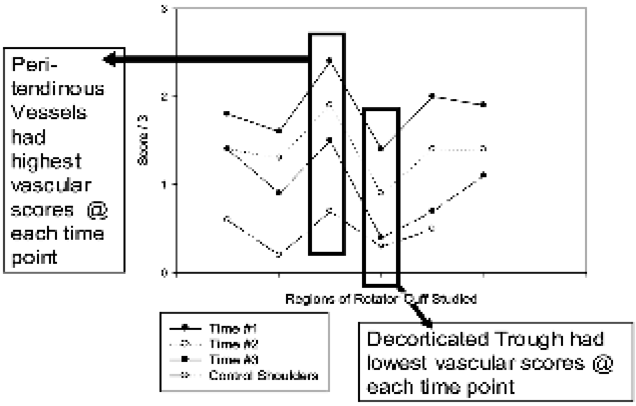

Figure 5. Regional vascular scores over time.

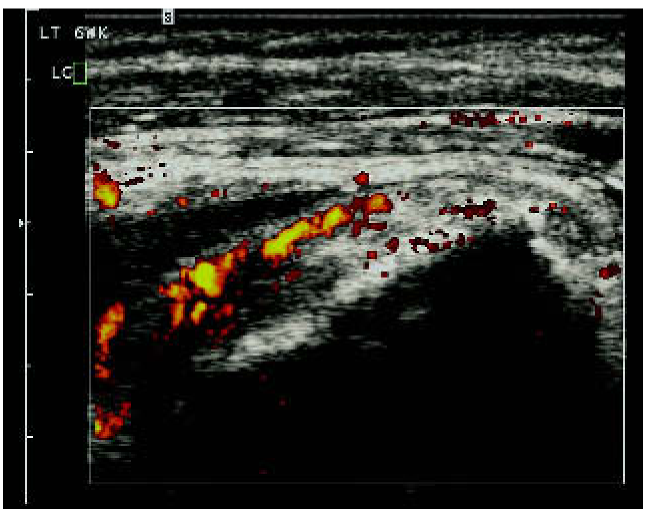

Figure 6. Power Doppler sonography depicting a robust arterial flow in an artery that is within a repaired tendon.

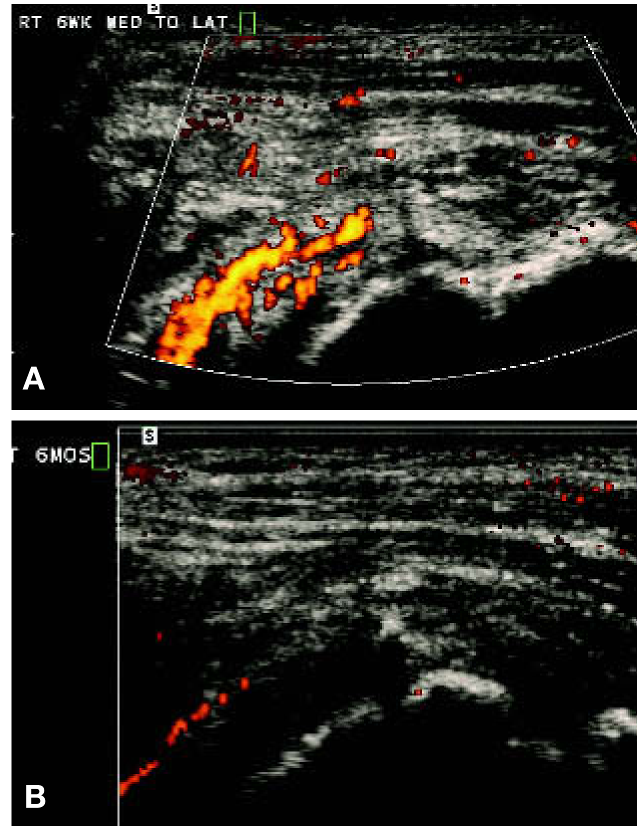

Figure 7. A, postoperative ultrasound performed at 1 month (time #1), demonstrating relatively high-flow state in an intact rotator cuff repair; B, postoperative ultrasound performed at 6 months (time #3) on the same patient, demonstrating relatively low-flow state in an intact rotator cuff repair. Scan was performed in the same arm position.

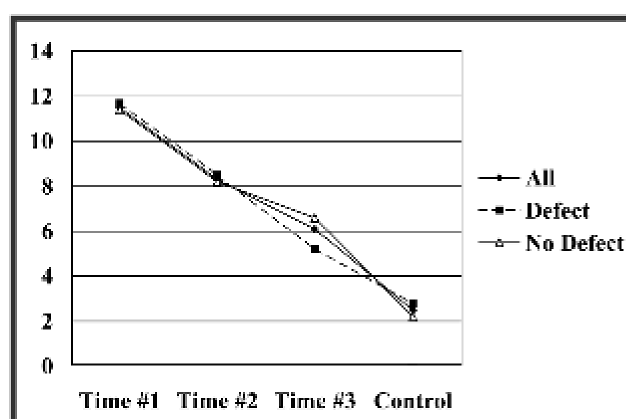

Figure 8. Vascular scores postoperatively: defect versus no defect.

after surgery. This finding is noteworthy when compared with the asymptomatic controls. Vascular scores noted from the control patients were consistently low in all regions of the rotator cuff. There was a stark graphic differentiation between high-flow and low-flow states that came to be readily recognizable and reproducible. It became clear that the initial high-flow state seen initially would decrease between time #1 and time #3 (Figure 7). The global amount of blood flow in and around the repaired tendon consistently and predictably decreased with time. No statistical trend was noted between techniques used for rotator cuff repair and the observed vascular scores.

The mean vascular score was 11.6 at time #1, 8.3 at time #2, 7.0 at time #3, and 2.4 for controls. There was a significant difference ($P < .05$) in vascular recruitment scores between each time period. Each of the 6 areas of the tendon studied demonstrated a consistent and equal decrease in the amount of blood seen at each time point postoperatively. There was no one area of the tendon repaired that did not show a drop in blood flow with time. The observed vascular recruitment score was consistent regardless of the size of the rotator cuff tear documented with preoperative MRI or observed at the time of surgery. Furthermore, vascular scores of the repaired tendons were similar, whether or not a defect in the tendon was noted with postoperative ultrasound (Figure 8). The vascular score was independent of social or medical history.

Anatomical

Nearly half (48%) of patients had a detectable defect in the rotator cuff repair at some time point postoperatively. Defects were seen in 50% of patients at time #1, in 45% at time #2, and in 43% at time #3. The majority of defects were classified as Type 1B, but several defects progressed from grade 0 to 1A/1B. The mean defect size at each time point was 1×1 cm^2. Although we were unable to obtain actual dimensions of the rotator cuff tear at the time of surgery for all patients, in those patients who had a rotator cuff tear with documented dimensions, the preoperative tear size was consistently greater than that seen ultrasonographically after surgery. Anatomical findings did not correlate with functional assessment and outcome at 6 months when the group with a rotator cuff defect was compared with the group without a defect. There was no significant difference in vascular score between the anatomical defect and no-defect groups.

Mean UCLA, L'Insalata, and ASES scores at 6 months were 28.6, 86.3, and 81.5, respectively. Thirty-three percent of asymptomatic controls were found to have a defect consistent with a rotator cuff tear that was 7.6×7.1 mm on average. There was not a statistically significant difference noted in any of the 3 outcomes metrics used between patients who had an intact repair and those with a documented persistent defect ($P > .05$) (Figure 9).

Each of the 3 outcome tools demonstrated a consistently worse short-term result with arthroscopic repair compared with mini-open or open repairs. We recognize the learning curve involved in applying arthroscopic techniques to rotator cuff repair and recognize that a small cohort was studied. The arthroscopic rotator cuff repair cohort evaluated in this study was at the beginning of our institution's surgical transition from mini-open repair to arthroscopic repair. Whether these poor short-term results are a function of the surgical learning curve or whether the results depend on the number of suture anchors and subsequent suture strands crossing the repair is unclear. Further investigation will evaluate these issues.

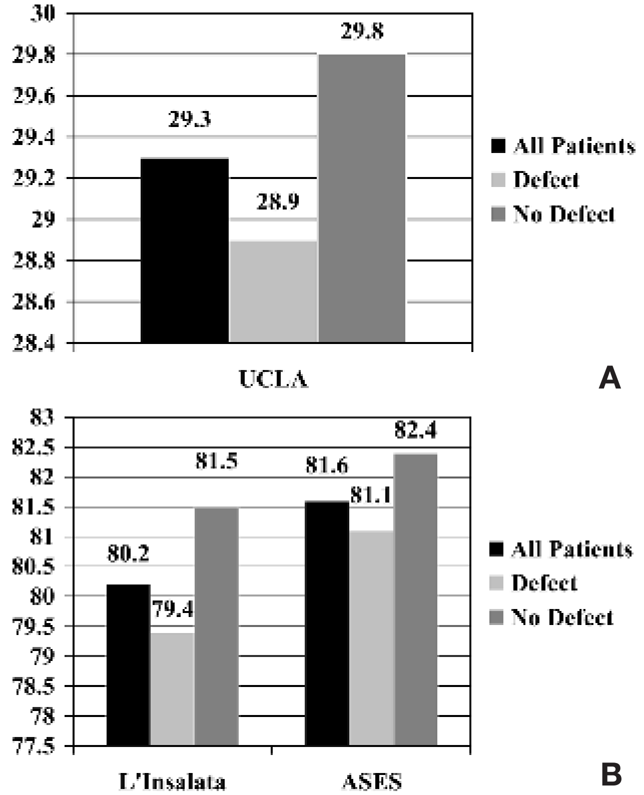

Figure 9. A, University of California, Los Angeles outcomes metrics did not show any significant difference in functional score between those patients with a documented intact repair and those shown to have a persistent anatomical defect. B, L'Insalata and American Shoulder and Elbow Surgeons scores (ASES) demonstrated similar and consistent findings to those produced with the University of California, Los Angeles. There was no significant difference in outcome between patients with a defect and those with no defect of the repaired tendon postoperatively.

DISCUSSION

Several authors have evaluated the utility and effectiveness of ultrasound in diagnosing rotator cuff tears preoperatively and recurrent tears in the postoperative setting. Several studies have demonstrated sensitivities and specificities of greater than 90% for the detection of full-thickness rotator cuff tears using ultrasound.[6,17,19,26,32-36] Several of these studies have also demonstrated a greater than 90% sensitivity and specificity for accurately predicting the dimensions of the detected rotator cuff tears.[26,27]

It has long been thought that blood at the site of a repaired tendon encourages healing. Power Doppler sonography can accurately assess and differentiate between arterial and venous flow patterns and evaluate the vascularity to a given region. However, the vascular patterns of the critical zone after a rotator cuff repair procedure have yet to be examined for their vascular dynamics.

This study is the first, to our knowledge, to describe and comment on the vascularity of the repaired rotator cuff tendon. We observed 6 distinct regions of the repaired tendon and were able to determine whether flow was arterial or venous. If blood flow was present, we subjectively quantified the degree of flow. A subjective scoring system was created to quantify this vascular pattern at 3 time points postoperatively. Recognizing that this new information is only relevant with respect to a reference, we performed the same evaluation on 20 asymptomatic shoulders with no history of shoulder injury. Power Doppler sonography of the control group revealed that the intact rotator cuff is relatively avascular and does not have 1 region in particular that could reliably be found to provide the majority of blood flow. We recognize that this subjective scoring system is a limitation of our current study. Accordingly, we have adjusted future studies to digitally capture and quantify the number of and density of signal points observed with the ultrasound scan. These new data will produce a more objective metric to an originally subjective scale.

Medical history and social comorbidities that may predispose a patient to vascular insufficiency, for example, smoking or diabetes, were documented and controlled for as a separate variable. We believed, incorrectly, that the degree of vascular flow in the repaired tendon may be relevant to both the functional outcome and the success of repair for the repaired tendon.

We described an initial robust vascular response that predictably and consistently dropped off with time. This vascular pattern and response were not seen in the control group. We were surprised to discover that the region of the decorticated trough and site of the suture anchor consistently yielded the least amount of blood flow postoperatively. Much like the work done by St. Pierre et al[29] in an animal model, these findings call into question the clinical practice of requiring a decorticated trough to repair the tendon. The peritendinous region consistently yielded the highest degree of blood flow. Whether these findings should be thought of as similar to those seen in a fracture setting is unclear. Namely, is the surgical experience essentially a traumatic one that disturbs the normal relatively avascular milieu of the intact rotator cuff tendon, thereby increasing the amount of blood flow to the region for a limited period of time? We were unable to find any correlation between observed vascular recruitment patterns and functional outcome at 6 months. Furthermore, we were unable to find a correlation between persistent rotator cuff defects postoperatively and the presence of blood flow to the region. These findings further call into question the surgical tenet that a bleeding bony bed and a relatively vascular environment are necessary for a tendon to heal after surgical repair. Further study is required to assess the biology of the tendon repair. Whether a prolonged increase in regional vascularity would help the healing process is unclear. Surprisingly, the vascular score did not correlate with whether there was a recurrent defect noted in the repaired tendon. The finding that the vascular score was lowest at the decorticated bony trough on the greater tuberosity was not anticipated. Clinically, a bleeding bony bed is routinely created to augment the natural healing process of tendon to bone. Whether this bleeding bony bed is a necessary component for tendons to heal to bone is unclear.

Nearly half of our patients studied had at least 1 time point postoperatively at which a defect in the repair was detected. We were careful to describe these findings as *defects* and not *recurrent tears,* as we are aware that imaging modalities are very sensitive and specific but not absolute. It was not uncommon for us to note patients to have a defect read as 1B at time #1 that was read as a 1A at time #2 and a 0 or intact rotator cuff repair at time #3. We did not have the opportunity to examine the histologic nature of the material that is filling in these defects, but we assume it to be a reparative scar. Our findings support those of other authors who note that the presence of a recurrent rotator cuff tear postoperatively does not correlate with functional outcome in the near term. How this seemingly paradoxical result is produced is unclear.

CONCLUSION

This study is the first to prospectively evaluate vascular recruitment patterns after rotator cuff repair. There is an initial robust vascular response after rotator cuff repair that predictably drops off with time, which is not seen in asymptomatic shoulders. We are surprised to learn that despite decortication, the cancellous trough is an area of low flow relative to the repaired tendon. Knowledge of this vascular response, not previously documented, may have implications for the biology of the repair. Nearly half of patients studied demonstrated areas of persistent rotator cuff defects after rotator cuff repair that did not correlate with functional outcome and physical findings at 6 months.

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