

Rotator cuff tears: An evidence based approach

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Abstract

Lesions of the rotator cuff (RC) are a common occurrence affecting millions of people across all parts of the globe. RC tears are also rampantly prevalent with an age-dependent increase in numbers. Other associated factors include a history of trauma, limb dominance, contralateral shoulder, smoking-status, hypercholesterolemia, posture and occupational dispositions. The challenge lies in early diagnosis since a high proportion of patients are asymptomatic. Pain and decreasing shoulder power and function should alert the heedful practitioner in recognizing promptly the onset or aggravation of existing RC tears. Partial-thickness tears (PTT) can be bursal-sided or articular-sided tears. Over the course of time, PTT enlarge and propagate into full-thickness tears (FTT) and develop distinct chronic pathological changes due to muscle retraction, fatty infiltration and muscle atrophy. These lead to a reduction in tendon elasticity and viability. Eventually, the glenohumeral joint experiences a series of degenerative alterations - cuff tear arthropathy. To avert this, a vigilant clinician must utilize and corroborate clinical skill and radiological findings to identify tear progression. Modern radio-diagnostic means of ultrasonography and magnetic resonance imaging provide excellent visualization of structural details and are crucial in determining further course of action for these patients. Physical therapy along with activity modifications, anti-inflammatory and analgesic medications form the pillars of nonoperative treatment. Elderly patients with minimal functional demands can be managed conservatively and reassessed at frequent intervals. Regular monitoring helps in isolating patients who require surgical interventions. Early surgery should be considered in younger, active and symptomatic, healthy patients. In addition to being cost-effective, this helps in providing a functional shoulder with

a stable cuff. An easily reproducible technique of maximal strength and sturdiness should be chosen among the armamentarium of the shoulder surgeon. Grade 1 PTTs do well with debridement while more severe lesions mandate repair either by trans-tendon technique or repair following conversion into FTT. Early repair of repairable FTT can avoid appearance and progression of disability and weakness. The choice of surgery varies from surgeon-to-surgeon with arthroscopy taking the lead in the current scenario. The double-row repairs have an edge over the single-row technique in some patients especially those with massive tears. Stronger, cost-effective and improved functional scores can be obtained by the former. Both early and delayed postoperative rehabilitation programmes have led to comparable outcomes. Guarded results may be anticipated in patients in extremes of age, presence of comorbidities and severe tear patterns. Overall, satisfactory results are obtained with timely diagnosis and execution of the appropriate treatment modality.

Key words: Rotator cuff tears; Partial thickness tears; Full thickness tear; Natural history; Ultrasonography; Magnetic resonance imaging; Single row repair; Double row repair; Healing

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Core tip: Close attention to history and examination enables early diagnosis in the frequently asymptomatic rotator cuff tear. Ultrasonography and magnetic resonance imaging serve as excellent visualization tools. While conservative measures are successful in elderly patients with minimal lesions and demands, regular monitoring helps in isolating the surgical candidate. Early surgery should be considered in younger, healthier, active and symptomatic patients. Lower grades of tears do well with debridement alone while more severe lesions warrant a repair. Arthroscopic double-row repairs are superior in patients with massive tears. Satisfactory results are obtained with timely diagnosis and execution of the appropriate treatment modality.

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INTRODUCTION

"Its been an ache and a joy both to look over this big shoulder of mine at all my yesterdays" - Ethel Waters. Tears of the rotator cuff (RC) have been inherited by man from his ancestors with an association leading to the great apes^[1,2]. With the advent of newer techniques, good to excellent results can be expected in the appropriately selected and compliant patient^[3]. The aim of this article is to provide a comprehensive review of

evidence-based concepts and present understanding of the epidemiology, etiopathogenesis, natural history, clinical evaluation, imaging, management and healing of RC tears.

PREVALENCE

Abundant data from across the world has been published on the prevalence of RC tears. Yamaguchi *et al*^[4], from Missouri, United States, evaluated 588 patients with unilateral (U/L) shoulder complaints. Their analysis revealed 199 (33.8%) U/L and 177 (30.1%) bilateral (B/L) RC tears with average ages of 58.7 and 67.8 years respectively. The authors found high correlation between advancing age and RC tears^[4]. In 2009, a study from the same institution on ultrasonographic (USG) screening of both shoulders in 237 asymptomatic individuals revealed a 17.3% prevalence of RC tear in at least one shoulder. Age-wise prevalence observed was 20% in 60-69 years old and 40.7% in subjects 70 years of age or older^[5]. In a larger cohort of 683 Japanese villagers with a mean age of 57.9 years, Yamamoto *et al*^[6] observed RC tears in 36% symptomatic against 16.9% in asymptomatic subjects with an overall prevalence of 20.7%. In a recent systematic review of 30 studies, Teunis *et al*^[7] analysed 6112 shoulders with 1452 cuff abnormalities. Overall prevalence of RC abnormalities ranged from 9.7% in patients younger than or 20 years and increased to 62% in patients aged 80 years and older ($P < 0.001$) regardless of symptoms, among the general population and in patients with a dislocated shoulder.

A German prospective study on 411 asymptomatic shoulders by Tempelhof *et al*^[8] revealed 23% overall prevalence of RC tears with high occurrence in patients over the age 70 and 80 years of 31% and 51% respectively. Further, Fehringer *et al*^[9] observed a 22% prevalence of full-thickness tears (FTT) of the RC in patients aged 65 and above. Other European studies have shown lower figures. In a study from Austria on 212 asymptomatic shoulders, Schibany *et al*^[10] reported a 6% prevalence of FTT. Likewise, Moosmayer *et al*^[11] in a Norwegian study on 420 asymptomatic volunteers aged 50-79, revealed FTT in 32 subjects (7.6%).

Cadaveric studies on the RC tears have also revealed varying results. Neer's study on 500 cadavers more than 3 decades ago observed a less than 5% occurrence of FTT^[12]. In 456 cadaver shoulders (mean age = 64.7) years, Lehman *et al*^[13] reported an higher, 17% prevalence of FTT. Cadavers below and above 60 years of age had tear incidences of 6% and 30% respectively^[13]. Still higher rates were observed by Reilly *et al*^[14] in a review comparing cadaveric against radiological studies. Overall prevalence among 30 cadaveric studies was 30.3% while 11 ultrasound studies reported a prevalence of 38.9% in asymptomatic individuals which rose to 41.4% in symptomatic patients. Further, 14 magnetic resonance imaging (MRI) based

studies reported 26.2% prevalence in the asymptomatic population vs 49.38% in symptomatic patients^[14]. The disparity between human and cadaveric studies can be attributed to differences in subject population and unknown historical and clinical backgrounds in cadavers.

Despite varied regional distribution, RC tears are prevalent in up to 39% of asymptomatic individuals. An age-related increase in incidence leaves one with the thought of whether the tears are a part of the normal aging process. Their overall prevalence in symptomatic individuals is up to 64%. Presence of pain and decreasing shoulder strength and scores, which increases with age, heralds the onset or increase in size of existing RC tears. The opposite shoulder must be evaluated in U/L complaints to rule out B/L RC tears.

PREDISPOSING FACTORS

Age

Advancing age has been consistently held accountable as one of the major risk factor for the development of cuff tears in various studies. Gumina *et al*^[15] on 586 patients with a history of arthroscopic tear repair reported a mean age of 59 years. Patients older than 60 were twice as likely to develop tear which were larger and more massive^[15]. The prevalence in human and cadaveric studies in patients 60 years and older ranges from 20% to 30% and touches 62% in individuals aged 80 and more^[4,5,7-9,11,13]. With a 10-year increase in age, the odds of an RC tear increase 2.69 fold ($P = 0.005$)^[8].

Sex

A study by Abate *et al*^[16] on menopausal women revealed increased prevalence of asymptomatic FTT in the postmenopausal period. Both sexes have otherwise been quoted as being equally predisposed to the development of RC tears^[17,18].

Hand dominance

While some evidence suggests greater risk of the dominant hand for developing RC tears, others find this predilection not significant^[6,18]. Dominant shoulders in veteran tennis players were more frequently torn suggesting an association of high energy activity with RC tears^[19].

Contralateral shoulder

In patients operated for ipsilateral partial-thickness tears (PTT) or FTT, opposite shoulders are at increased risks of developing the same^[20]. Ro *et al*^[21] reported a higher prevalence of RC tears in contralateral (C/L) asymptomatic shoulders in U/L symptomatic RC tears, medium-sized or large operated RC tears and in patients with symptomatic RC tears of the non-dominant arm. B/L tears are common in U/L symptomatic tears with 35.5% prevalence FTT on the opposite side as observed by Yamaguchi *et al*^[4]. The likelihood of a bilateral tear after 60 years of age is as high as 50%^[4].

Smoking

A strong dose and time-dependent association has been established between smoking and the development of RC tears. Baumgarten *et al*^[22], among 586 consecutive patients with unilateral shoulder pain, found 375 patients with RC tears. A smoking history was elicited in 61.9% patients with a mean 23.4 years of smoking 1.25 packs per day and 30.1 mean pack-years. In a systematic review by Bishop *et al*^[23], increased rates and sizes of RC degeneration and symptomatic RC tears were seen in smokers which could consequently increase the number of surgical procedures in these patients. In a study on 408 patients, Carbone *et al*^[24] found higher frequencies of smokers with at least a type II tear (34.8%) differing significantly from the type I patients (23.2%) and concluded that smoking negatively affects vascularity of tendons.

Family history

Increased risk in relatives of individuals with RC disease has been identified. In a study by Tashjian *et al*^[25], patients diagnosed before 40 years showed significant relatedness for individuals with RC disease in close and distant relationships (up to 3rd cousins) ($P = 0.001$).

Posture

In a recent cross-sectional study by Yamamoto *et al*^[26], RC tears were observed in 65.8% patients with kyphotic-lordotic postures, 54.3% with flat-back postures and 48.9% with sway-back postures while only 2.9% patients with ideal alignment had RC tears. The authors found poor posture as an independent predictor of symptomatic and asymptomatic RC tears^[26]. In an Italian study, Gumina *et al*^[27] compared the radiologically calculated subacromial space (SAS) width in 47 patients with thoracic hyperkyphosis with normal controls. They found reduced acromio-humeral space in hyperkyphotic patients, females and patients older than 60 years. The authors attributed this decrease to less posterior tilting and dyskinesis of the scapula^[27].

Others

They are history of trauma, hypercholesterolemia and occupational demands of heavy labour^[6].

ETIOPATHOGENESIS

Bursal and articular sided tears

The classical description by Ellman classifies RC tears on the basis of location into articular-sided tears (AST) and bursal-sided tears (BST) which are further staged according to their depths (Figure 1)^[28]. These two varieties have differing properties and vasculature.

The precarious vascularity of the articular side has been demonstrated by Lohr and Uthoff^[29] who found the predominance of a zone of hypovascularity on the on the articular side. While ASTs result more commonly from intrinsic factors alone, intrinsic and extrinsic factors

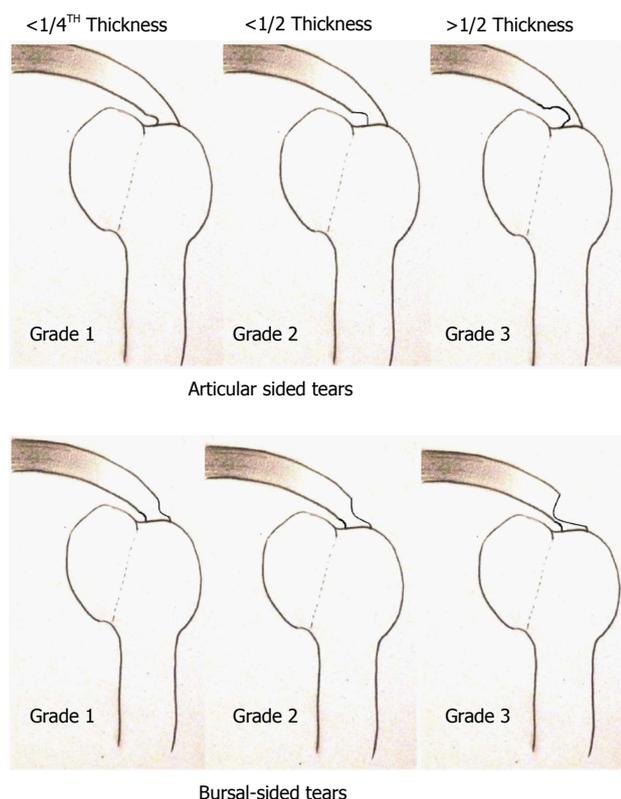


Figure 1 Types of partial thickness tears.

and greater wear and impingement more often result in BST. Ozaki *et al.*^[30] in a cadaveric study on 200 shoulders confirmed the association of BST with attritional lesions on the coracoacromial ligament (CAL) and anterior third of the undersurface of the acromion while ASTs had a normal acromion. Although an acromial lesion was always associated with an RC tear, the reverse was not true^[30].

Extrinsic mechanisms

Tears of the RC have been theorized by Neer *et al.*^[31] to occur as a sequel of shoulder impingement due to repetitive translation of the cuff tendons under the acromion. Anatomical factors implicated in impingement and consequent tears of the RC include, among others, abnormalities in the coracoacromial arch. The acromion has been classified as flat, curved and hooked by Bigliani *et al.*^[32] (Figure 2).

Extrinsic sources arise from developmental aberrations in the form of os acromiale, hooked and keeled acromion, enthesophytes at acromial insertion of CAL and acromion-uncovered portion of humeral head (HH) leading to SSP impingement between the two^[33]. Lower successful rates of nonoperative methods have been demonstrated in curved (73%) and hooked (58.3%) vs flat types (89%) by Wang *et al.*^[34]. Neer^[35] in 1972 on 50 shoulders managed by anterior acromioplasty for impingement over 5 years demonstrated good results in 39. He concluded that acromioplasty provides good pain relief in mechanical impingement, exposure for

SSP repair and prevents further impingement and wear. Moor *et al.*^[36], on the other hand, found no association between the acromion morphology and slope and RC tears. They avowed higher acromial indices, smaller lateral acromial angles and larger critical shoulder angles in degenerative RC tears. Anterior and lateral acromial bony spurs have been associated with FTT in symptomatic patients^[37]. Other structures implicated in RC tears include spurs in CAL, altered coracoid morphology, increased pillar angulation, reduced inter-pillar distance or pillar length resulting in subcoracoid impingement. The subdeltoid, subcoracoid and subacromial bursae (SAB) are recognized causes of adhesions, bursitis and impingement^[33]. The SAB may however, prove beneficial in tendon healing^[38].

Intrinsic mechanisms

Besides extrinsic factors, the degeneration-microtrauma theory links advancing age and chronic microtrauma with PTT. Involvement of deep fibres leads to retraction, increased tension on intact fibres and conversion to FTT. Inflammatory changes and oxidative stresses causing tenocyte apoptosis along tissue remodelling are responsible for these tears^[39]. Hypovascularity predisposes to development of RC tears in an age-dependent manner as shown by Rudzki *et al.*^[40] in 2008. A critical hypovascular zone exists 10-15 mm proximal to the RC insertion on the HH. In a study on 18 human specimens, the presence this zone close to SSP insertion was confirmed by selective vascular injection with a silicon-rubber compound. Uniformly sparse vascular distribution at the articular side against a well-vascularized bursal side could explain development of AST^[29]. A few, however, have refuted this theory^[41,42]. Laser Doppler flowmetry analysis by Levy *et al.*^[41] reported areas of increased flux at the RC tear edges suggesting areas of hypervascularity.

Internal impingement

Walch *et al.*^[42] in young, athletic individuals described impingement occurring between the deep side of SSP and posterosuperior edge of glenoid. Arthroscopic visualization confirmed AST involving posterior and anterior regions of the SSP and infraspinatus (ISP) respectively in the abducted and externally rotated shoulder.

Molecular basis

In a recent study, Choo *et al.*^[43] found patients with bursitis and tendinopathy expressing pro-myogenic genes while those with FTT expressed genes linked with fatty atrophy and fibrosis. Massive tears had down-regulation of most genes except inhibition of myogenesis which explains the difficulty in treating them. The authors also suggested earlier surgical intervention for a more favourable response.

To conclude, RC tears result from multiple etiological factors ranging from tendon injury due to narrowed SAS and anatomical aberrations, degeneration from

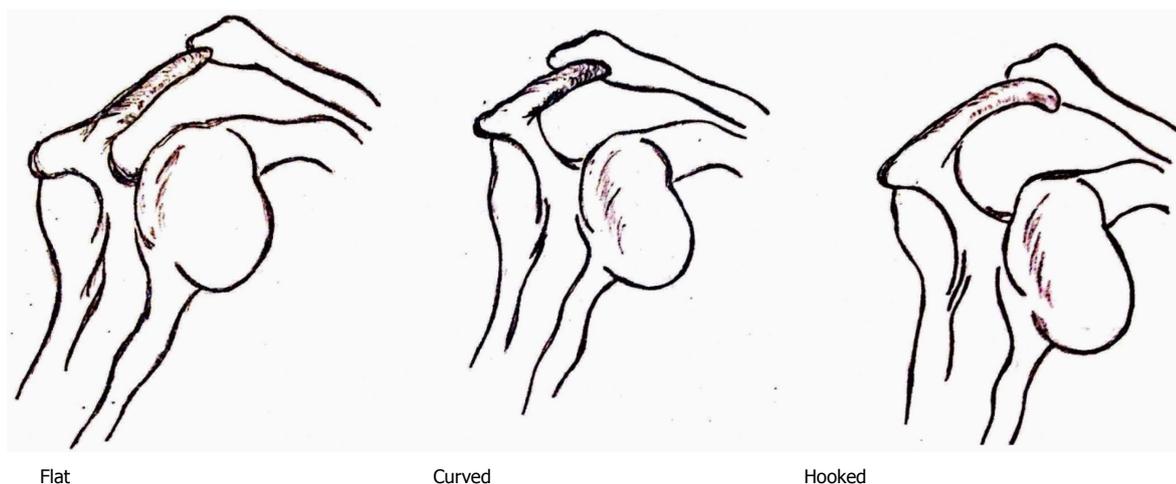


Figure 2 Types of acromion.

within the tendon and predilections resulting from non-physiological positioning in extremes of abduction and external rotation (ER). A relation of the tear process with regulation of gene expression may have a negative effect in the outcome of repairs.

NATURAL HISTORY

Symptom progression

Tears have been described as the ultimate consequence of impingement occurring in the final stage III of RC disease^[13].

Asymptomatic and symptomatic FTT

Studies in the past have revealed a substantial symptomatic conversion of asymptomatic FTT. Moosmayer *et al.*^[44], in a three-year follow-up of 50 patients found 18 symptomatic at the end of 3 years with significantly larger mean tear sizes (10.6 mm vs 3.3 mm, $P = 0.02$), faster muscular atrophy (MA), fatty degeneration (FD) and development of a pathological long head of biceps (LHB). Yamaguchi *et al.*^[45], while evaluating asymptomatic C/L tears in patients with U/L symptoms over 5 years, found greater symptoms and tear progression in 23 (51%) of 45 previously asymptomatic patients over a mean 2.8 years. In 2010, Mall *et al.*^[46] compared 44 newly symptomatic subjects over a two-year period, with 55 subjects who remained asymptomatic. The development of pain and increase in size of FTT by more than 5 mm occurred in 18% of the FTT. A 40% conversion of PTT to FTT was associated with significant reductions in the American Shoulder and Elbow Surgeons (ASES) scores. Newly symptomatic patients had significantly larger tears at initial evaluation. The development of symptoms in asymptomatic tears should, therefore, alert the surgeon towards suspecting tear enlargement^[46].

The natural history of symptomatic RC tears often puzzles the reader with doubts regarding worsening and improvement of symptoms, risk of tear progression, indications and benefits of nonoperative and surgical intervention and the presence of FD and MA. Improved

pain relief and arm function was seen in 19 of 33 symptomatic FTT at 3.8 years of follow-up by Hawkins *et al.*^[47] in 1995. Goldberg *et al.*^[48] in a 2.5-year follow-up of 46 nonoperatively managed symptomatic FTT, found functional improvement in 59% patients. Fucentese *et al.*^[49] in 24 nonoperatively managed FTT found no increase in tear size and FD over a mean 3.5 years. Tear progression, reported in 25% patients wasn't related to tear reparability. A sample containing small (mean 1.6 cm), isolated tears in patients aged around 54 years could adversely affect generalization of these results^[49]. MRI monitored progression in 33 nonoperatively treated FTT by Maman *et al.*^[50] in 2009 demonstrated increased sizes in 52% patients. Older patients (> 60 years) with longer symptom duration (> 18 mo) and initial fatty infiltration were likely to progress (FI). Safran *et al.*^[51] in 2011, prospectively evaluated 61 nonoperatively managed FTT with a minimum size of 5 mm in patients younger than 60 years of age. At follow-up (mean 29 mo), 30 (49%) of the 61 tears were found to be larger with significant association with pain ($P = 0.002$).

Progression rates of symptomatic PTT to FTT have ranged from 10% to 50%^[46,50]. The presence of pain has shown to be significantly indicative of an increase in tear size and should be, therefore, closely watched.

Chronic changes

Tissue quality plays an important role in RC healing^[52]. Cuff pathology has effects on both muscles and tendons. Muscle retraction from FTT can alter angulations between the muscle fibres and allow adhesions and eventual FI. The twofold effects of FI produces MA and higher failure rates of surgical procedures^[53,54].

The term fatty infiltration signifies infiltration of adipose cells^[55,56]. Melis *et al.*^[57] in 1688 shoulders found statistical correlation ($P < 0.0005$) between FI, type of tendon lesion and patient age for SSP, ISP and subscapularis (SS). Severe FI was observed in extensive lesions, longer duration following rupture and increased patient age. A study involving 251 FTT revealed eighty-seven (34.7%) tears with FI having significantly greater

dimensions and shorter distances posterior from the biceps than those without FI ($P < 0.0001$). The latter was the most important predictor for SSP FI. Tear width and length were found to be the most important predictors for ISP FI^[58]. ISP FI has shown poorer results following repairs attributed to traction injuries of suprascapular nerve, disturbance to the anterior-posterior glenohumeral (GH) force couple and under-diagnosis^[59].

As a part of the RC pathology, muscle atrophy has been documented by various authors. Swan *et al.*^[60] observed increases in muscle mass by 30%, fibre length by 7%, and physiological cross-sectional area by 27% in normal growing rats. The sarcomere length, however, were nearly constant. A comparative 53% SSP and 45% ISP rat RC mass reduction 30 d after tear was reported by Gumucio *et al.*^[61]. Barton *et al.*^[62] demonstrated rapid yet reversible loss of muscle mass, increase in fast muscle fibres, and fibrotic content of the muscle bed and tendon adhesions following RC tears in rats. Adhesion-induced reversal of changes may however, occur on return of load to the muscle. Ditsios *et al.*^[63] observed 30% and 35% reduction in SSP and ISP forces respectively in massive tears vs normal rat shoulders. FI and MA were more evident near the tendon on the dorsal aspect. Recently, Mendias *et al.*^[64] in 13 human shoulders elicited reductions in muscle fibre force production correlating with ASES scores and tear sizes. Disordered sarcomeres with lipid-laden macrophages in the extracellular matrix were seen surrounding SSP fibres. Reports exist on compensatory hypertrophy with MA. Kikukawa *et al.*^[65] in 2014, in a retrospective review of 279 subjects, confirmed hypertrophic changes in teres minors of patients with RC tear involving ISP. Mechanical unloading and denervation have been shown to result in FI and MA. These two independent predictors (part of the same pathological process) along with increased connective tissue content and fibrosis eventually result in decreased elasticity, viability and healing of the RC^[59]. These unique, specific changes differ from denervation-induced changes after suprascapular nerve entrapment with respect to muscle border, perineural fat and overall FI distribution^[66].

Tear-induced changes in GH kinematics have been described by Keener *et al.*^[67]. HH migration in 98 asymptomatic and 62 symptomatic RC tears showed significant correlation between PHM and RC tear size ($\geq 175 \text{ mm}^2$), tear extension into ISP and presence of pain. The net result, cuff-tear arthropathy occurs more commonly than realized^[68]. Neer *et al.*^[69] ascribed this phenomenon to inactivity, disuse, synovial fluid leakage and HH migration. Next, cartilage atrophy, subchondral bone osteoporosis and impingement leads to acromial and acromioclavicular (AC) joint erosion. The collapsed HH finally erodes into the scapula from glenoid to as far as the coracoid resulting in a condition extremely difficult to manage^[69].

Muscle retraction leads to tear-size, site, duration

and age-dependent FI and reduction in muscle mass and force. Incongruent GH surfaces result in a challenging cuff-deprived joint. Surgical decision-making solely based on natural history seems inadequate and inappropriate due to conflicting results with nonoperative treatment. Further studies are required to establish guidelines assisting surgeons with the decision making process. Early surgical intervention in young, active adults with RC tears can avert advanced changes and GH arthropathy, both of which have poor outcomes.

CLINICAL EVALUATION

Progressive shoulder pain typically occurs around the anterolateral shoulder margin, lateral surface of the arm down to the elbow^[70]. Night pain can occur in 83% patients while 41% may experience muscle weakness^[71]. Local examination reveals disuse-related SSP and ISP MA. Among various tests, the empty can test is most sensitive (68.4%), drop arm and lift-off tests most specific (100%) and Neer test most accurate (75%) for RC tears overall^[71].

For the SSP and ISP, the Jobe sign and the full can test have comparable accuracies^[72]. High sensitivities (83% and 97%) and low specificities (23% and 5%) are reported with Hawkins sign and the painful arc test. Higher specificities (91% and 86%) have been observed with the external rotation lag sign (ERLS) and the drop-arm test (DAT) in diagnosing FTT. The sensitivity of lag tests reduces after subacromial lidocaine injection, while specificities of the Jobe, ERLS and DAT have been seen to improve^[73]. A positive lift-off test is highly specific for diagnosing FTT and severe FI of SS^[74]. No test in isolation however, is adequate for diagnosing an RC tear and a combination of tests improves the diagnostic yield^[75].

IMAGING

Once clinically suspected, the RC tear requires radiological establishment of diagnosis. Ultrasonography (USG) is invaluable providing excellent tendon visualization. In a meta-analysis of 6066 shoulders, USG showed good sensitivity (84%) and specificity (89%) for the assessment of PTT and FTT (sensitivity 0.96; specificity 0.93)^[76]. Orthopaedician-performed USG displayed better accuracy in large and massive tears against small tears (96.5% vs 91.6%)^[77]. In a study by Iannotti *et al.*^[78] on 99 shoulders with RC disease, comparable sensitivities and specificities of MRI and USG were reported. Errors with USG were due to inability to distinguish between PTT and FTT around 1 cm in size^[78]. FI can also be reported by USG with remarkable precision. Wall *et al.*^[79] have reported, as percentage-agreement with MRI, 92.5% and 87.5% accuracy in detection of FI with USG in SSP, ISP and SS respectively.

Read *et al.*^[80] compared preoperative and postoperative USG findings in 42 consecutively operated patients obtaining excellent sensitivity and specificity for

FTT (100% and 97%). The results were more dismal for PTT with sensitivity of 46%. A Cochrane Database review has similarly reported poor sensitivity of USG in diagnosis of PTT^[81]. The 3D technique has demonstrated lower inter and intra-observer reliability than 2D USG for RC tears especially in the interpretation of small hypoechoic lesions close to the footprint as PTT^[82]. Ok *et al.*^[83], in a prospective analysis of orthopaedician-performed USG in 51 shoulders, reported significantly poor correlation of USG-reported and arthroscopically-determined tear sizes ($P < 0.05$). In contrast, Roy *et al.*^[84] in a meta-analysis have demonstrated similar accuracy of USG by the radiologist/sonographer or orthopaedician.

A steep learning curve, operator and technique-dependence with inaccuracies in measuring tear size and PTT are few drawbacks of USG. Nonetheless it remains a reliable, fast, accurate, cost and time-saving tool in experienced hands providing excellent depiction of the RC tendon fibres. It also possesses easy availability, portability and speed, lacks motion artefacts and allows instant comparison with C/L side, dynamic evaluation of tendons and quantitative and qualitative assessment of FI^[85,86].

The MRI can provide vital information and outstanding details not only on the RC tear size, extent, location retraction, FI and MA, but also on LHB, acromial morphology, AC joint and SAS^[87]. A prospective follow-up of 48 patients revealed 100% PPV of MRI in detecting surgical tears^[88]. Lower MRI accuracy has been reported in severe GH arthritis. Sershon *et al.*^[89] in 100 patients reported a 100% sensitivity, 68% specificity and 6% PPV. The MRI thus has an edge over USG in detecting smaller tears and possibly better evaluation of PTT.

Literature is flooded with studies comparing the two techniques. Teefey *et al.*^[90] in 124 consecutive painful shoulders reported similar accuracies of USG and MRI (87%). Likewise, Lenza *et al.*^[81] evaluating 20 studies with 1147 shoulders failed to illustrate any significant difference. Roy *et al.*^[84], in their meta-analysis, observed sensitivity and specificity of over 90% for FTT with USG and MRI. While specificity for PTT with both modalities was over 90%, lower sensitivities (67%-83%) were seen for PTT. Dinnes *et al.*^[91] in a systematic review found USG more cost-effective and accurate at picking up PTT than MRI. Over a 4-year period, Rutten *et al.*^[92] evaluated 5216 patients with shoulder symptoms and reported comparable accuracies of 95% and 100% for USG and MRI in diagnosing FTT and 89% and 67% in diagnosing PTT respectively. A smaller study on 21 patients demonstrated similar sensitivity, specificity, PPV, NPV and accuracy of USG and MRI^[93].

Other, less frequently utilized and indication-specific modalities of imaging include plain radiographs with arthrography, computed tomography scans and MRI arthrography^[80].

The decision regarding which to perform can be made on parameters like importance of obtaining

data on lesions of the glenoid labrum, joint capsule or surrounding structures, the presence of an implanted device, patient tolerance and cost^[78]. The ultimate decision needs to be based on these facts as well as availability, affordability and high-quality training of personnel performing the USG.

NONOPERATIVE MANAGEMENT

Management options RC tears includes nonsurgical measures, partial repair and/or debridement, open or arthroscopic repair, reconstruction and arthroplasty^[94]. While the benefits of nonoperative measures include: avoiding surgery and its potential complications, less obvious risks include persisting and recurring symptoms, lack of healing, tear extension, fatty infiltration, muscle atrophy, tendon retraction and arthritis^[5]. In a follow-up of 19 massive, nonoperatively managed RC tears, Zingg *et al.*^[95] observed satisfactory shoulder function for at least four years despite significant progression of degenerative structural joint changes. This risk of a reparable tear progressing to an irreparable tear needs to be averted by prompt recognition and early surgical intervention. Various modalities include analgesics, anti-inflammatory medications, physical therapy, activity modification and subacromial injections of local anaesthetics and/or steroids^[96].

PTT are managed nonoperatively by tailored rehabilitation, ROM optimization and RC and scapular rotator strengthening. Anterior capsular tightness is addressed by ER stretching with the shoulder adducted while posterior capsular contractures require stretching of the abducted and internally rotated arm. With subsequent improvements, a strengthening programme is initiated of the shoulder girdle, core abdominal and thoracic muscles^[97]. In a retrospective study on conservatively managed 26 PTT, Maman *et al.*^[50] found 2 increased and one decreased tears sizes. Contrasting reports however, exist. Hamada *et al.*^[98] in 1997 utilized in-situ hybridization to localize cells containing $\alpha 1$ type-I procollagen mRNA in 13 PTT to determine RC healing. Maintained numbers of labelled cells at the tear and margins of concomitant intratendinous extensions led the authors to conclude that PTT and these extensions can continue to rupture after initial injury. Further, Yamanaka *et al.*^[99] in 40 AST observed tear reduction and disappearance in 4 cases each while tear enlargement and progression to FTT was seen in 21 and 11 patients respectively at 2 years.

Existing evidence on nonsurgical management of FTT is also conflicting. In a series by Fucentese *et al.*^[49], 24 symptomatic, isolated FTT of SSP were offered operative treatment only to be declined by the patients. Re-examination and MRI (at median 42 mo after diagnosis) reported high patient satisfaction and no increase in the average tear size. While 9 tears each remained constant and decreased, 2 were no longer detected at follow-up. In another 20 conservatively managed FTT, Baydar *et al.*^[100] observed statistically significant improvements in

ROM, pain and function scores at 6 mo follow-up. In a study by the Moon shoulder group on 452 patients with atraumatic FTT, significantly improved patient reported outcomes were observed at 6 and 12 wk after diagnosis and patients opted for surgical treatment in only 25% of instances^[101]. In a long-term follow-up of 43 RC tears over 13 years, Kijima *et al.*^[102] observed nil or only slight pain in 90% of the patients while 70% patients had no disturbance in the ADLs. Younger patients had more significant symptoms.

Poor results with conservative treatment for FTT have been shown by Maman *et al.*^[50]. A 52% progression in 33 FTT over a mean 20 mo demonstrated SSP atrophy in 24% patients. Safran *et al.*^[51], in 61 nonoperatively treated symptomatic RC tears at mean 29 mo reported increased sizes in about 50% patients.

The effects of physical therapy were prospectively analysed in a multi-center study on 389 patients with symptomatic RC tears. Higher scores were seen in females ($P = 0.001$), higher education ($P < 0.001$), active abduction ($P = 0.021$) and strength in forward elevation ($P = 0.002$) and abduction ($P = 0.007$). Lower scores were seen in males ($P = 0.001$), supra and ISP atrophy ($P = 0.04$, 0.003) and scapulothoracic dyskinesia ($P < 0.001$). The authors concluded that factors associated with pain and loss of function including scapulothoracic dyskinesia, active abduction, and strength in forward elevation and abduction should be addressed nonoperatively with therapy^[103]. The Appropriate Use Criteria (AUC) developed by the American Academy of Orthopaedic Surgeons recommend nonoperative treatment is always appropriate in patients who have a response to conservative care^[104].

Nonoperative management should be individualised considering patient expectations, symptoms and response to previous nonoperative treatment. Our experience suggests earlier surgery in patients below 60 years or healthy symptomatic 60-70 year olds having increased demand for activity. Patients older than 70 years with low functional demands can be managed nonoperatively.

OPERATIVE MANAGEMENT

Surgical repair of the RC is a cost-effective solution for all populations and reduces the societal burden of the disease^[105]. Surgical techniques have evolved from open to arthroscopic procedures^[106]. Arthroscopic repairs have witnessed a dramatic 600% increase in the United States over the last decade^[107]. The ideal repair of the RC tear must have the potential to withstand physiological loads while allowing simultaneous healing to occur^[39]. The repair configuration opted for must be most reproducible and provide the best possible outcome and healing^[94]. Predictable success, pain relief and patient satisfaction has been met with after repair of RC tears^[108]. In a recent study on 103 shoulder surgeons, Robinson *et al.*^[109] observed overall higher overall popularity of arthroscopic repairs while open and mini-

open procedures were preferred by the long-timers.

Several biomechanical factors to consider while repairing RC tears include the suture material properties which should be sufficiently strong, stiff, requiring a simple and reliable operative technique and configuration. Bioabsorbable anchors over their metallic counterparts offer no lasting foreign object, graduated loss of strength, minimum imaging artefacts and suture-abrading eyelets. Potential drawbacks include unpredictable loss of strength, eyelet rupture and foreign body reaction. Anchor insertion at standard depths (manufacturer-dependent), 0°-45° angulation with double loaded suture in the anterior and middle regions of the greater tuberosity with screw-type metal anchors for osteoporotic bones impart a good fixation^[39].

PTT can be operated after a fair trial with conservative therapy. Repairs in non-overhead and overhead athletes are considered for tears more than 30%-50% and 75% respectively. Higher positional forces in throwers threaten repair integrity and preservation of motion. Options available include arthroscopic cuff debridement and open/arthroscopic repair with or without subacromial decompression^[97]. Excellent postoperative outcomes have been reported, in data from 16 studies, ranging from 28.7% to 93%^[110]. Thirty-nine PTT managed by acromioplasty, debridement and suturing, at a mean follow-up of 55 mo revealed satisfactory to excellent results in 33 (85%) patients. Four of six unsatisfactory results had unsuccessful previous surgery^[111]. Evidence to suggest good to excellent results in more than 80% patients treated by debridement exists in literature^[112,113]. Cordasco *et al.*^[114] in 162 patients with either normal, grade 1 (frayed) or grade 2 (< 50%) PTT in an average 4.5 years postoperatively reported significantly higher failure rates in grade 2B BST while the outcomes of in grades 1 and 2 and normal tears were not significantly different. The authors believed grade 2B BST may have been better served with primary repair.

Satisfactory results with arthroscopic BST repairs have been obtained. Koh *et al.*^[115] retrospectively evaluated 38 patients with a mean age of 50.8 years undergoing full-layer repair for more than 50% PTT with preservation of articular fibres. At a mean 26.9 mo of follow-up of 33 shoulders, 29 (87.9%) had intact repaired tendons with significant improvements in the patient scores. Investigators have also evaluated various techniques of AST repairs. In a prospective study by Franceschi *et al.*^[116], 2 arthroscopic modalities were compared. While 32 AST were repaired with TTT, 28 were converted to FTT and repaired. The authors reported significant improvements in clinical and functional outcomes and healing. Both methods were safe, comparable and effective. The addition of a biceps tendon tenotomy and augmentation to the TTT for AST has shown significant improvements in pain, function and ROM with no re-tears in preliminary results on 39 consecutive patients^[117]. The direct visualization of the retracted AST layer to its insertion on the GT followed by DR fixation has been also shown to provide a stable

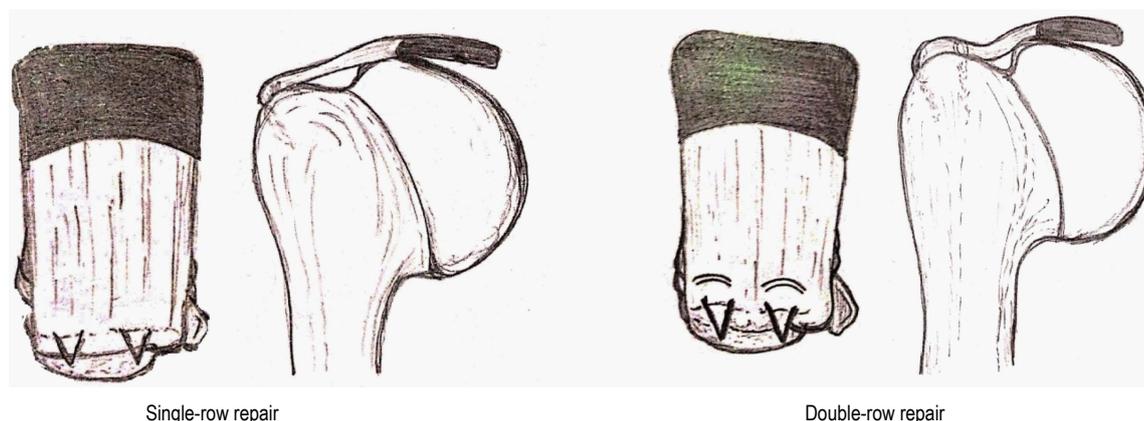


Figure 3 Single and double row repairs of full thickness tears.

shoulder with good ROM^[118]. A reduction in GH contact pressures has been identified with TTT for AST, in a study on 9 cadavers leading to diminished GH and SA impingement. Laxity however, can unwisely result^[119]. Reports also exist of FTT medial side tearing with TTT of AST in 21.2 mo follow-up of 7 out of 8 patients despite improved clinical outcomes^[120].

Excellent healing after arthroscopic conversion of PTT to FTT has been reported by Kamath *et al.*^[121] in repairs of 42 PTT (after conversion to FTT). Thirty-seven (88%) shoulders had intact repairs 11 mo postoperatively which were significantly younger (average age 51.8, $P = 0.02$) than those with persistent defects (62.6). Overall patient satisfaction rate was 93%. No significant differences have been reported between AST and BST following conversion to FTT. A recent paper by Kim *et al.*^[122] comparing 20 AST with 23 BST conversions to FTT and repairs reported comparable improvements in both groups at mean 35.53 mo follow-up with higher re-tear rates in BST (9.5% vs 0%).

Outcomes of repaired PTT and FTT have had comparisons. Peters *et al.*^[123] compared 105 arthroscopically repaired small-medium FTT with 64 PTT demonstrating excellent results in both groups. Postoperative stiffness and re-tear rates were similar. Chung *et al.*^[124] compared repairs of 34 high-grade PTT with 21 small FTT and observed healing failure in 12 PTT related to severity of tendinosis (7.64 times higher in high-grade tendinosis). Despite good to excellent results in a majority of PTT repairs, patients operated previously with poor tendon quality and advanced age can disappoint.

The AUC recommendations suggest repair of full-thickness RC tears: maybe appropriate for reparable tears (even in patients responding conservatively), is appropriate for healthy symptomatic patients failing conservative treatment, maybe appropriate in chronic massive tears while arthroplasty maybe appropriate for healthy pseudoparalytic irreparable tears^[104]. Early surgical intervention is needed in the setting of weakness and substantial functional disability^[108]. Factors contributing to optimal repair include intact tendon-footprint motion and contact area, tendon and bone

quality. Hypoxia, decreased vascularity, fibrocartilaginous changes and extrinsic compression along with MA and FI reduce the healing response^[125].

Comparable long-term results have been demonstrated for open and all-arthroscopic modalities. Lindley *et al.*^[126] in a systematic review of 10 studies comparing postoperative outcomes in mini-open repair and all-arthroscopic repair techniques found no significant differences in patient demographics, RC pathology, rehabilitation protocols, ASES scores and recurrent defects. Short-term pain reduction was seen in the all-arthroscopic repairs. A recent meta-analysis on 12 studies with 770 patients failed to identify any significant differences in functional outcomes, pain scores, re-tear rates or presence of adhesive capsulitis between the 2 groups^[127]. Parallel results have been demonstrated by other authors^[128,129]. A randomized study on 125 patients receiving either mini-open or arthroscopic procedures for RC tears revealed similar results in both groups. Functional outcomes and re-tears were higher in FTT managed arthroscopically^[130]. A lateral approach for mini-open RC repair permits improved visualization and function as described by Cho *et al.*^[131].

Popular among arthroscopic techniques are the single-row repair (SRR) and the double-row repairs (DRR) (Figure 3).

Varying degrees of clinical outcomes, healing and repair integrity and cost-effectiveness have been reported of DRR over SRR. A randomized controlled trial by Carbonel *et al.*^[132] on 160 patients revealed significantly greater improvements with DRR. Higher ASES scores, IR and ER along with lower re-tears following DRR have been reported in 2 recent meta-analyses^[133,134]. A systematic review by Duquin *et al.*^[135] demonstrated significantly lower re-tear rates with DRR when compared to SRR for tears more than 10 mm in size. Another recent meta-analysis by Millett *et al.*^[136] comparing SRR with DRR revealed significantly higher re-tear rates in SRR especially in PT re-tears.

The repair of large, massive tears with DRR have shown better, though not statistically significant, functional outcome than with SRR in a systematic review

by Saridakis and Jones^[137]. This improvement in larger tears has been confirmed in a meta-analysis by Chen *et al.*^[138]. Other investigators have found equally improved outcomes after SRR and DRR^[139-141]. Superiority of DRR in terms of healing rates has more clearly documented. Significantly higher healing has been observed in DRR surgeries^[134,142]. This has also been confirmed in biomechanical studies. A systematic review by Wall *et al.*^[143] found DRR stronger than SRR with lower rates of failure and gap formation. A cadaveric study by Ahmad *et al.*^[144] demonstrated lesser extravasation of fluid from DRR suggesting an enhanced healing potential. Pauly *et al.*^[145] have also, in a systematic review demonstrated biomechanical and radiographic superiority with DRR in terms of structural integrity and reduced re-tear rates.

Few studies have criticized the DRR and proclaimed superiority for the simpler time-saving SRR method. Aydin *et al.*^[146], documented no significant differences in clinical outcomes and found DRR to be demanding, expensive and time consuming. Longer operating times with DRR have been supported by other studies^[134,147]. The cost-effectiveness of DRR has been questioned by Genuario *et al.*^[148]. However, costs variations and probability of re-tear with SRR can have profound effects and prove DRR to be more cost effective in the first place. Higher re-tears with DRR have been reported. Kim *et al.*^[149] in a comparative analysis in 78 larger than medium-sized RC tears observed higher re-tear, lower UCLA and ASES scores in remnant tendons lengths less than 10 mm. Park *et al.*^[150] observed improved ultimate failure loads, better footprint restoration and stronger repairs with transosseous-equivalent (TOE) RC repair technique when compared to DRR. Gap formation was similar for both techniques.

Double-loaded suture anchors and margin-convergence sutures have been shown by Miškulin *et al.*^[151] to provide excellent results with significant improvements in functional parameters. The use of triple-loaded anchors in SRR has been shown to yield comparable and have shown to increase footprint coverage in cadaveric shoulders and potentially reduce costs^[152]. The results of knotless self-reinforcing DRR have shown high patient satisfaction and serve as an alternative option in managing RC tears^[153].

Based on the above discussion of the existing evidence, the suture technique should be chosen based on tissue properties, tear pattern and dimension and surgeon experience and comfort. PTT (BST or AST), do well with surgery. In FTT, mini-open and arthroscopic repairs provide comparable outcomes with better short-term pain control and more re-tears in arthroscopic methods. While the best biomechanical characteristics are possessed by the TOE repair, DRR may prove beneficial in tears more than 10 mm by providing stronger repairs closely replicating the native cuff at the cost of increased expenditure and failure at the MTJ which is harder to repair. Smaller (< 10 mm) tears can be repaired successfully by SRR the biomechanical superiority of which can be increased by increasing the

suture limbs^[104].

POSTOPERATIVE REHABILITATION

Physical rehabilitation is a vital component of postoperative patient care involving strict adherence and compliance. Poor patient cooperation, observed most frequently between 6-12 wk postoperatively, can lead to re-tears and failure^[154]. Despite several reviews of rehabilitative programmes, high-level evidence is presently lacking^[155]. Primary goals include restoring function while maintaining repair integrity. Gradual rehabilitation has been advocated in 4 phases beginning with 4 to 6 wk of immobilization, followed by protected passive ROM, followed by a gradual progression to active ROM and appropriate resistance exercise program^[156]. Millett *et al.*^[157] have advocated protecting the repair initially and gradually progressing from early passive ROM through return to preoperative levels of activity.

Aggressive and early rehabilitation with continuous passive motion has been associated with improved early ROM, pain relief and outcomes^[158]. In a prospective randomized controlled trial of 88 patients who underwent SRR, postoperative immobilization for 4 and 8 wk were compared. No significant differences were observed in terms of re-tears, ROM or clinical scores. Increased stiffness was however, higher in the 8 wk group ($P = 0.038$)^[159]. Keener *et al.*^[160], in a study on 124 patients comparing early with delayed motion at 6 wk after DRR reported no differences in function, ROM and strength between the 2 groups. Active elevation and ER were better in early mobilization group at 3 mo. Gallagher *et al.*^[161] observed improved function in the first 3-6 mo with early ROM. Increased re-tears in medium to large tears, though statistically insignificant, occurred with early ROM. Identical outcomes were seen at 1 year. Lee *et al.*^[162] compared early and limited early passive rehabilitation in 64 patients after arthroscopic RC repair. Significant and faster improvements were seen in the early rehabilitation group in forward flexion, ER and IR at 90° of abduction and abduction 3 mo postoperatively. No significant differences were seen at 1-year follow-up. Postoperative MRI scans showed higher re-tears in the early vs limited early rehabilitated group (23.3% against 8.8%). The authors advocated gentler rehabilitation after arthroscopic RC repair for improved for tendon healing.

Less aggressive delayed immobilization has been associated with stiffness. Parsons *et al.*^[163] evaluating 43 arthroscopically repaired FTT in full-time sling immobilization without formal therapy for 6 wk found 10 patients (23%) developing initial stiffness. No difference in mean forward elevation, ER or IR and functional scores with the remaining patients at 1 year postoperatively. Lower re-tears were seen among the stiff patients. Newer modalities including combined aquatic and land-based postoperative therapy have shown encouraging results with significant improvements in both ROM and outcome scores ($P < 0.001$)^[164].

An individualized rehabilitation approach is warranted in order to achieve a strong and mobile with maximum function and preserved repair integrity.

HEALING

Healing, as described by Mall *et al.*^[52], is formation of a continuous layer of tissue from the RC muscle belly to its insertion on the greater tuberosity. The evidence of spontaneous RC healing, without surgical repair, has been shown to be inadequate, inferior and limited in animal models.

Pathological changes described earlier along with delay in repair adversely influence postoperative outcomes as shown in animal studies^[54,165,166]. Studies have however, reported excellent outcomes despite significant rates of recurrence, re-tearing and poor cuff healing. Deniz *et al.*^[167] reported excellent results in 66 out of 87 arthroscopically repaired shoulders despite re-ruptures in 26 patients. Neither the MA nor FI, over 30 mo, demonstrated any MRI documented improvements. While the MA pattern in re-tears was identical in the intact and the re-torn tendons, FI was significantly greater in the latter. Though complete healing demonstrates a greater improvement on follow-up, patient age, sizes of initial and re-tears are other factors correlating with final results^[168-171]. Postoperative USG is an asset in evaluating repair integrity with 85% concordance with MRI readings and can be employed by sufficiently trained and experienced surgeons^[172].

In recent literature, patient related factors affecting RC healing have been identified as demographic variables, comorbidity-status and tear-related factors. Demographic variables include: advancing patient age, longer duration of symptoms and longer follow-up^[52,173-175]. Comorbidities including: Diabetes, hypercholesterolemia, smoking-status and nonsteroidal anti-inflammatory drug (NSAID) use have been shown to affect and delay bone-tendon healing^[52,173,174,176]. Smoking has been associated with worsened histopathology and degenerative changes and increased apoptosis^[175]. A reduced bone mineral density in a cohort study by Chung *et al.*^[173] was identified as an independent factor affecting postoperative RC healing. Tear-related factors with poor healing have included: Larger tears of longer duration with multi-tendon involvement. Small to medium-sized tears show higher healing rates (87%) as against large to massive-sized tears (62%)^[177]. Tashjian *et al.*^[175] followed-up 49 shoulders at mean 16 mo postoperatively after DR-repairs identified lower healing rates (36%) in multi-tendon tears against single-tendon tears (67%). Retraction of the muscle-tendon units, tendon shortening, FI and MA along with presence of matrix metalloproteinases -1, 9 and tumor necrosis factor-alpha have also yielded poor results^[52,128,173-175,177]. Medialization of the muscle-tendon junction (MTJ) is associated with significantly poorer healing rates (55%) when compared to MTJs lateral to the face of the glenoid (93%)^[177]. The anterior sub-region of tendon has been

associated with significantly higher gap formation^[178]. Large tears with additional biceps or AC procedures have a negative impact on cuff integrity^[179].

Various surgeon-associated factors influencing healing have included the choice and timing of technique, greater tuberosity preparation, acromioplasty, structural augmentation, platelet-rich plasma (PRP) and rehabilitation protocol^[52]. Open vs arthroscopic methods have been systematically reviewed with no significant differences in the rates on healing^[126,180]. While DRR has been shown to be stronger with improved healing rates as compared to single-row techniques, the functional outcomes have been equivalent in all except large and massive tears where DRR has provided a functional advantage^[173]. Knotted vs knotless techniques have shown comparable functional outcomes and repair integrity. Mall *et al.*^[181], however, have reported greater hysteresis, reduced gap formation and higher ultimate load in medially knotted shoulders. Repair of chronically torn tears can result in injury at the time of repair. Davis *et al.*^[182] observed injury to almost 70% rat muscle fibres at the time of repair. Concomitant acromioplasty and the use of PRP have failed to demonstrate improvements in structural healing^[52]. While early and delayed mobilizations continue to be debated, slower rehabilitation programmes can be safely adopted in light of improved healing and equivocal outcomes^[52,173].

Compromised RC healing ability has questionable association with outcomes. Tear and patient age, comorbidities, NSAIDS, smoking-status, osteoporosis and tendon shortening and retraction adversely affect outcomes. Surgical and rehabilitation techniques have varying degrees of impact on the final result.

CONCLUSION

With increasing likelihood of occurrence RC tears with advancing age and longevity, the future poses a unique challenge to the orthopaedic surgeon. The morbidity of activity restriction added to severe pain makes matters worse for the debilitated patient. In such circumstances, it becomes essential for us to give due regard and promptly recognise cuff tears and timely intervene by providing the most appropriate treatment. Nonoperative treatment should be offered and continued in those with a good initial response and improvement of symptoms. Surgical intervention however, must not be postponed endlessly, especially in the younger and active population with worsening symptoms and progressing tears. With inherent advantages and promising outcomes, arthroscopic repair seems a propitious approach. The addition of a rehabilitation plan to the above provides the requisite nourishment and environment essential for the repaired and recovering tendons. An evidence-based and systematic modus operandi can help the surgeon in comprehensively managing RC tears with high degrees of success in the present scenario. Future directions point towards application of principles of tissue engineering to achieve enhanced repairs and

functional outcomes.

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