Partial-Thickness Rotator Cuff Tears

Current Concepts

Andrew S. Bi, MD
Allison M. Morgan, MD
Michael O'Brien, MD
Brian R. Waterman, MD
Eric J. Strauss, MD
Alexander Golant, MD

Investigation performed at the Division of Sports Medicine, NYU Langone Health, New York, New York

Abstract

» Partial-thickness rotator cuff tears (PTRCTs) are a common pathology with a likely high asymptomatic incidence rate, particularly in the overhead athlete.

» The anatomy, 5-layer histology, and relationship to Ellman's classification of PTRCTs have been well studied, with recent interest in radiographic predictors such as the critical shoulder angle and acromial index.

» Depending on the definition of tear progression, rates of PTRCT progression range from 4% to 44% and appear related to symptomatology and work/activity level.

» Nearly all PTRCTs should be managed conservatively initially, particularly in overhead athletes, with those that fail nonoperative management undergoing arthroscopic debridement ± acromioplasty if <50% thickness or arthroscopic conversion repair or in situ repair if >50% thickness.

» Augmentation of PTRCTs is promising, with leukocyte-poor platelet-rich plasma having the most robust body of supportive data. Mesenchymal signaling cell biologics and the variety of scaffold onlay augments require more rigorous studies before regular usage.

Partial-thickness rotator cuff tears (PTRCTs) present a challenging treatment dilemma to the orthopaedic surgeon, particularly those in the throwing or overhead athlete. At multiple stages of treatment, the surgeon is faced with several critical choices: whether to watch and wait, inject and with what, debride or repair, complete the tear or repair in situ, and augment. We attempt to answer these questions using an up-to-date review of the literature, focusing solely on PTRCTs of the supraspinatus and infraspinatus.

Epidemiology, Anatomy, and Etiology of Partial Rotator Cuff Tears

PTRCTs represent a large burden on the healthcare system, with the average cost per episode totaling nearly $10,000[1]. Prior studies have cited a prevalence of up to 12% to 18.5%, particularly in the aging population, although these numbers were primarily based on cadaveric rather than population studies[2,3]. Intratendinous tears were historically noted to be the most common location for PTRCTs in cadaveric dissections, with Yamanaka demonstrating, in 268 specimens, a 13.8% overall PTRCT incidence with intratendinous tears being the most common at 7.5%, articular at 3.7%, and bursal at 2.6%[4]. However, several recent clinical studies have challenged this doctrine, with Kong et al. demonstrating, in 81 PTRCTs, bursal-sided tears as the most common with an incidence of 72% on magnetic resonance imaging (MRI)[5]. Frandsen et al. demonstrated that, in 84 PTRCTs, 58% were articular, compared

Disclosure: The **Disclosure of Potential Conflicts of Interest** forms are provided with the online version of the article (http://links.lww.com/JBJSREV/B121).

with 22% being bursal and 20% being intratendinous, highlighting the discrepancies between cadaveric and radiologic studies[6,7]. There does not appear to be a gender predilection for PTRCTs, with a large insurance database study demonstrating slightly increased incidence in women (54.1%), with the most common age group between 65 and 69 years[1].

Little advancement in the understanding of the histological layers of the rotator cuff has been made since Clark and Harryman's landmark cadaveric study in 1992, demonstrating 5 distinct layers from the bursal-sided vascular extension of the coracohumeral ligament in layer 1 to the articular-sided deep capsular layer 5[2,8]. Layer 2 represents the thickest and main structural layer of the rotator cuff, comprising a large bundle of densely packed parallel tendon fibers of 3 to 5 mm thick, which is the critical portion when involved in PTRCTs. When correlated with Ellman's classification and recent advanced imaging studies, PTRCTs with an articular involvement of 3+ mm and bursal involvement of 6+ mm disrupt layer 2 and represent 25% and 50% thicknesses of the rotator cuff[8-10], respectively. These histologic layers also correspond to footprint anatomy, which was originally described in detail by Dugas et al. and Mochizuki et al. in cadaveric studies, as a triangular supraspinatus footprint on the anterior-most area of the most superior portion of the greater tuberosity, with a mean maximal cross-sectional area of 6.9 mm × 12.6 mm, which inserts less than 1 mm from the articular margin[11,12]. This is in contrast to the trapezoidal infraspinatus footprint of 10.2 mm × 32.7 mm, of which the articular insertion inserts more lateral to the articular surface[11,12].

The etiologies of PTRCTs can be divided broadly into intrinsic and extrinsic causes. Intrinsic causes of PTRCTs are usually due to increased tendon strain and degeneration within histologic layers from chronic microtrauma, internal impingement, or age-related decreases in tendon vascularity. These lead most commonly to intratendinous PTRCTs, although tear propagation to articular-sided or bursal-sided PTRCTs can occur because failure of tendon fibers progresses[2,6]. Extrinsic causes of PTRCTs are usually due to direct compression with subacromial impingement in bursal-sided PTRCTs and internal impingement in articular-sided PTRCTs, with a high incidence in overhead athletes, particularly of the posterior supraspinatus and infraspinatus tendon[2,6,13].

Risk factors for PTRCTs have been well studied. A recent meta-analysis demonstrated that increased chronological age, body mass index, smoking, diabetes, hypertension, and dominant arm were associated with an increased risk of PTRCTs[14]. Radiographic risk factors have more recently come under investigation, with the most commonly identified being an increased critical shoulder angle (CSA) and increased acromial index, which are radiographic parameters of a more lateral, hooked acromion. These have been shown to increase rotator cuff forces required for abduction and increase the retear risk after rotator cuff repair[15,16]. Caffard et al. and Li et al. demonstrated increased retear rate in patients with larger CSA, increased acromial slope, and increased acromial index[16,17] (Fig. 1).

Classification

There are a myriad of classification methods for rotator cuff tears, varying from descriptive classifications based on chronology (acute vs. chronic), or anatomy (involved rotator cuff tendon), to general classifications that apply to all tears, such as those proposed separately

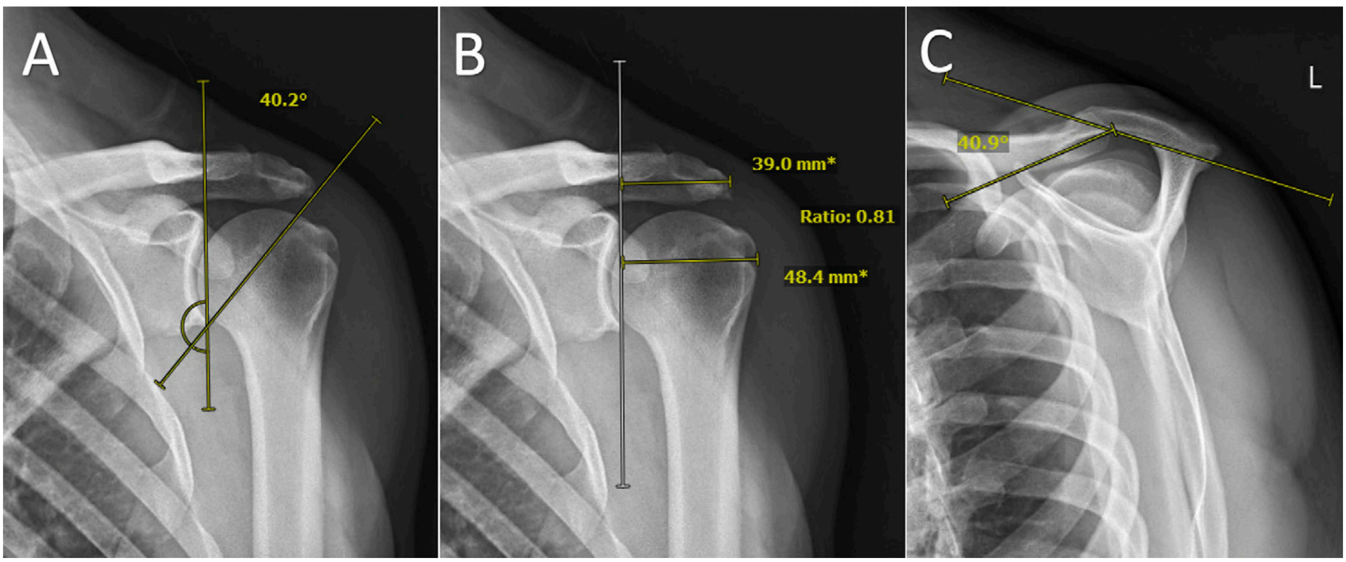

Fig. 1

Radiographic predictors of partial-thickness rotator cuff tear incidence and retear risk after repair. **Fig. 1-A** Critical shoulder angle. **Fig. 1-B** Acromial index. **Fig. 1-C** Acromial slope.

by Cofield, Collin, and Goutallier[18-20]. Two classification systems were developed specific to PTRCTs in the early 1990s by Ellman and Snyder et al.[9,21]. Both share similarities, with Harvard Ellman's classification describing location (articular, bursal, or intratendinous), grade (grade I = <3 mm, grade 2 = 3-6 mm, grade 3 = >6 mm), and tear area (in squared millimeter)[9]. Stephen Snyder's classification also classifies for tear anatomic location (articular or bursal, with less focus on intratendinous) and severity (0 = normal to IV = very severe partial tear often encompassing more than a single tendon of >4 cm involvement)[21].

Imaging of PTRCTs

The radiographic workup for a painful shoulder always begins with a standard radiographic series (Grashey true anteroposterior, scapular-Y, and axillary views). Despite low sensitivity and specificity in the diagnosis of PTRCTs, radiographs can provide useful information in risk factor evaluation of the CSA and acromial morphology as aforementioned and rule out advanced rotator cuff disease with decreased acromiohumeral interval or the presence of glenohumeral arthritis. MRI has become the standard for diagnostic evaluation with its ability to identify rotator cuff tears and associated pathologies (Fig. 2). Although some smaller cohort studies demonstrate limited accuracy of MRI for detecting PTRCTs with a sensitivity of only 51.6% and specificity of 77.2%, recent meta-analyses have demonstrated excellent accuracy of MRI above 90%[22,23]. MRI evaluation of fatty atrophy of the supraspinatus can be identified with more accuracy, with Barry et al. demonstrating in MRIs of 377 shoulders increasing Goutallier grades of fatty atrophy with increasing tear severity from 6.5% ≥ grade 2 atrophy in no tears, 10.5% in PTRCTs, and 41.4% in full-thickness rotator cuff tears (FTRCTs)[24]. Davis et al. later corroborated these findings of increased fatty atrophy with increased tear severity and additionally demonstrated good-excellent inter-rater reliabilities, although Chung et al. actually demonstrated increased fatty atrophy in high-grade PTRCTs than small FTRCTs and an increased failure rate of tendon healing in PTRCTs with worse tendinosis[25,26].

Given the controversy surrounding MRI diagnosis of PTRCTs, MR arthrography (MRA) may be helpful for the identification of subtle articular-

Fig. 2

Magnetic resonance imaging findings of partial-thickness rotator cuff tears: (**Fig. 2-A**) T2 coronal demonstrating both articular-sided tearing at the supraspinatus footprint and intramuscular edema, (**Fig. 2-B**) T2 coronal demonstrating intratendinous tearing, (**Fig. 2-C**) T2 coronal demonstrating a bursal-sided tear, (**Fig. 2-D**) T2 sagittal demonstrating a small articular-sided anterior supraspinatus tear, (**Fig. 2-E**) T2 sagittal demonstrating a large bursal-sided anterior supraspinatus tear, and (**Fig. 2-F**) T2 axial demonstrating an intratendinous tear of the supraspinatus. Arrowheads mark the location of the tear in all panels.

sided tears or intrasubstance tears that may be missed when an adducted arm position compresses the fibers to each other[27]. A recent meta-analysis by Liu et al. demonstrated greater diagnostic accuracy with MRA for the diagnosis of PTRCTs compared with MRI, which may also have more applicability when used for articular-sided and intratendinous PTRCTs than for bursal-sided PTRCTs[23] (Fig. 3). Ultrasound (US) presents a low-cost, readily available, alternative diagnostic modality for PTRCTs for experienced providers. Roy et al. demonstrated that trained providers, whether radiologists, US technicians, or orthopaedists, could use US to diagnose PTRCTs at an equivalent accuracy to both MRI and MRA[22,28].

Nonoperative Treatment

Nonoperative management remains the first-line treatment for most PTRCTs, given the widely reported incidences of tear progression in the literature ranging from 4% to 44%[5,7,29]. Mall et al. demonstrated a 4% rate of significant tear progression in asymptomatic patients compared with 23% progression in symptomatic patients and found significantly larger tears in symptomatic patients compared with those without symptoms[30]. Keener et al. demonstrated an overall 44% progression of PTRCTs at a median of 5.1 years, defined by an increase in ≥5 mm in size in any orientation based on US evaluation, and found that the presence of tear enlargement was associated with the onset of new pain[31]. When considering indications for overhead athletes, even high-grade PTRCTs with up to 80% of involved tendons should be considered for nonoperative management because multiple studies have demonstrated inferior results with repair for PTRCTs in these athletes[13,32]. The initial first-line treatment includes activity modification, such as cessation of throwing for overhead athletes, anti-inflammatory medications, and a formal rehabilitation program focused on the restoration of strength and function of the rotator cuff[2,6,13]. Both individual rotator cuff focused on strengthening and periscapular stabilization, while addressing concomitant pathologies, such as sleeper stretches for posterior capsular tightness/internal rotation deficits, are the focus of therapy.

Injections

Either subacromial or glenohumeral injections can be used for short-term pain relief to allow for an earlier return to function and more aggressive therapy, with subacromial injections preferred for external impingement and bursal-sided PTRCTs and glenohumeral injections preferred for articular-sided PTRCTs. Injection options range from corticosteroid injections (CSI) and autologous platelet-rich plasma (PRP) to cellular therapies such as concentrated bone marrow aspirate (CBMA) or adipose-derived mesenchymal signaling cells (AD-MSCs). CSI generally provides good pain relief, but the results are often short-lived, and multiple CSIs can increase the risk of tear progression because in vivo and translational studies

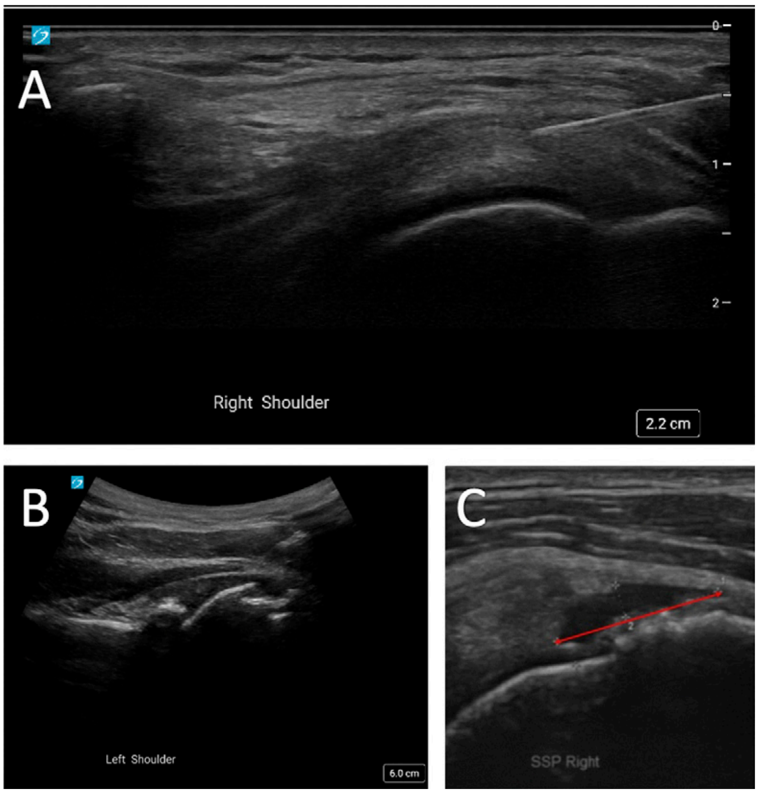

Fig. 3

Ultrasound images of (**Fig. 3-A**) injection of bursal-sided supraspinatus tear, (**Fig. 3-B**) partial articular-sided tear of the supraspinatus, and (**Fig. 3-C**) intratendinous tear of the supraspinatus (red line indicates longitudinal length of tear).

have demonstrated detrimental effects on rotator cuff histology and biomechanical strength with the increasing number and frequency of CSIs[33]. Frequent CSIs may also jeopardize the future rotator cuff repair because a trio of early 2019 studies demonstrated a time-dependent relationship between CSI before RCR and increased revision rates after surgical repair[34-36].

Recent meta-analyses have demonstrated that PRP, in particular, demonstrates promise for PTRCTs about both pain relief and functional outcomes at short-term follow-up; however, studies with a follow-up longer than a year are still needed[37]. Attention should be paid to PRP formulation in these studies because leukocyte-poor PRP has been demonstrated to be more anti-inflammatory than leukocyte-rich PRP and may be more beneficial in the treatment of PTRCTs[38]. In addition, comparative studies between PRP and CSI do not always analyze comparable approaches because corticosteroids are typically administered into the subacromial or glenohumeral space, whereas PRP may be administered intralesional (with image guidance)[39]. Table I demonstrates relevant recent studies (within 5 years) on the use of biologics as nonoperative treatment for PTRCTs. Nonoperative treatment should near-universally be attempted as initial management because it often provides significant benefits and does not lead to inferior outcomes with delayed repair, as demonstrated by Kim et al.[40]. Nonoperative management can provide excellent outcomes because 37 patients with PTRCTs at a mean of 46-month follow-up had an American Shoulder and Elbow Surgeons (ASES) score of 85.1 and Simple Shoulder Test score of 10.0, with atraumatic tears, nondominant side, and PTRCT thickness <50% demonstrating superior outcomes[41].

Operative Management

Although there remains a lack of definitive evidence for surgical indications for PTRCTs, in general, surgical management is indicated when there has been failure of nonoperative modalities for 3 to 6 months with continued symptoms or tear progression[2,6,13]. Tears greater than 50% in thickness or those involving the anterior supraspinatus with anterior rotator cable involvement may benefit more from surgical management[6,41-43]. Other modulating factors include concomitant pathology, patient age and physical demands (e.g., arm dominance, laborers, and overhead athletes), etiology (traumatic tears are more likely to require repair), tear length, and tear location[2,6,41]. Overhead athletes with partial articular supraspinatus tendon avulsion or partial infraspinatus tears (although rare), even up to 80% in thickness in their dominant arm, may be candidates for prolonged nonoperative treatment or a simple arthroscopic debridement because these options frequently provide pain relief and allow faster return to sport; however, individualized discussions should always be held with the athlete, trainer, coach, agent, and/or parents in the case of pediatric athletes[13].

Arthroscopic Diagnosis

Diagnostic arthroscopy remains the gold standard for determining tear type and concomitant pathology, paying particular attention to the articular surface attachment from the glenohumeral joint and the bursal-sided insertion from the subacromial space. A view of the posterior rotator cuff insertion from the lateral portal in the subacromial space should always be performed because partial bursal-sided tears of the infraspinatus are often missed if only viewing from the posterior portal. With the arthroscope in the glenohumeral joint, a "30-30" position, with 30° of forward flexion and 30° of shoulder abduction, relaxes the superior capsule and provides ideal visualization of the rotator cuff footprint[27]. When partial tears are thought to be identified, using a blunt instrument to "fall in" to the defect remains the most definitive and illustrative method of diagnosing PTRCTs. The Fukuda "color test" using methylene blue or indigo carmine solution was described in 1992 as a useful tool for detecting subtle PTRCTs but has fallen out of favor due to time intensiveness and concerns for tissue toxicity, particularly of chondrocytes[44]. The Snyder suture marking technique for identifying articular-sided PTRCT extension into the subacromial space remains a useful intraoperative technique[45] (Fig. 4). Intratendinous tears remain particularly challenging to localize, with several arthroscopic findings described, such as rotator cuff tissue fibrillation and congestion or an arthroscopic "Bellows sign", indicative of tear location[46] (Fig. 5-C). If high suspicion for an intratendinous PTRCT arises, an intraoperative test for the "Bubble sign" can be performed with an injection of saline into the suspected lesion with a resultant bulging expansion of the rotator cuff tendon, as described by Lo and Burkhart in 2002[47]. This should not be confused with more recent descriptions of "Bubble signs", in which during entry of the arthroscope through the posterior portal, or lifting of the long head of the biceps tendon (LHBT) through an anterior portal within the glenohumeral joint, air bubbles are visualized rushing into the relatively negative pressure glenohumeral joint from the positively pressured subacromial space through the presence of a FTRCT, helping differentiate them from PTRCTs[48] (Figs. 5-A and 5-B). Finally, a thorough subacromial bursectomy is vital to be able to fully evaluate the broad rotator cuff insertion.

Surgical Algorithm

After PTRCT identification, surgical treatment can be performed. The authors prefer to view the surgical treatment options in 3 decisions: (1) whether to debride only (with or without acromioplasty) or to perform a repair; (2) if repair is chosen, whether to complete the tear (and perform a repair for a full-thickness tear) or to preserve the intact tissue and perform an in situ transtendinous repair; and (3) whether to augment the rotator cuff repair.

TABLE I Nonoperative Injection Treatments and Outcomes for Partial-Thickness Rotator Cuff Tears Within the Past 5 Years*

Study	Study Type	PRP Formulation Control Group	Injection Technique	Patients (n, Age in Years When Reported)	Follow-up (mo)	Outcomes
Platelet-rich plasma comparative studies						
Schwitzguebel et al. (*Am J Sports Med* 2019)[87]	RCT	LP-PRP Normal saline	US-guided Intralesional	80; 41 PRP (48.2), 39 saline (47.6)	19.5	Lesion volume on MRA, VAS, SANE, ASES, constant, adverse events
Cai et al. (*Med Sci Sports Exerc* 2019)[88]	RCT	LP-PRP Normal saline Sodium hyaluronate	US-guided Subacromial space	200; 50 in each group	12	Constant, ASES, VAS, tear progression on MRI
Jo et al. (*J Bone Joint Surg Am* 2020)[89]	RCT	Allogeneic PRP Triamcinolone acetonide	US-guided Subacromial space	49; 23 PRP (55.3), 26 corticosteroid (52.5)	6	Constant, VAS, ROM, ASES, UCLA, SST, DASH, adverse events
Thepsoparn et al. (*Orthop J Sports Med* 2021)[90]	RCT	LP-PRP Triamcinolone acetonide	US-guided Subacromial space	31; 15 PRP (51.3), 16 corticosteroid (62.4)	6	VAS, OSS, adverse events
Kwong et al. (*Arthroscopy* 2021)[91]	RCT	LP-PRP Triamcinolone acetonide	US-guided Subacromial space	99: 47 PRP (49.9), 52 corticosteroid (49.1)	12	VAS, ASES, failure rates
Tanpowpong et al. (*Sports Med Open* 2023)[39]	RCT	LP-PRP Triamcinolone acetonide	US-guided Intralesional	30: 15 PRP (58.3), 15 corticosteroid (63.3)	6	Tear size on MRI, VAS, ASES, constant
Rossi et al. (*Arthroscopy* 2023)[92]	Prospective cohort	LR-PRP	US-guided Subacromial space	150 (36.6)	12	ASES, VAS, SANE, sleep quality, return to sports
Mesenchymal signaling cell injections						
Kim et al. (*J Orthop Surg Res* 2019)[93]	Prospective, non-randomized, comparative study	CBMA Physical therapy	US-guided Subacromial space	24: 12 CBMA (54.9), 12 therapy (59.6)	3	VAS, DASH, SANE, tear size on MRI
Centeno et al. (*Stem Cells Int* 2020)[94]	RCT	CBMA Physical therapy	US-guided Intralesional	25: 14 CBMA (46), 11 therapy (49)	24	Retear rate, UCLA, constant, JOA, SST
Jo et al. (*Arthroscopy* 2020)[95]	Prospective cohort study	AD-MSC	US-guided Intralesional	19 (57.1)	24	VAS, ROM, constant, ASES, UCLA, DASH, failures, tear size on MRI
Hurd et al. (*J Orthop Surg Res* 2020)[96]	RCT	AD-MSC Methyl-prednisolone	US-guided Intralesional	15: 11 AD-MSC (64.6), 5 corticosteroid (57.6)	12	Adverse events, ASES, VAS, tear size on MRI
Lundeen et al. (*Sci Rep* 2023)[97]	RCT	AD-MSC Methyl-prednisolone	US-guided Intralesional	15: 11 AD-MSC (64.6), 4 corticosteroid (59.0)	40.6	Adverse events, Short Form-36, ASES, VAS, ROM, tear size on MRI

*AD-MSC = adipose-derived mesenchymal signaling cells, ASES = American Shoulder and Elbow Surgeons Score, CBMA = concentrated bone marrow aspirate, DASH = Disabilities of the Arm, Shoulder, and Hand, LP = leukocyte poor, LR = leukocyte poor PRP, MRA = magnetic resonance angiogram, MRI = magnetic resonance imaging, OSS = Oxford Shoulder Score, PRP = platelet-rich plasma, RCT = randomized controlled trial, ROM = range of motion, SANE = Single Assessment Numeric Evaluation, SST = Simple Shoulder Test, UCLA = University of California Los Angeles score, US = ultrasound, and VAS = visual analog scale.

Arthroscopic Debridement With or Without Acromioplasty

Arthroscopic debridement is indicated for PTRCTs that have failed nonoperative management, which are less than 50% of tendon thickness on the articular side and <25% on the bursal side[2,42]. High-level overhead athletes, particularly throwers, should be considered for debridement over repair (even with greater than 50% involvement), particularly when in season, after discussion with the trainer, therapist, and coach[13]. Articular-sided PTRCTs when diagnosed arthroscopically within the glenohumeral joint should be debrided with a motorized shaver to stable borders. Forward flexion and external

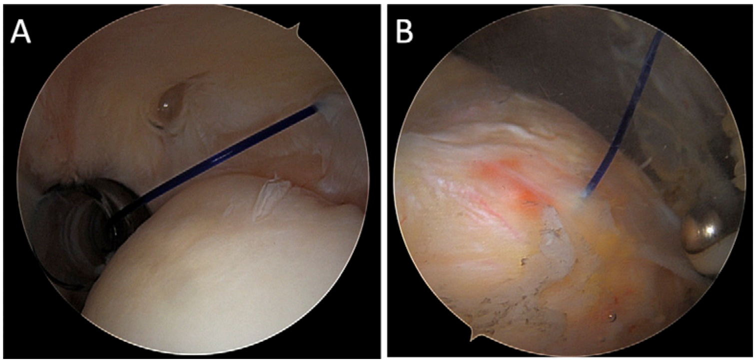

Fig. 4

Arthroscopic images of a right shoulder in beach-chair position viewing from the posterior portal of (**Fig. 4-A**) glenohumeral and (**Fig. 4-B**) subacromial views of the Snyder suture marking technique of a partial articular-sided rotator cuff tear.

rotation to 30° can assist in visualization and access to the supraspinatus and anterior infraspinatus insertion, with switching of the arthroscope to the anterior portal or usage of a 70° arthroscope from the posterior portal to better view the posterior infraspinatus or teres minor insertions. The partial tear area can then be tagged with a monofilament suture[45]. A subacromial bursectomy for visualization and access to the tendinous insertion of the supraspinatus and infraspinatus is then performed after switching to the subacromial space. A complete bursectomy can be performed with viewing from the anterior portal or lateral portal to visualize the underappreciated posterior cuff insertion. Although the bursa over the tendinous insertion is often pathologic and a pain generator, the bursal tissue over the muscular portion of the tendons medially should be preserved, not only to prevent bleeding but also to preserve progenitor cells that have been found to be abundant in bursal tissue[49]. The suture-marked area of concern should be probed and debrided gently with a shaver to investigate for full-thickness extension of the articular-sided PTRCT. Bursal-sided PTRCTs should be probed with a blunt instrument to investigate if the partial tear involves >50% of the tendon thickness. A preferred technique used by the authors is to primarily use a 5.5-mm bone cutting shaver without teeth in the subacromial space, which allows for both the gentle debridement of the bursal tissue off the rotator cuff and the efficient completion of any necessary bony work.

Outcomes

Several cohort studies with long-term follow-up have demonstrated conflicting results after arthroscopic debridement of PTRCTs with or without acromioplasty. Jaeger et al. and Ranebo et al., analyzing cohorts of 95 and 69 patients with the 19.9-year and 22-year follow-ups, respectively, showed excellent results with debridement and acromioplasty alone for partial-thickness tears, demonstrating 90.9% "successful outcomes" and a mean Constant-Murray score of 101, respectively[50,51]. These 2 studies demonstrated that 42% of PTRCTs progressed over 20 years with a 7% rate of cuff tear arthropathy, whereas 87% of FTRCTs progressed with a 74% rate of cuff tear arthropathy[50,51]. However, Cordasco et al. demonstrated worse outcomes at a mean of 52.7 months in bursal-sided PTRCTs than articular tears with up to a 38% failure rate[42]. The addition of acromioplasty is no longer considered beneficial as demonstrated by a meta-analysis by Lähdeoja et al.; in fact, a

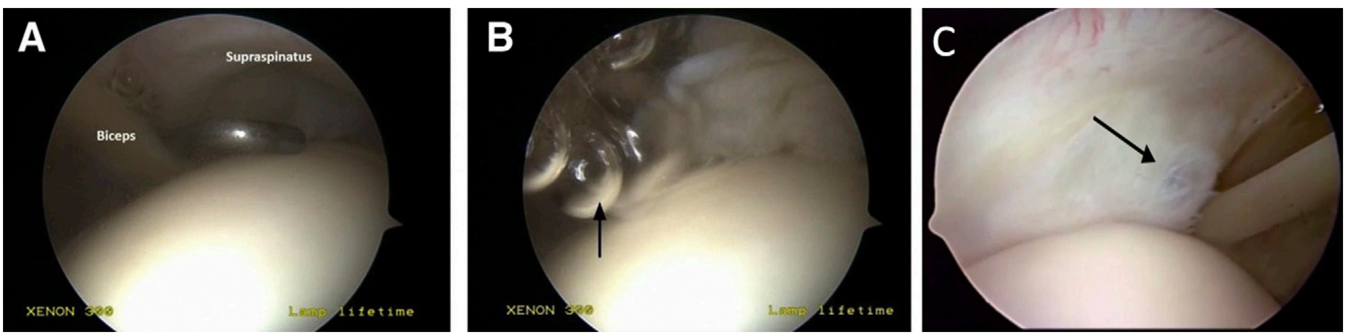

Fig. 5

Fig. 5-A Intra-articular diagnostic arthroscopy of the right glenohumeral joint from the posterior viewing portal in the beach-chair position. **Fig. 5-B** As the supraspinatus tendon is raised by the probe, air bubbles (the "bubble sign"; black arrow) can be seen entering down the negative pressure gradient from the subacromial space. **Fig. 5-C** Left glenohumeral joint viewed from the posterior portal in the beach-chair position showing the "bellows" sign (black arrow) of the anterior supraspinatus tendon insertion. (Reprinted, with permission, from Upadhyay D, Scheidt M, Garbis N, Salazar D. Bubble sign: an arthroscopic technical trick to differentiate between partial- and full-thickness rotator cuff tears. Arthrosc Tech. 2022;11[7]:e1353-7 [**Figs. 5-A and 5-B**] and Fanelli MG, Field LD. The arthroscopic "bellows" sign identifies hidden rotator cuff tears. Arthrosc Tech. 2022;11[5]:e723-5 [**Fig. 5-C**]. Reprinted from Elsevier under the terms of the CC BY-NC-ND license [http://creativecommons.org/licenses/by-nc-nd/4.0/]).

matched comparative study by Swindell et al. demonstrated increased revision surgery in rotator cuff repairs that underwent concomitant acromioplasty compared with those without[52]. It is the authors' practice to perform concomitant acromioplasty only in cases when necessary for visualization or with a large type III hooked acromion in the presence of bursal-sided PTRCTs. In addition, a limited acromioplasty may be of value in recruiting a biologic healing response by exposing marrow elements into the subacromial space, akin to a notch microfracture in the knee for isolated meniscus repairs; however, there are no studies available to date to support this approach.

Arthroscopic Partial Rotator Cuff Repair

Arthroscopic repair of PTRCTs is indicated for tears >50% thickness that have failed nonoperative management. Nearly all tears should undergo a trial of nonoperative management because immediate vs. delayed surgical repairs (as defined by 6 months of nonoperative treatment) have been shown to be equivalent in visual analog scale (VAS), ASES scores, and retear rates in a randomized controlled trial (RCT) by Kim et al.[40]. The 2 main strategies for PTRCT repairs are either conversion to full thickness followed by repair vs. a transtendinous, "in situ" repair.

Conversion Repair

Arthroscopic conversion of PTRCTs to FTRCT followed by a standard full-thickness repair provides several advantages and disadvantages. It is often technically easier because of familiarity and allows for a thorough assessment of the rotator cuff footprint and the full extent of the tear after debridement. Disadvantages include the need to remove some extent of intact rotator cuff tissue during the takedown and possible distortion of the rotator cuff length-tension-footprint relationship. Conversion to FTRCTs can be performed with a variety of instruments, including but not limited to the arthroscopic shaver, radiofrequency wand, specialized arthroscopic blade, or an 11-blade scalpel, inserted from the lateral portal. Good mid-term outcomes have been reported after conversion repair, including in middle-age patients (mean age 51 years, by Brockmeyer et al.) and in young and athletic patients (Olympic-level volleyball athletes with a mean age of 26 years, by Porcellini et al.)[53,54]. Bursal-sided vs. articular-sided conversions appear to do equally well, with excellent ASES and Constant scores in both groups in a study by Kim et al. with a mean 35-month follow-up; however, there was a nonsignificant increase in a retear rate of 9.5% in the bursal-sided group compared with 0% in the articular-sided group[55].

Transtendinous In Situ Repair

In situ PTRCT repairs involve repairing either the articular-sided or bursal-sided partial tear while leaving the remnant

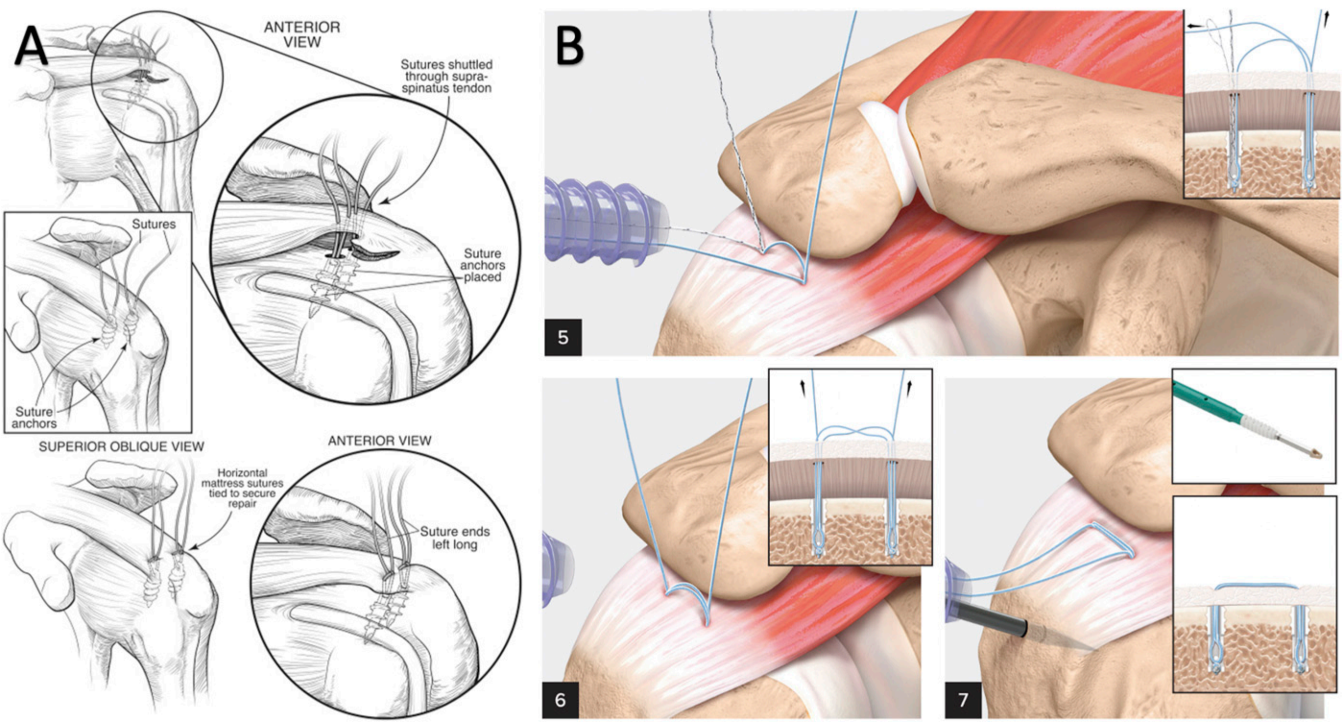

Fig. 6

Two partial articular rotator cuff tear repairs using in situ transtendinous repair techniques. **Fig. 6-A** Medial row anchors tied with knots. **Fig. 6-B** Medial row anchors tensioned with knotless technology. (Reprinted, with permission, from Johnson JS, Caldwell PE, Pearson SE. Arthroscopic transtendinous modified double-row suture bridge repair of a bony PASTA lesion. Arthrosc Tech. 2014;3[4]:e449-53. Reprinted from Elsevier with permission).

TABLE II Conversion Repair vs. Transtendinous in Situ Repair*

Study	Study Type	Tear Type	Mean Follow up (mo)	Tear Completion (N, Mean Age in Years)	Patient-Reported Outcomes	Retears, n (%)	In Situ Repair (N, Mean Age in Years)	Patient-Reported Outcomes	Retear Rate	Significant Difference
Shin et al. (*Am J Sports Med* 2015)[60]	Retrospective cohort comparative	Bursal-sided	32.5	47, 59.3 ± 9.9	VAS: 0.9 ± 0.5 ASES: 93.4 ± 2.2 Constant: 89.4 ± 1.8	3 (8.1%)	37, 48.2 ± 9.0	VAS: 0.9 ± 0.5 ASES: 88.6 ± 4.5 Constant: 88.1 ± 2.4	4 (8.5%)	No
Kim et al. (*Arthroscopy* 2015)[98]	Prospective comparative	Articular-sided and bursal-sided	19.1	45, 59.0	VAS: 1.9 ± 1.6 ASES: 87.1 ± 9.9 Constant: 71.1 ± 6.1	7 (15.6%)	47, 55.8	VAS: 2.6 ± 2.2 ASES: 80.6 ± 15.6 Constant: 71.1 ± 4.1	2 (4.3%)	No
Katthagen et al. (*Knee Surg Sports Traumatol Arthrosc* 2018)[43]	Systematic review; 19 studies	Articular-sided and bursal-sided	40.1	119, NR	ASES: 82.7-90.6	9.5%-21.5%	277, NR	ASES: 76-93	15.1%	N/A
Liu et al. (*J Orthop Surg* 2018)[99]	Retrospective cohort comparative	Articular-sided	13	38, 60.3 ± 6.3	VAS: 1.1 ± 0.8 ASES: 85.0 ± 5.7	0 (0%)	30, 63.1 ± 6.9	VAS: 0.9 ± 0.9 ASES: 81.9 ± 10.9	0 (0%)	No
Castricini et al. (*Arch Orthop Trauma Surg* 2019)[100]	Retrospective cohort comparative	Articular-sided	73.9	94, NR	Constant: 84.1 SST: 10.1	10 (13.5%)	59, NR	Constant: 84.3 SST: 10.1	6 (13.9%)	No
Kanatli et al. (*Acta Orthop Traumatol Turc* 2020)[101]	Retrospective cohort comparative	Articular-sided and bursal-sided	44	20, 48.9 ± 13.8	ASES: 84.0 Flexion increase: 15°	0 (0%)	20, 47.6 ± 12.1	ASES: 82.7 Flexion increase: 18°	0 (0%)	No
Thamrongskulsiri et al. (*Knee Surg Sports Traumatol Arthrosc* 2023)[61]	Meta-analysis, 7 studies	Articular-sided	NR	NR, NR	VAS: 0.21 MD (−0.18, 0.60) favoring	11.6%	NR, NR	ASES: −0.93 MD (−4.96, 3.11) favoring Constant: −0.83 MD (−2.84, 1.17) favoring	7.7%	No
Yang et al. (*J Orthop Surg Res* 2023)[102]	Meta-analysis, 6 studies	Articular-sided	NR	272, NR	Constant: −0.21 (−0.76, 0.35) favoring	OR 0.94 (0.37, 2.38) favoring	229, NR	VAS: 0.36 MD (−0.76, 1.48) favoring ASES: 0.26 MD (−0.53, 1.05) favoring	N/A	No
Yuan et al. (*J Shoulder Elbow Surg* 2023)[103]	Retrospective cohort comparative	Articular-sided	24	28, 48.5 ± 8.4	VAS: 1.1 ± 0.2 ASES: 92 ± 5 Constant: 94 ± 4 Flexion: 171° ± 11°	1 (3.6%)	28, 51.3 ± 9.6	VAS: 1.0 ± 0.3 ASES: 91 ± 5 Constant: 91 ± 6 Flexion: 167° ± 7°	0 (0%)	No
Zhuo et al. (*Orthop Surg* 2023)[104]	Retrospective cohort comparative	Bursal-sided	15	30, 54.2 ± 7.2	VAS: 0.0 ± 0.2 ASES: 95.9 ± 2.7 Constant: 94.0 ± 2.6 Flexion: 167.7° ± 6.9°	1 (3.3%)	28, 52.3 ± 6.4	VAS: 0.1 ± 0.4 ASES: 95.5 ± 4.3 Constant: 93.5 ± 3.5 Flexion: 165.9° ± 8.7°	2 (7.1%)	No

*ASES = American Shoulder and Elbow Surgeons Score, MD = mean difference, NR = not-recorded, OR = odds ratio, SST = Simple Shoulder Test, and VAS = visual analog scale.

rotator cuff insertional fibers intact. For articular-sided tears, the techniques involve transtendinous placement of suture anchors into the exposed rotator cuff footprint within the glenohumeral joint, suture retrieval (through the cuff) in the subacromial space, and compression of the intact bursal-sided tendon using tied knots or knotless technology. In the glenohumeral joint, suture passage through the rotator cuff can be performed with various self-retrieving suture instruments, such as the BirdBeak (Arthrex) or NanoPass (Stryker) (Fig. 6-A). Alternatively, using knotless suture anchor technology (Knotless FiberTak; Arthrex), sutures can be retrieved once in the subacromial space, converted through the opposing suture anchor to form a horizontal mattress repair suture without the need for transtendinous retrieval or knot tying (Fig. 6-B). Advantages include possible biomechanical advantage when compared with conversion repairs, with Mihata et al. demonstrating, in a biomechanical analysis, improved glenohumeral and subacromial contact pressures at time zero and improved maintenance of intact rotator cuff tissue and thus the length-tension relationship[56]. Disadvantages are a demanding surgical technique and unfamiliarity when compared with FTRCT repair techniques. Transtendinous in situ repairs can be performed with a single suture anchor for small tears, or 2 anchors for larger tears, and with knots or knotless fixation for maximal tendon footprint compression. Rossi et al. demonstrated excellent long-term outcomes after in situ repair for both articular-sided and bursal-sided PTRCTs with ASES and VAS scores, as well as an 87% return to sport rate at a mean of 5.6 months in 2 separate retrospective cohorts[57,58]. Dey Hazra also published excellent 10-year outcomes after transtendinous repair of both articular-sided and bursal-sided PTRCTs using ASES, Single

Assessment Numeric Evaluation, and Quick Disabilities of the Arm, Shoulder, and Hand scores, with no revision surgeries reported[59].

Comparative Outcomes

Most comparative studies of arthroscopic repair techniques for PTRCTs demonstrate excellent outcomes without significant differences between both repair techniques. Shin et al. retrospectively compared 47 in situ single-row repairs and 37 tear completion and double-row repairs in bursal-sided PTRCTs and found no significant differences in ASES, Constant scores, or retear rate (8.5% vs. 8.1%, respectively)[60]. In a recent meta-analysis, Thamrongskulsiri et al. compiled 497 shoulders in 7 studies for articular-sided PTRCTs and demonstrated no differences between ROM and retear rate, with 7.7% for in situ repairs and 11.6% for tear completion repairs[61]. A comprehensive list of recent comparative studies can be found in Table II.

Augmentation for PTRCTs

Although repair of PTRCTs has demonstrated good-excellent outcomes, persistent pain or retears remain an issue for surgeons and have given rise to recent interest in augmented repairs. Just as a variety of orthobiologics can be used in the nonoperative treatment of PTRCTs, they can also be used to augment arthroscopic repairs of PTCRTs. Other more structural techniques can also be used to augment partial rotator cuff tears, including collagen scaffolds, synthetic augments, or autologous tissues such as LHBT or subacromial bursa (Table III). Rotator cuff augmentation can be typically broken down into (1) biologic augmentation, in which growth factors/signaling cells are delivered into the subacromial space, or (2) onlay augmentation, in which an autograft, allograft, xenograft, or synthetic augment is secured either over or into the rotator cuff repair[62]. A third realm of rotator cuff augmentation that we would like to propose is indirect augmentation, in which a pharmacologic therapy is used to indirectly improve the biologic or mechanical environment for rotator cuff healing, with current focuses on vitamin D supplementation and bisphosphonate therapy.

Biologic Augmentation

Biologic augmentation of PTRCT repairs includes many of the same injectable options as they are used for nonoperative treatment, such as PRP, platelet-rich fibrin, CBMA, and AD-MSCs, although the vast majority of existing literature focuses on the repair of FTRCTs. Hurley et al. demonstrated improved VAS, Constant, University of California Los Angeles, but not ASES scores, in PRP-augmented repairs of PTRCTs and FTRCTs compared with standard repairs, with no significant differences reported for platelet-rich fibrin-augmented repairs[63]. Several other recent meta-analyses have corroborated these findings (Table III). Mesenchymal signaling cells (MSCs), which are often but should not be labeled "stem cells", provide powerful sources of growth factors and signaling cells to promote tendon healing and have been clinically implemented in rotator cuff surgery as the "crimson duvet" technique, where bone marrow stimulation is performed to release MSCs from the greater tuberosity[64,65]. Cole et al. recently published the first RCT in humans of the use of CBMA augmentation in rotator cuff repair, demonstrating significantly decreased retear rates with cell-based augmentation[66]. CBMA can be harvested from the iliac crest or for a more local source from the proximal humerus during rotator cuff repair, as described previously by Mazzocca et al.[67]. Although there has been significant interest in MSCs derived from fat, there are only 2 studies investigating the use of AD-MSCs in vivo in human rotator cuff repairs (Table III).

Finally, a newer autologous source of MSCs has gained interest specifically for the treatment of PTRCTs and exists immediately available intraoperatively: the subacromial bursa. Mazzocca et al. demonstrated both the feasibility of the use of subacromial bursa to produce progenitor and fibroblast-type cells and the viability in human subjects with 93.8% of patients reaching substantial clinical benefit[49,68]. Briefly, the technique involves standard rotator cuff repair technique per surgeon preference, with simple harvesting of the subacromial bursa using either a grasper or proprietary shaver collector device (GraftNet; Arthrex), a combination of harvest bursal tissue with thrombin, and reimplantation using a trocar into the repair site between the medial and lateral row anchors[49,68]. These findings have been recently corroborated by Güler et al. in a comparative study, demonstrating superior VAS, Constant, and ASES scores when using subacromial bursal MSCs to augment acromioplasty and PTRCT debridement, when compared with acromioplasty and debridement of the PTRCT and subacromial bursa[69].

Onlay Scaffold Augments: "Patches"

In contrast to the aforementioned biologic augmentations, several onlay augmentation options can be used as either a nonstructural scaffold or structural grafts, in which the augment is overlaid on top of the debrided or repaired PTRCT. These can be autologous, allograft, xenograft, or synthetic. Autograft options include removing the coracoacromial ligament during subacromial decompression and reincorporating it into the partial repair as reported in a recent proof-of-concept series by Zhang et al., or by harvesting the intra-articular portion of the LHBT and using it as a patch onlay augment as recently described by Tokish et al.[70-73]. Allograft options mainly center around human dermal allograft patches (Fig. 7) (ArthroFLEX; Arthrex or Dermis on Demand; Depuy Synthes); however, clinical outcome literature is limited to 2 case series of in vivo human use as patch augmentation, with more interest as interpositional bridging graft or superior capsular reconstruction for massive irreparable tears.

Xenograft options include bovine collagen patch onlay augmentation

TABLE III Studies of Augmentation Strategies for Rotator Cuff Tears in Humans*

Study	Study Type	Augmentation	Surgical Technique	Patients (n, Age in Years When Reported)	Follow-up (mo)	Outcomes
Non-cell based biologic augmentation						
Han et al. (*J Orthop Surg Res* 2019)[105]	Meta-analysis, 13 RCTs	PRP, differentiated LR and LP	Included full- and partial-thickness repairs	880	6-16	Retear rate, VAS, constant, UCLA, ASES, SST
Hurley et al. (*Am J Sports Med* 2019)[63]	Meta-analysis, 18 RCTs	PRP and PRF, differentiated LR and LP	Included full- and partial-thickness repairs	1,147	4-24	Retear rate, VAS, constant, ASES, UCLA, operative time, patient satisfaction
Ryan et al. (*Arthroscopy* 2021)[106]	Meta-analysis, 17 RCTs	PRP and PRF, differentiated LR and LP	Included full- and partial-thickness repairs	1,104	3-60	Retear rate, constant, VAS, ASES, SST, UCLA
Zhao et al. (*J Shoulder Elbow Surg* 2021)[107]	Meta-analysis, 10 RCTs	LP-PRP only	Included full- and partial-thickness repairs	742	1.5-60	Retear rate, constant, UCLA, ASES, Oxford
Li et al. (*Arthroscopy* 2022)[108]	Meta-analysis, 23 RCTs	PRP and PRF, differentiated LR and LP	Partial-thickness through massive tears	1,440	17.6	Retear rate, constant, VAS, ASES, UCLA
Jeong et al. (*J Orthop Surg* 2017)[109]	Prospective cohort study	HA-carboxymethyl cellulose	Full-thickness repairs only	80, 60.2	6	VAS, constant, ASES
Mesenchymal signaling cells augmentation						
Ajrawat et al. (*J Shoulder Elbow Surg* 2019)[64]	Meta-analysis, 2 RCTs, 2 retrospective cohort	BMS	Full-thickness repairs only	365, 61.7	27	Retear rate, DASH, UCLA, constant
Shibata et al. (*J Shoulder Elbow Surg* 2023)[65]	RCT	BMS	Full-thickness knotless suture-bridge repairs	50, 63.8	24	Retear rate, UCLA, constant, JOA, SST
Cole et al. (*Am J Sports Med* 2023)[66]	RCT	CBMA	Full-thickness 1-3 cm tear repairs	82, 55.8	38.9	ASES, SANE, SST, SF-12, VR-12
Kim et al. (*Am J Sports Med* 2017)[110]	Prospective cohort	AD-MSC	Full-thickness repairs	70, 58.4	28	VAS, ROM, constant, UCLA, retear rate
Randelli et al. (*Am J Sports Med* 2022)[111]	RCT	AD-MSC	Full-thickness single-row repair	46, 58.9	24	Constant, ASES, VAS, retear rate
Muench et al. (*Arthrosc Sports Med Rehabil* 2020)[68]	Case series	Subacromial bursa	Included full- and partial-thickness repairs	16, 57.4	12.6	ASES, SST, constant, SANE, VAS, retear rate
Güler et al. (*Orthop J Sports Med* 2023)[69]	Retrospective cohort	Subacromial bursa	Acromioplasty, Ellman type 2 bursal-sided partial tears	40, 47.8	18	VAS, constant, ASES, retear rate
Autologous onlay scaffold augments						
Zhang et al. (*Orthop Surg* 2023)[70]	Case series	CA ligament	Bursal-sided partial tears	3, 51	24	ASES, SST, muscle strength, retear rate
Colbath et al. (*Arthroscopy* 2022)[73]	Biomechanical and in vitro study	LHBT	N/A	N/A	N/A	Augment area, tensile properties, tenocyte viability, support of ADMSC differentiation
Allograft or xenograft onlay scaffold augments						
Hohn et al. (*J Shoulder Elbow Surg* 2018)[75]	Case series	Human dermal allograft	Primary and revision rotator cuff repairs	28, 60.1	48	ASES, SANE, retear rate
Namdari et al. (*Am J Sports Med* 2021)[76]	Case series	Human dermal allograft	Primary and revision rotator cuff repairs			
McIntyre et al. (*Arthroscopy* 2019)[112]	Case series	Bovine collagen patch (Regeneten; Smith & Nephew)	Included full- and partial-thickness repairs	173, 54.2	12.7	VAS, SANE, VR-12, ASES, complications
Dai et al. (*Bull Hosp Jt Dis* 2020)[113]	Case series	Bovine collagen patch (Regeneten; Smith & Nephew)	Bursal- and articular-sided partial tears	24, 54.5	19.1	ASES, VAS, satisfaction, tendon thickness on MRI
Schlegel et al. (*J Shoulder Elbow Surg* 2021)[114]	Case series	Bovine collagen patch (Regeneten; Smith & Nephew)	Bursal- and articular-sided partial tears	33, 54	25.5	ASES, constant, satisfaction, tendon thickness on MRI
Bushnell et al. (*Orthop J Sports Med* 2021)[115]	Case series	Bovine collagen patch (Regeneten; Smith & Nephew)	Bursal- and articular-sided partial tears	272, 52.1	12.7	ASES, SST, SANE, VR-12, revision surgery
Synthetic onlay augments						
Cai et al. (*Am J Sports Med* 2018)[79]	RCT	3D printed collagen scaffold	Included full- and partial-thickness repairs	112, 50-85	28.2	VAS, UCLA, constant, retear rate
No existing clinical studies		Balloon spacer				

*AD-MSC = adipose-derived mesenchymal signaling cells, ASES = American Shoulder and Elbow Surgeons Score, BMS = bone marrow stimulation, CBMA = concentrated bone marrow aspirate, DASH = Disabilities of the Arm, Shoulder, and Hand, HA = hyaluronic acid, JOA = Japanese Orthpaedic Association, LP = leukocyte poor PRP, LR = leukocyte rich PRP, PRF = platelet-rich fibrin, PRP = platelet-rich plasma, RCT = randomized controlled trial, SANE = Single Assessment Numeric Evaluation, SF-12 = 12-Item Short Form Survey, SST = Simple Shoulder Test, UCLA = University of California Los Angeles score, VAS = visual analog scale, and VR-12 = Veterans RAND 12-Item Health Survey.

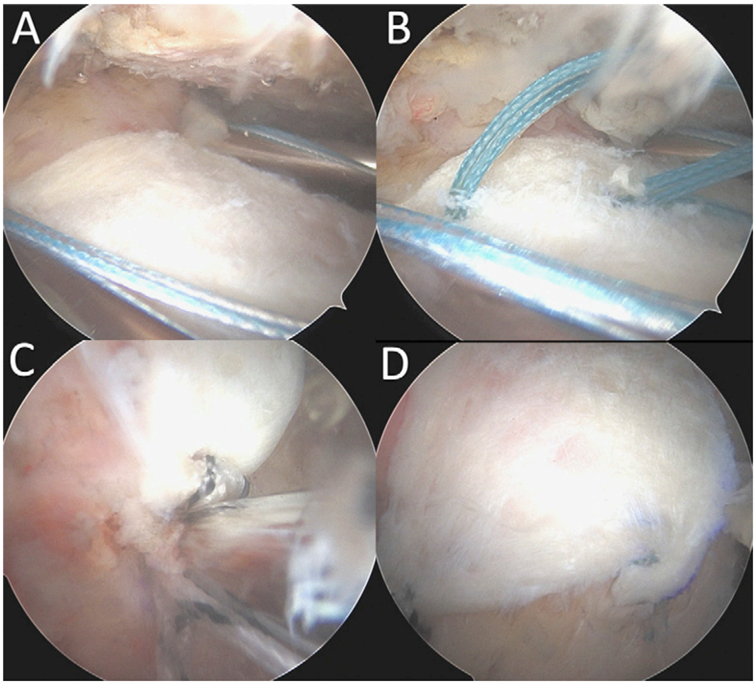

Fig. 7

Arthroscopic images of a right shoulder subacromial space from the (**Figs. 7-A and 7-B**) posterior viewing portal demonstrating a high-grade partial-thickness tear treated with human dermal allograft patch with medial all-suture fixation, and (**Figs. 7-C and 7-D**) lateral viewing portal demonstrating lateral fixation using a polyetheretherketone suture anchor and final implant coverage.

(REGENETEN; Smith & Nephew), although the developers report that all bovine DNA has been removed to create a pure, nonxenograft collagen implant[74-76]. This scaffold can be incorporated into a PTRCT repair using polylactic acid graft-tendon staples and polyetheretherketone graft-bone staples. Despite abundant popularity, the literature is limited to several case series with consistent improvements in ASES, satisfaction, and tendon thickness on follow-up MRI, with no existing comparative studies or RCTs focused on PTRCTs (Table III). Care should be taken, however, as there have been preliminary reports of adverse xenograft tissue reaction, and the American Academy of Orthopaedic Surgeons Clinical Practice Guideline provides only limited evidence against the use of selected xenografts for augmentation[77]. Prior xenograft reactions published in the early 2000s continue to remind us of the dangers of continuously spinning the wheel and ignoring past attempts at tissue engineering in rotator cuff repairs[78]. Synthetic augments can also be used, with Cai et al. demonstrating improved Constant and University of California Los Angeles scores at a 12-month follow-up using a synthetic 3D printed collagen scaffold onlay augment compared with repair alone[79]. A bioinductive collagen scaffold (BioBrace; ConMed) composed of highly porous type I collagen and bioresorbable poly (L-lactide) microfilaments, has been reported as another synthetic option for PTRCT augmentation[80]. It is the author's practice to use augmentation techniques only in PTRCTs of concern, which include attenuated tissue quality, severe delamination, difficulties with tissue mobilization, and revision settings.

Indirect Augmentation

Indirect rotator cuff repair augmentation involves the use of pharmacologics to improve either the biologic or mechanical milieu for rotator cuff healing. Vitamin D has been identified in musculoskeletal research to be a previously underappreciated nutrient vital to the health of rotator cuff tendons. Kim et al. identified that vitamin D deficiency correlated with increased expression of inflammatory interleukin-1B and interleukin-6 in supraspinatus and deltoid muscles in arthroscopic repair in an in vitro laboratory study[81]. Harada et al. demonstrated in a national claims database study that patients with vitamin D (25(OH)D) levels <20 ng/dL had significantly increased rates of revision surgery, and Patel et al. demonstrated cost-effectiveness of preoperative vitamin D screening and treatment in deficient patients undergoing rotator cuff surgery[82,83]. Osteoporosis has also been recently demonstrated to be detrimental to the biomechanical environment after rotator cuff repair, with Schanda et al. demonstrating, in rat models, improved bone volume, number of trabeculae, and maximum load to failure in rats that had undergone 1 injection of subcutaneous zoledronic acid at 100 μg/kg on postoperative day 1 compared with placebo[84]. Lei et al. performed a RCT in postmenopausal women with osteoporosis using postoperative day 1 and year 1 zoledronic acid infusions after rotator cuff surgery and demonstrated significantly higher tendon healing rates than controls at a 2-year follow-up[85]. In addition to standard preoperative evaluations of inhibitors to soft-tissue healing (i.e., smoking history, inflammatory disease, immunologic medications, or fluoroquinolones), we recommend that surgeons evaluate vitamin D levels of patients and treat if it is <30 ng/dL and pursue bone density testing if patients meet the criteria according to the US Preventative Services Task Force guidelines[86].

Conclusion

PTRCTs present a challenging and unique set of considerations for the orthopaedic surgeon. An appreciation for the histologic layers of the rotator cuff and pathophysiology behind Ellman's classification of PTRCTs is essential to understand treatment principles. Nonoperative management should be trialed initially, with those that fail undergoing arthroscopic debridement vs. repair depending on tear thickness beyond the 50% cutoff. There is some clinical and biomechanical evidence supporting in situ transtendinous repairs for articular-sided tears and conversion repairs for bursal-sided tears; however, each tear should be treated independently based on preoperative considerations and intraoperative findings. Biologic and scaffold augmentation provides a promising adjunct to both improve patient outcomes and decrease retear rates; however, a larger body of evidence is required before widespread adoption.

Sources of Funding

There were no sources of funding for this study.

Andrew S. Bi, MD[1],
Allison M. Morgan, MD[1],
Michael O'Brien, MD[2],
Brian R. Waterman, MD[3],
Eric J. Strauss, MD[1],
Alexander Golant, MD[1]

[1]Division of Sports Medicine, NYU Langone Health, New York, New York

[2]Division of Shoulder and Elbow, Tulane University School of Medicine, New Orleans, Louisiana

[3]Division of Sports Medicine, Atrium Health Wake Forest Baptist, Winston-Salem, North Carolina

Email address for corresponding author: andrewsbi822@gmail.com

References

1. Ardeljan A, Palmer J, Drawbert H, Ardeljan A, Vakharia RM, Roche MW. Partial thickness rotator cuff tears: patient demographics and surgical trends within a large insurance database. J Orthop. 2020;17:158-61.

2. Matava MJ, Purcell DB, Rudzki JR. Partial-thickness rotator cuff tears. Am J Sports Med. 2005;33(9):1405-17.

3. Reilly P, Macleod I, Macfarlane R, Windley J, Emery R. Dead men and radiologists don't lie: a review of cadaveric and radiological studies of rotator cuff tear prevalence. Ann R Coll Surg Engl. 2006;88(2):116-21.

4. Yamanaka K. Pathological study of the supraspinatus tendon [in Japanese]. Nihon Seikeigeka Gakkai Zasshi. 1988;62(12):1121-38.

5. Kong BY, Cho M, Lee HR, Choi YE, Kim SH. Structural evolution of nonoperatively treated high-grade partial-thickness tears of the supraspinatus tendon. Am J Sports Med. 2018; 46(1):79-86.

6. Plancher KD, Shanmugam J, Briggs K, Petterson SC. Diagnosis and management of partial thickness rotator cuff tears: a comprehensive review. J Am Acad Orthop Surg. 2021;29(24):1031-43.

7. Frandsen JJ, Quinlan NJ, Smith KM, Lu CC, Chalmers PN, Tashjian RZ. Symptomatic rotator cuff tear progression: conservatively treated full- and partial-thickness tears continue to progress. Arthrosc Sports Med Rehabil. 2022; 4(3):e1091-6.

8. Clark JM, Harryman DT. Tendons, ligaments, and capsule of the rotator cuff. Gross and microscopic anatomy. J Bone Joint Surg Am. 1992;74(5):713-25.

9. Ellman H. Diagnosis and treatment of incomplete rotator cuff tears. Clin Orthop Relat Res. 1990;(254):64-74.

10. Longo UG, De Salvatore S, Zollo G, Calabrese G, Piergentili I, Loppini M, Denaro V. Magnetic resonance imaging could precisely define the mean value of tendon thickness in partial rotator cuff tears. BMC Musculoskelet Disord. 2023;24(1):718.

11. Dugas JR, Campbell DA, Warren RF, Robie BH, Millett PJ. Anatomy and dimensions of rotator cuff insertions. J Shoulder Elbow Surg. 2002;11(5):498-503.

12. Mochizuki T, Sugaya H, Uomizu M, Maeda K, Matsuki K, Sekiya I, Muneta T, Akita K. Humeral insertion of the supraspinatus and infraspinatus. New anatomical findings regarding the footprint of the rotator cuff. J Bone Joint Surg Am. 2008;90(5):962-9.

13. Liu JN, Garcia GH, Gowd AK, Cabarcas BC, Charles MD, Romeo AA, Verma NN. Treatment of partial thickness rotator cuff tears in overhead athletes. Curr Rev Musculoskelet Med. 2018;11(1):55-62.

14. Zhao J, Luo M, Liang G, Pan J, Han Y, Zeng L, Yang W, Liu J. What factors are associated with symptomatic rotator cuff tears: a meta-analysis. Clin Orthop Relat Res. 2022;480(1):96-105.

15. İncesoy MA, Yıldız KI, Türk Öİ, Akıncı Ş, Turgut E, Aycan OE, Bayhan IA. The critical shoulder angle, the acromial index, the glenoid version angle and the acromial angulation are associated with rotator cuff tears. Knee Surg Sports Traumatol Arthrosc. 2021;29(7):2257-63.

16. Li H, Chen Y, Chen J, Hua Y, Chen S. Large critical shoulder angle has higher risk of tendon retear after arthroscopic rotator cuff repair. Am J Sports Med. 2018;46(8):1892-900.

17. Caffard T, Kralewski D, Ludwig M, Dornacher D, Fuchs M, Kappe T, Reichel H, Sgroi M. High acromial slope and low acromiohumeral distance increase the risk of retear of the supraspinatus tendon after repair. Clin Orthop Relat Res. 2023;481(6):1158-70.

18. Cofield RH. Rotator cuff disease of the shoulder. J Bone Joint Surg Am. 1985;67(6): 974-9.

19. Collin P, Matsumura N, Lädermann A, Denard PJ, Walch G. Relationship between massive chronic rotator cuff tear pattern and loss of active shoulder range of motion. J Shoulder Elbow Surg. 2014;23(8):1195-202.

20. Goutallier D, Postel JM, Bernageau J, Lavau L, Voisin MC. Fatty muscle degeneration in cuff ruptures. Pre- and postoperative evaluation by CT scan. Clin Orthop Relat Res. 1994;(304): 78-83.

21. Snyder SJ, Pachelli AF, Del Pizzo W, Friedman MJ, Ferkel RD, Pattee G. Partial thickness rotator cuff tears: results of arthroscopic treatment. Arthroscopy. 1991;7(1): 1-7.

22. Roy JS, Braën C, Leblond J, Desmeules F, Dionne CE, MacDermid JC, Bureau NJ, Frémont P. Diagnostic accuracy of ultrasonography, MRI and MR arthrography in the characterisation of rotator cuff disorders: a systematic review and meta-analysis. Br J Sports Med. 2015;49(20): 1316-28.

23. Liu F, Dong J, Shen WJ, Kang Q, Zhou D, Xiong F. Detecting rotator cuff tears: a network meta-analysis of 144 diagnostic studies. Orthop J Sports Med. 2020;8(2):2325967119900356.

24. Barry JJ, Lansdown DA, Cheung S, Feeley BT, Ma CB. The relationship between tear severity, fatty infiltration, and muscle atrophy in the supraspinatus. J Shoulder Elbow Surg. 2013; 22(1):18-25.

25. Davis DL, Gilotra MN, Calderon R, Roberts A, Hasan SA. Reliability of supraspinatus intramuscular fatty infiltration estimates on T1-weighted MRI in potential candidates for rotator cuff repair surgery: full-thickness tear versus high-grade partial-thickness tear. Skeletal Radiol. 2021;50(11):2233-43.

26. Chung SW, Kim JY, Yoon JP, Lyu SH, Rhee SM, Oh SB. Arthroscopic repair of partial-thickness and small full-thickness rotator cuff tears: tendon quality as a prognostic factor for repair integrity. Am J Sports Med. 2015;43(3): 588-96.

27. Jung JY, Jee WH, Chun HJ, Ahn MI, Kim YS. Magnetic resonance arthrography including ABER view in diagnosing partial-thickness tears of the rotator cuff: accuracy, and inter- and intra-observer agreements. Acta Radiol. 2010; 51(2):194-201.

28. Chen X, Wang Y, Chen J, Zhang F, Xu L, Yan X, Zhu Y, Zhang Q, Tang J. Clinical value of three-dimensional ultrasonography in the morphologic evaluation of rotator cuff tear: a prospective study. Eur Radiol. 2023;33(4):2331-9.

29. Tsuchiya S, Davison EM, Rashid MS, Bois AJ, LeBlanc J, More KD, Lo IKY. Determining the rate of full-thickness progression in partial-thickness rotator cuff tears: a systematic review. J Shoulder Elbow Surg. 2021;30(2):449-55.

30. Mall NA, Kim HM, Keener JD, Steger-May K, Teefey SA, Middleton WD, Stobbs G, Yamaguchi K. Symptomatic progression of asymptomatic rotator cuff tears: a prospective study of clinical and sonographic variables. J Bone Joint Surg Am. 2010;92(16):2623-33.

31. Keener JD, Galatz LM, Teefey SA, Middleton WD, Steger-May K, Stobbs-Cucchi G, Patton R, Yamaguchi K. A prospective evaluation of survivorship of asymptomatic degenerative rotator cuff tears. J Bone Joint Surg Am. 2015;97(2):89-98.

32. Reynolds SB, Dugas JR, Cain EL, McMichael CS, Andrews JR. Débridement of small partial-thickness rotator cuff tears in elite overhead throwers. Clin Orthop Relat Res. 2008;466(3):614-21.

33. Puzzitiello RN, Patel BH, Forlenza EM, Nwachukwu BU, Allen AA, Forsythe B, Salzler MJ. Adverse impact of corticosteroids on rotator cuff tendon health and repair: a systematic review of basic science studies. Arthrosc Sports Med Rehabil. 2020;2(2):e161-9.

34. Desai VS, Camp CL, Boddapati V, Dines JS, Brockmeier SF, Werner BC. Increasing numbers of shoulder corticosteroid injections within a year preoperatively may Be associated with a higher rate of subsequent revision rotator cuff surgery. Arthroscopy. 2019;35(1):45-50.

35. Traven SA, Brinton D, Simpson KN, Adkins Z, Althoff A, Palsis J, Slone HS. Preoperative shoulder injections are associated with increased risk of revision rotator cuff repair. Arthroscopy. 2019;35(3):706-13.

36. Weber AE, Trasolini NA, Mayer EN, Essilfie A, Vangsness CT Jr, Gamradt SC, Tibone JE, Kang HP. Injections prior to rotator cuff repair are associated with increased rotator cuff revision rates. Arthroscopy. 2019;35(3):717-24.

37. Jiang X, Zhang H, Wu Q, Chen Y, Jiang T. Comparison of three common shoulder injections for rotator cuff tears: a systematic review and network meta-analysis. J Orthop Surg Res. 2023;18(1):272.

38. Hurley ET, Colasanti CA, Anil U, Luthringer TA, Alaia MJ, Campbell KA, Jazrawi LM, Strauss EJ. The effect of platelet-rich plasma leukocyte concentration on arthroscopic rotator cuff repair: a network meta-analysis of randomized controlled trials. Am J Sports Med. 2021;49(9):2528-35.

39. Tanpowpong T, Thepsoparn M, Numkarunarunrote N, Itthipanichpong T, Limskul D, Thanphraisan P. Effects of platelet-rich plasma in tear size reduction in partial-thickness tear of the supraspinatus tendon compared to corticosteroids injection. Sports Med Open. 2023;9(1):11.

40. Kim YS, Lee HJ, Kim JH, Noh DY. When should we repair partial-thickness rotator cuff tears? Outcome comparison between immediate surgical repair versus delayed repair after 6-month period of nonsurgical treatment. Am J Sports Med. 2018;46(5):1091-6.

41. Lo IK, Denkers MR, More KD, Nelson AA, Thornton GM, Boorman RS. Partial-thickness rotator cuff tears: clinical and imaging outcomes and prognostic factors of successful nonoperative treatment. Open Access J Sports Med. 2018;9:191-7.

42. Cordasco FA, Backer M, Craig EV, Klein D, Warren RF. The partial-thickness rotator cuff tear: is acromioplasty without repair sufficient? Am J Sports Med. 2002;30(2):257-60.

43. Katthagen JC, Bucci G, Moatshe G, Tahal DS, Millett PJ. Improved outcomes with arthroscopic repair of partial-thickness rotator cuff tears: a systematic review. Knee Surg Sports Traumatol Arthrosc. 2018;26(1):113-24.

44. Fukuda H, Mikasa M, Ogawa K, Yamanaka K, Hamada K. "The color test": an intraoperative staining test for joint-side rotator cuff tearing and its extension. J Shoulder Elbow Surg. 1992;1(2):86-90.

45. Snyder SJ. Shoulder Arthroscopy. Philadelphia, PA: Lippincott Williams & Wilkins; 2003.

46. Fanelli MG, Field LD. The arthroscopic "bellows" sign identifies hidden rotator cuff tears. Arthrosc Tech. 2022;11(5):e723-5.

47. Lo IKY, Gonzalez DM, Burkhart SS. The bubble sign: an arthroscopic indicator of an intratendinous rotator cuff tear. Arthroscopy. 2002;18(9):1029-33.

48. Upadhyay D, Scheidt M, Garbis N, Salazar D. Bubble sign: an arthroscopic technical trick to differentiate between partial- and full-thickness rotator cuff tears. Arthrosc Tech. 2022;11(7):e1353-7.

49. Levy BJ, McCarthy MB, Lebaschi A, Sanders MM, Cote MP, Mazzocca AD. Subacromial bursal tissue and surrounding matrix of patients undergoing rotator cuff repair contains progenitor cells. Arthroscopy. 2022;38(4):1115-23.

50. Jaeger M, Berndt T, Rühmann O, Lerch S. Patients with impingement syndrome with and without rotator cuff tears do well 20 Years after arthroscopic subacromial decompression. Arthroscopy. 2016;32(3):409-15.

51. Ranebo MC, Björnsson Hallgren HC, Norlin R, Adolfsson LE. Clinical and structural outcome 22 years after acromioplasty without tendon repair in patients with subacromial pain and cuff tears. J Shoulder Elbow Surg. 2017;26(7):1262-70.

52. Swindell HW, Kang HP, Mueller JD, Heffernan JT, Saltzman BM, Ahmad CS, Levine WN, Weber AE, Trofa DP. Rotator cuff repair with acromioplasty is associated with an increased rate of revision and subsequent procedures. Arthrosc Sports Med Rehabil. 2022;4(6):e2065-71.

53. Brockmeyer M, Haupert A, Lausch AL, Wagenpfeil G, Stroeder J, Schneider G, Kohn D, Lorbach O. Outcomes and tendon integrity after arthroscopic treatment for articular-sided partial-thickness tears of the supraspinatus tendon: results at minimum 2-year follow-up. Orthop J Sports Med. 2021;9(2):2325967120985106.

54. Porcellini G, Ziroglu N, De Santis E, Micheloni GM, Tarallo L, Giorgini A. Midterm clinical outcomes after arthroscopic rotator cuff repair in Olympic volleyball players: return to sports and return to performance. Orthop J Sports Med. 2023;11(8):23259671231186820.

55. Kim KC, Shin HD, Cha SM, Park JY. Repair integrity and functional outcome after arthroscopic conversion to a full-thickness rotator cuff tear: articular- versus bursal-side partial tears. Am J Sports Med. 2014;42(2):451-6.

56. Mihata T, McGarry MH, Ishihara Y, Bui CNH, Alavekios D, Neo M, Lee TQ. Biomechanical analysis of articular-sided partial-thickness rotator cuff tear and repair. Am J Sports Med. 2015;43(2):439-46.

57. Rossi LA, Atala N, Bertona A, Tanoira I, Bongiovanni S, Maignon G, Ranalletta M. Return to sports after in situ arthroscopic repair of partial rotator cuff tears. Arthroscopy. 2019;35(1):32-7.

58. Rossi LA, Atala NA, Bertona A, Bongiovanni S, Tanoira I, Maignon G, Ranalletta M. Long-term outcomes after in situ arthroscopic repair of partial rotator cuff tears. Arthroscopy. 2019;35(3):698-702.

59. Dey Hazra RO, Dey Hazra ME, Hanson JA, Rutledge JC, Doan KC, Horan MP, Millett PJ. Minimum 10-year outcomes after arthroscopic repair of partial-thickness supraspinatus rotator cuff tears. Am J Sports Med. 2023;51(9):2404-10.

60. Shin SJ, Kook SH, Rao N, Seo MJ. Clinical outcomes of modified Mason-Allen single-row repair for bursal-sided partial-thickness rotator cuff tears: comparison with the double-row suture-bridge technique. Am J Sports Med. 2015;43(8):1976-82.

61. Thamrongskulsiri N, Limskul D, Itthipanichpong T, Tanpowpong T, Kuptniratsaikul S. Similar outcomes between transtendon repair and tear completion repair techniques for partial articular-sided supraspinatus tendon avulsion lesions: a systematic review and meta-analysis. Knee Surg Sports Traumatol Arthrosc. 2023;31(10):4575-84.

62. Yanke A, Dandu N, Credille K, Damodar D, Wang Z, Cole BJ. Indications and technique: rotator cuff repair augmentation. J Am Acad Orthop Surg. 2023;31(24):1205-10.

63. Hurley ET, Lim Fat D, Moran CJ, Mullett H. The efficacy of platelet-rich plasma and platelet-rich fibrin in arthroscopic rotator cuff repair: a meta-analysis of randomized controlled trials. Am J Sports Med. 2019;47(3):753-61.

64. Ajrawat P, Dwyer T, Almasri M, Veillette C, Romeo A, Leroux T, Theodoropoulos J, Nauth A, Henry P, Chahal J. Bone marrow stimulation decreases retear rates after primary arthroscopic rotator cuff repair: a systematic review and meta-analysis. J Shoulder Elbow Surg. 2019;28(4):782-91.

65. Shibata T, Izaki T, Miyake S, Shibata Y, Yamamoto T. Efficacy of bone marrow stimulation for arthroscopic knotless suture bridge rotator cuff repair: a prospective randomized controlled trial. J Shoulder Elbow Surg. 2023;32(5):909-16.

66. Cole BJ, Kaiser JT, Wagner KR, Sivasundaram L, Otte RS, Tauro TM, White GM, Ralls ML, Yanke AB, Forsythe B, Romeo AA, Verma NN. Prospective randomized trial of biologic augmentation with bone marrow aspirate concentrate in patients undergoing arthroscopic rotator cuff repair. Am J Sports Med. 2023;51(5):1234-42.

67. Mazzocca AD, McCarthy MBR, Chowaniec DM, Cote MP, Arciero RA, Drissi H. Rapid isolation of human stem cells (connective tissue progenitor cells) from the proximal humerus during arthroscopic rotator cuff surgery. Am J Sports Med. 2010;38(7):1438-47.

68. Muench LN, Kia C, Berthold DP, Uyeki C, Otto A, Cote MP, McCarthy MB, Beitzel K, Arciero RA, Mazzocca AD. Preliminary clinical outcomes following biologic augmentation of arthroscopic rotator cuff repair using subacromial bursa, concentrated bone marrow aspirate, and platelet-rich plasma. Arthrosc Sports Med Rehabil. 2020;2(6):e803-13.

69. Güler Y, Keskin A, Yerli M, Imren Y, Karslıoglu B, Dedeoglu SS. Arthroscopic biological augmentation with subacromial bursa for bursal-sided partial-thickness rotator cuff tears. Orthop J Sports Med. 2023;11(8):23259671231190335.

70. Zhang Y, Zhou M, Hou J, Zhang J, Zhou C, Long Y, Ke M, Tang Y, Yang R. Arthroscopic autologous coracoacromial ligament augment technique for particle thickness of rotator cuff with at least two years follow-up. Orthop Surg. 2023;15(8):2157-66.

71. Xu J, Li Y, Ye Z, Wu C, Han K, Zheng T, Jiang J, Yan X, Su W, Zhao J. Biceps augmentation outperforms tear completion repair or in situ repair for bursal-sided partial-thickness rotator cuff tears in a rabbit model. Am J Sports Med. 2022;50(1):195-207.

72. Tokish JM, Shaha JS, Denard PJ, Mercuri JJ, Colbath G. Compressed biceps autograft augmentation of arthroscopic rotator cuff repair. Arthrosc Tech. 2022;11(11):e2113-8.

73. Colbath G, Murray A, Siatkowski S, Pate T, Krussig M, Pill S, Hawkins R, Tokish J, Mercuri J. Autograft long head biceps tendon can Be used as a scaffold for biologically augmenting rotator cuff repairs. Arthroscopy. 2022;38(1):38-48.

74. Ruiz Ibán MÁ, García Navlet M, Moros Marco S, Diaz Heredia J, Hernando Sánchez A, Ruiz Díaz R, Vaquero Comino C, Rosas Ojeda ML, Del Monte Bello G, Ávila Lafuente JL. Augmentation of a transosseous-equivalent repair in posterosuperior nonacute rotator cuff tears with a bioinductive collagen implant decreases the retear rate at one year: a randomized controlled trial. Arthroscopy. 2024;40(6):1760-73.

75. Hohn EA, Gillette BP, Burns JP. Outcomes of arthroscopic revision rotator cuff repair with acellular human dermal matrix allograft augmentation. J Shoulder Elbow Surg. 2018;27(5):816-23.

76. Namdari S, Nicholson T, Brolin TJ, Lu J, Abboud JA, Lazarus MD. Healing and functional results of dermal allograft augmentation of complex and revision rotator cuff repairs. Am J Sports Med. 2021;49(8):2042-7.

77. Yeazell S, Lutz A, Bohon H, Shanley E, Thigpen CA, Kissenberth MJ, Pill SG. Increased stiffness and reoperation rate in partial rotator cuff repairs treated with a bovine patch: a propensity-matched trial. J Shoulder Elbow Surg. 2022;31(6S):S131-5.

78. Malcarney HL, Bonar F, Murrell GAC. Early inflammatory reaction after rotator cuff repair with a porcine small intestine submucosal implant: a report of 4 cases. Am J Sports Med. 2005;33(6):907-11.

79. Cai YZ, Zhang C, Jin RL, Shen T, Gu PC, Lin XJ, Chen JD. Arthroscopic rotator cuff repair with graft augmentation of 3-dimensional biological collagen for moderate to large tears: a randomized controlled study. Am J Sports Med. 2018;46(6):1424-31.

80. Cheesman QT, Szukics PF, Stark M, Kramer SC, McMillan S. Arthroscopic rotator cuff repair technique using a bio-composite scaffold for tissue augmentation. Arthrosc Tech. 2022;11(4):e517-22.

81. Kim HT, Lee SH, Lee JK, Chung SW. Influence of vitamin D deficiency on the expression of genes and proteins in patients with medium rotator cuff tears. Am J Sports Med. 2023;51(10):2650-8.

82. Harada GK, Arshi A, Fretes N, Formanek B, Gamradt S, McAllister DR, Petrigliano FA. Preoperative vitamin D deficiency is associated with higher postoperative complications in arthroscopic rotator cuff repair. J Am Acad Orthop Surg Glob Res Rev. 2019;3(7):e075.

83. Patel D, Roy G, Endres N, Ziino C. Preoperative vitamin D supplementation is a cost-effective intervention in arthroscopic rotator cuff repair. J Shoulder Elbow Surg. 2023;32(12):2473-82.

84. Schanda JE, Keibl C, Heimel P, Monforte X, Tangl S, Feichtinger X, Teuschl AH, Baierl A, Muschitz C, Redl H, Fialka C, Mittermayr R. Zoledronic acid substantially improves bone microarchitecture and biomechanical properties after rotator cuff repair in a rodent chronic defect model. Am J Sports Med. 2020;48(9):2151-60.

85. Lei M, Zhu Z, Hu X, Wu D, Huang W, Zhang Y, Chen H. Postoperative antiosteoporotic treatment with zoledronic acid improves rotator cuff healing but does not improve outcomes in female patients with postmenopausal osteoporosis: a prospective, single-blinded, randomized study. Arthroscopy. 2024;40(3):714-22.

86. Viswanathan M, Reddy S, Berkman N, Cullen K, Middleton JC, Nicholson WK, Kahwati LC. Screening to Prevent Osteoporotic Fractures: An Evidence Review for the U.S. Preventive Services Task Force. Rockville, MD: Agency for Healthcare Research and Quality (US); 2018. Accessed May 14, 2024. http://www.ncbi.nlm.nih.gov/books/NBK532075/.

87. Schwitzguebel AJ, Kolo FC, Tirefort J, Kourhani A, Nowak A, Gremeaux V, Saffarini M, Lädermann A. Efficacy of platelet-rich plasma for the treatment of interstitial supraspinatus tears: a double-blinded, randomized controlled trial. Am J Sports Med. 2019;47(8):1885-92.

88. Cai YU, Sun Z, Liao B, Song Z, Xiao T, Zhu P. Sodium hyaluronate and platelet-rich plasma for partial-thickness rotator cuff tears. Med Sci Sports Exerc. 2019;51(2):227-33.

89. Jo CH, Lee SY, Yoon KS, Oh S, Shin S. Allogeneic platelet-rich plasma versus corticosteroid injection for the treatment of rotator cuff disease: a randomized controlled trial. J Bone Joint Surg Am. 2020;102(24):2129-37.

90. Thepsoparn M, Thanphraisan P, Tanpowpong T, Itthipanichpong T. Comparison of a platelet-rich plasma injection and a conventional steroid injection for pain relief and functional improvement of partial supraspinatus tears. Orthop J Sports Med. 2021;9(9):23259671211024937.

91. Kwong CA, Woodmass JM, Gusnowski EM, Bois AJ, Leblanc J, More KD, Lo IKY. Platelet-rich plasma in patients with partial-thickness rotator cuff tears or tendinopathy leads to significantly improved short-term pain relief and function compared with corticosteroid injection: a double-blind randomized controlled trial. Arthroscopy. 2021;37(2):510-7.

92. Rossi LA, Piuzzi N, Tanoira I, Brandariz R, Huespe I, Ranalletta M. subacromial platelet-rich plasma injections produce significantly worse improvement in functional outcomes in patients with partial supraspinatus tears than in patients with isolated tendinopathy. Arthroscopy. 2023;39(9):2000-8.

93. Kim SJ, Kim EK, Kim SJ, Song DH. Effects of bone marrow aspirate concentrate and platelet-rich plasma on patients with partial tear of the rotator cuff tendon. J Orthop Surg Res. 2018;13(1):1.

94. Centeno C, Fausel Z, Stemper I, Azuike U, Dodson E. A randomized controlled trial of the treatment of rotator cuff tears with bone marrow concentrate and platelet products compared to exercise therapy: a midterm analysis. Stem Cells Int. 2020;2020:5962354.

95. Jo CH, Chai JW, Jeong EC, Oh S, Yoon KS. Intratendinous injection of mesenchymal stem cells for the treatment of rotator cuff disease: a 2-year follow-up study. Arthroscopy. 2020;36(4):971-80.

96. Hurd JL, Facile TR, Weiss J, Hayes M, Hayes M, Furia JP, Maffulli N, Winnier GE, Alt C, Schmitz C, Alt EU, Lundeen M. Safety and efficacy of treating symptomatic, partial-thickness rotator cuff tears with fresh, uncultured, unmodified, autologous adipose-derived regenerative cells (UA-ADRCs) isolated at the point of care: a prospective, randomized, controlled first-in-human pilot study. J Orthop Surg Res. 2020;15(1):122.

97. Lundeen M, Hurd JL, Hayes M, Hayes M, Facile TR, Furia JP, Maffulli N, Alt C, Alt EU, Schmitz C, Pearce DA. Management of partial-thickness rotator cuff tears with autologous adipose-derived regenerative cells is safe and more effective than injection of corticosteroid. Sci Rep. 2023;13(1):19348.

98. Kim YS, Lee HJ, Bae SH, Jin H, Song HS. Outcome comparison between in situ repair versus tear completion repair for partial thickness rotator cuff tears. Arthroscopy. 2015;31(11):2191-8.

99. Liu CT, Ge HA, Hu R, Huang JB, Cheng YC, Wang M, Wu P, Cheng B. Arthroscopic knotless single-row repair preserving full footprint versus tear completion repair for partial articular-sided rotator cuff tear. J Orthop Surg (Hong Kong). 2018;26(2):2309499018770897.

100. Castricini R, La Camera F, De Gori M, Orlando N, De Benedetto M, Galasso O, Gasparini G. Functional outcomes and repair integrity after arthroscopic repair of partial articular supraspinatus tendon avulsion. Arch Orthop Trauma Surg. 2019;139(3):369-75.

101. Kanatlı U, Ayanoğlu T, Ataoğlu MB, Özer M, Çetinkaya M, Eren TK. Midterm outcomes after arthroscopic repair of partial rotator cuff tears: A retrospective study of correlation between partial tear types and surgical technique. Acta Orthop Traumatol Turc. 2020;54(2):196-201.

102. Yang Y, Hu D, Chen S, Guan S, Shang X. Transtendon technique versus repair after completion of the tear for articular-sided partial rotator cuff tear: a meta-analysis of comparative studies. J Orthop Surg Res. 2023;18(1):378.

103. Yuan T, Yang S, Qian H, Lai C, Jiang H, Meng J, Zhao J, Bao N. All-inside technique versus in situ transtendon repair for Ellman III partial articular supraspinatus tendon avulsion. J Shoulder Elbow Surg. 2023;32(1):24-32.

104. Zhuo H, Pan L, Li J. Functional and MRI outcomes after in situ repair versus tear completion before repair of bursal-side partial-thickness rotator cuff tears. Orthop Surg. 2023;15(8):2082-90.

105. Han C, Na Y, Zhu Y, Kong L, Eerdun T, Yang X, Ren Y. Is platelet-rich plasma an ideal biomaterial for arthroscopic rotator cuff repair? A systematic review and meta-analysis of randomized controlled trials. J Orthop Surg Res. 2019;14:183.

106. Ryan J, Imbergamo C, Sudah S, Kirchner G, Greenberg P, Monica J, Gatt C. Platelet-rich product supplementation in rotator cuff repair reduces retear rates and improves clinical outcomes: a meta-analysis of randomized controlled trials. Arthroscopy. 2021;37(8):2608-24.

107. Zhao D, Han YH, Pan JK, Yang WY, Zeng LF, Liang GH, Liu J. The clinical efficacy of leukocyte-poor platelet-rich plasma in arthroscopic rotator cuff repair: a meta-analysis of randomized controlled trials. J Shoulder Elbow Surg. 2021;30(4):918-28.

108. Li Y, Li T, Li J, Tang X, Li R, Xiong Y. Platelet-rich plasma has better results for retear rate, pain, and outcome than platelet-rich fibrin after rotator cuff repair: a systematic review and meta-analysis of randomized controlled trials. Arthroscopy. 2022;38(2):539-50.

109. Jeong JY, Chung PK, Yoo JC. Effect of sodium hyaluronate/carboxymethyl cellulose (Guardix-sol) on retear rate and postoperative stiffness in arthroscopic rotator cuff repair patients: A prospective cohort study. J Orthop Surg (Hong Kong). 2017;25(2):2309499017718908.

110. Kim YS, Sung CH, Chung SH, Kwak SJ, Koh YG. Does an injection of adipose-derived mesenchymal stem cells loaded in fibrin glue influence rotator cuff repair outcomes? a clinical and magnetic resonance imaging study. Am J Sports Med. 2017;45(9):2010-8.

111. Randelli PS, Cucchi D, Fossati C, Boerci L, Nocerino E, Ambrogi F, Menon A. Arthroscopic rotator cuff repair augmentation with autologous microfragmented lipoaspirate tissue is safe and effectively improves short-term clinical and functional results: a prospective randomized controlled trial with 24-month follow-up. Am J Sports Med. 2022;50(5):1344-57.

112. McIntyre LF, Bishai SK, Brown PB, Bushnell BD, Trenhaile SW. Patient-reported outcomes after use of a bioabsorbable collagen implant to treat partial and full-thickness rotator cuff tears. Arthroscopy. 2019;35(8):2262-71.

113. Dai A, Campbell A, Bloom D, Baron S, Begly J, Meislin R. Collagen-based bioinductive implant for treatment of partial thickness rotator cuff tears. Bull Hosp Jt Dis (2013). 2020;78(3):195-201.

114. Schlegel TF, Abrams JS, Angelo RL, Getelman MH, Ho CP, Bushnell BD. Isolated bioinductive repair of partial-thickness rotator cuff tears using a resorbable bovine collagen implant: two-year radiologic and clinical outcomes from a prospective multicenter study. J Shoulder Elbow Surg. 2021;30(8):1938-48.

115. Bushnell BD, Bishai SK, Krupp RJ, McMillan S, Schofield BA, Trenhaile SW, McIntyre LF. Treatment of partial-thickness rotator cuff tears with a resorbable bioinductive bovine collagen implant: 1-year results from a prospective multicenter registry. Orthop J Sports Med. 2021;9(8):23259671211027850.