Introduction

Rotator cuff tears (RCTs) are a common cause of pain and shoulder dysfunction (1,2). With increasing age, the prevalence of RCTs also increases (3,4). In those aged 80 years and older, as many as 62% of patients have been noted to have rotator cuff (RC) abnormalities (3). This is particularly important when considering the rate of aging in the global population (5). Between 2015 and 2030, the number of people aged 60 and older is predicted to grow by 56%, from 901 million to 1.4 billion; by 2050 this number is projected to double (2.1 billion) (5). Meanwhile, adult participation in recreational activities, including sports, has increased (6). In the last decade, the understanding of RC pathology in this group of patients has improved. Advances in diagnosis, patient selection, perioperative management, and surgical techniques have led to more sophisticated treatment strategies, negating the dogma of strict nonoperative management in elderly patients with RCTs.

Epidemiology

RC injury is the most common cause of shoulder disability (1), and is associated with pain and decreased function (2). As age increases, the prevalence of RCTs also increases, and the development of RC pathology is considered a normal consequence of aging (3,4,7). Studies have shown that over half of patients (62%) aged 80 years and older may have RC
abnormalities (3). Additionally, the pattern of RC injury changes noticeably with age. In older individuals RCTs are usually atraumatic, resulting from chronic degeneration (8). Furthermore, older patients possess a higher likelihood of suffering larger, irreparable RCTs (9).

RC injuries are defined anatomically and present along a spectrum, ranging in severity from tendinopathy, to partial tear, to complete tear (10). The progression of pathology is thought to occur relatively slowly and can oftentimes occur without associated symptoms. Older patients with asymptomatic partial and full thickness tears, may frequently progress to symptomatic tears without trauma; these are accompanied by muscle atrophy and fatty infiltration (7). Yamaguchi et al. reported that patients older than 66 years with a painful RCT in one shoulder have a 50% chance of having a contralateral tear even without noticeable symptoms (4). Asymptomatic tears may be expected to become painful in roughly 30–40% of patients within 2 to 5 years (11-14).

Older individuals are predisposed to a variety of risk factors that complicate RC disease, including age-related conditions such as lower bone density, decreased vascularity, and more complicated medical comorbidities such as diabetes mellitus, rheumatoid arthritis, and renal disease (15,16).

**Classification**

Multiple classification schemes have been proposed for RCTs. Current classification systems are generally divided into three groups: partial-thickness tears, full-thickness tears, and massive tears. Each group contains subclassifications which are pertinent to the particular tear type, generally involving size, shape, and muscular atrophy.

**Partial-thickness tears**

Partial-thickness rotator cuff tears (PTRCTs) are most commonly classified by the RC tendons involved, tear location, and by the thickness of the tear. In the Ellman classification system (17) the tear is first identified by location: A. articular-surface, B. bursal-surface, or C. interstitial. The tear is then graded according to its depth: (I) <3 mm (<25% thickness); (II) 3–6 mm (25–50% thickness); and (III) >6 mm (>50% thickness). This grading system assumes the RC footprint to be approximately 10–12 mm in the medial to lateral dimension. However, this classification system does not take into account several factors such as the length of the tear (anterior to posterior size of tear along the tendon footprint), tissue quality of the tendon, or the etiology of the tear (traumatic or degenerative). Compounding upon these limitations, the MOON group has demonstrated poor interobserver reliability in predicting the tear grade on MRI, and only moderate interobserver reliability in predicting the location of the tear (articular or bursal-sided) (18). Regardless of these shortcomings, the Ellman classification system continues to be the most universally utilized system for PTRCTs. Treatment recommendations are based upon the understanding of the histopathology of the tendon, and the depth of the tear. As the depth of the tear increases, there is increased strain on the remaining tendon (19), which may propagate development of a full-thickness tear. Also, the articular side of the tendon has only half of the strength of the bursal side, and accordingly, bursal sided tears are treated more aggressively. Articular sided tears over 6 mm are recommended to be repaired (20), while the threshold to repair bursal sided tears is >3 mm (21).

**Full-thickness tears**

Classification schemes have been developed to describe full-thickness rotator cuff tears (FTRCTs), which have attempted to include tendons involved, tear size, tear shape, chronicity, and muscle atrophy (Figure 1). Perhaps the most recognized system was described by DeOrio and Cofield (22). This system classifies FTRCTs according to tear size: less than 1 cm is small, 1–3 cm is medium, 3 to 5 cm is large, and >5 cm is defined as a massive tear. However, as this is one-dimensional, the system may not properly predict a repairable vs. non-repairable tear (23,24).

The classification system by Harryman et al. (25) incorporated the number of tendons torn: stage 0 is an intact RC, stage IA is a PTRCT of supraspinatus, stage IB is a FTRCT of supraspinatus only, stage II is a FTRCT of supraspinatus involving infraspinatus, stage III involves supraspinatus, infraspinatus, and subscapularis, and stage IV is RCT arthropathy.

Similarly, the Collin et al. classification scheme (26) defines five types of massive RCTs according to tendon involvement: type A are tears of the supraspinatus and superior subscapularis; type B are tears of the supraspinatus and entire subscapularis; type C are tears of the supraspinatus, superior subscapularis, and infraspinatus; type D are tears of the supraspinatus and infraspinatus; and type E are tears of the supraspinatus, infraspinatus, and
teres minor. This subclassification of massive tears offers a prediction of pseudoparalysis, or loss of function including forward elevation, external and internal rotation.

Davidson and Burkhart (23) proposed a geometric system of classification which links tear pattern on MRI to treatment and prognosis (24). Type 1 Crescent tears have a medial to lateral depth that is less than or equal to the anterior-posterior width of the tear, or a length under two centimeters, and can usually be repaired with good to excellent results by fixing the tendon directly to bone. Type 2 Longitudinal (L or U) shaped tears have a greater medial to lateral depth than anterior to posterior width, and a tear width under 2 cm; these tears typically are repairable with side-to-side (margin convergence) stitches followed by repair of tendon to bone, resulting in good to excellent outcomes. Type 3 Massive tears are defined by tear length and width greater than 2 cm each; in the majority of these cases interval slides and partial repairs are necessary, with only fair to good results. Finally, Type 4 Cuff tear arthropathy is defined by arthrosis of the glenohumeral joint and decrease of the acromiohumeral distance; these tears are irreparable, and the treatment of choice is arthroplasty.

**Massive tears**

Chronic massive RCTs are associated with tendon contraction and muscle belly atrophy, which increase the difficulty of reconstruction and are associated with poorer outcomes after repair (27) (Figure 2). Goutallier et al. (28) first described the pattern of fatty infiltration on CT scans. In this system, Stage 0 defines normal muscle without fatty streaking, stage 1 demonstrates some fatty streaks, stage 2 demonstrates significant fatty infiltration (but still more muscle than fat), stage 3 represents equal fat and muscle, and in stage 4 a greater amount of fat is present than muscle (Figure 3). Stage 3 and 4 are regarded by some to be indicators of an irreparable tear, although Burkhart et al. demonstrated significant functional improvement in repair of massive RCTs with grade 3 atrophy or higher (27).

Patte developed a system of tear classification (29), which incorporates tear size, coronal and sagittal plane tear imaging, tendon quality, and biceps tendon involvement; the amount of tendon retraction is the most commonly utilized portion of this scheme to evaluate massive tears (Figure 4). In the Patte classification of tendon retraction, a stage 1 tear remains close to the bony insertion, a stage 2 tear is retracted to the level of the humeral head, and a stage 3 tear is retracted to the level of the glenoid. However, this does not provide a treatment or prognosis for tendon repair, unlike the Davidson and Burkhart scheme (23).

**Nonoperative treatment**

Nonoperative treatment has been shown to be effective in RCTs of the elderly (30). Treatment may consist of complimentary conservative therapies, including ice and anti-inflammatory drugs, physical therapy (PT), and/or corticosteroid and orthobiologic injections. The goals of treating RCTs in the elderly patient are to decrease pain, improve shoulder function, and improve shoulder biomechanics.

In a recent meta-analysis of randomized controlled trials...
comparing surgical repair to conservative treatment or subacromial decompression (SAD) for degenerative tears of the RC, Schemitsch et al. (31) concluded that at one year, surgical repair resulted in significantly higher Constant-Murley scores, versus conservative treatment alone or SAD in elderly patients. However, the authors offer a caveat that this difference may be small, and that due to the high success rate of conservative treatment in elderly patients, surgeons may be judicious in recommending surgery or conservative management.

In a prospective study of 68 patients, Agout et al. (32) reported significant functional gains in patients treated conservatively with massive RCTs. Gains plateaued at six months, after which time the authors recommended consideration of surgical treatment.

PT

Moosmayer et al. (33) performed a randomized controlled trial comparing PT to surgical repair for small- to medium-sized tears. Treatment benefits were shown to be greater in the surgical group; however, over 80% in the PT group were satisfied with conservative management at one-year follow-up, and the remaining patients who crossed over to surgical management were effectively treated with delayed surgical repair. The MOON group demonstrated that approximately 75% of patients treated with PT had effective symptom alleviation at two-year follow-up (34).

Corticosteroid injections

Corticosteroid injections provide symptom relief by inhibiting the inflammatory cascade in the injured tendons, relieving pain and stiffness associated with RCTs (35). However, results have been mixed and concerns exist regarding steroid effects on tear propagation, tendon strength and degeneration, resultant infection, and poorer outcomes with subsequent need for revision after ultimate surgical intervention (36).

In a 2003 Cochrane review, Buchbinder et al. (37)
Figure 3 Exemplary magnetic resonance images illustrating fatty infiltration according to the Goutallier classification (28). (A) Goutallier grade 1. (B) Goutallier grade 2. (C) Goutallier grade 3. (D) Goutallier grade 4.

Figure 4 Exemplary magnetic resonance images illustrating tendon retraction according to the Patte classification (29). (A) Grade 1. (B) Grade 2. (C) Grade 3.
reported only small benefit for corticosteroid treatment over placebo in the treatment of RC disease, questioning the efficacy of corticosteroid treatment. Similarly, a recent meta-analysis performed by Mohamadi et al. (38), comparing corticosteroid to placebo treatment for RC tendinosis, found only a minimal and transient decrease in pain in those treated with corticosteroids. Accordingly, the authors did not recommend this treatment due to potential deleterious side effects of corticosteroids on the RC.

Orthobiologics

Platelet-rich plasma (PRP) injections have proven to be an effective modality in treatment of RC tendinosis and PTRCTs (39-41). However, these studies comprise mostly younger patients below the age of 65 years. In regard to more severe RCTs, a meta-analysis of level I and II evidence investigated the use of PRP in patients undergoing arthroscopic repair of FTRCTs and demonstrated no overall benefit on clinical outcomes and re-tear rates (42). However, the authors did not elaborate on the age of included patients. A randomized controlled trial performed by Zumstein et al. (43) reported on a cohort of 35 elderly patients with a mean age of 65.3 years (range, 54–74 years) who underwent arthroscopic repair of FCRCTs. The authors found no beneficial effect of platelet- and leucozyte-rich fibrin on clinical outcome, healing rate, postoperative defect size and tendon quality at 12 months follow-up (43). Nevertheless, there remains a paucity of literature specifically investigating the use of PRP in older patients.

Operative treatment

Operative treatment is generally performed for symptomatic RCTs in younger patients, as tear progression can be expected in over 80% of patients with symptomatic full-thickness tears and over 25% of patients with symptomatic partial-thickness tears (44,45).

In patients aged 65 years or older, the benefit of operative treatment has been historically debated. Comorbidities correlated with age such as diabetes, osteoporosis and cardiovascular disease can influence the fixation strength of RCR; these factors and the inherent compromised healing capability of the tendon has influenced surgeons towards nonoperative treatment (15,16,46). Additionally, high re-tear rates over 50% have been observed following fixation of RCTs in patients older than 70 years (47-49). With the advent of reverse total shoulder arthroplasty (RTSA), surgeons have debated whether joint replacement is superior to other reconstructive approaches in this group of patients (2). However, in recent years, the paradigm has shifted towards a more liberal approach to rotator cuff repair (RCR) in the elderly, as the literature shows promising results when these patients are properly indicated (2,49,50). Furthermore, Dornan et al. (51) compared three treatment strategies (I) arthroscopic RCR with the option to arthroscopically revise once; (II) arthroscopic RCR with conversion to RTSA on potential failure; (III) primary RTSA] for patients with massive RCTs with pseudoparalysis and without osteoarthritis using a Markov decision model. The authors found that initial arthroscopic RCR for massive RCTs and conversion to RTSA on potential failure was the most cost-effective strategy for treatment in patients with pseudoparalysis and without osteoarthritis. These findings were independent of patient age.

SAD

Some authors have suggested performing a simple SAD for the treatment of RCTs in low-demand elderly patients, arguing that this procedure is less invasive (52). However, when comparing the results of simple SAD to arthroscopic RCR in patients older than 60 years, the repair group achieved better functional outcomes, and eccentric humeral head position and cuff tear arthropathy were avoided in the medium term (53). This is in concordance with the prospective, randomized study performed by Flurin et al. (54). Both the SAD group and the arthroscopic RCR group demonstrated improvements in ASES and Constant scores; however, the RCR group scored significantly better than decompression alone. Palliative SAD is a feasible minimally invasive technique leading to postoperative improvements. Nonetheless, in the authors’ opinion, this should be reserved for older, low-demand patients (54), those who have massive RCTs with high-grade fatty infiltration that seem unlikely to heal following fixation (54), those who do not desire RTSA, and patients who should not undergo a longer procedure due to medical conditions.

Repair

Historically, when repair was chosen for treatment, RCTs were managed with an open approach. With this technique, treatment of massive RCTs in patients older than 70 years of age yielded satisfactory outcomes according to the UCLA score (mean: 30.9 points) in 78.2% of patients.
in a study published in 1999 (55). Over the last 20 years however, understanding of RC pathology, as well as surgical techniques, has evolved greatly.

In 2005, Rebuzzi et al. (56) were among the first to demonstrate satisfactory results of arthroscopic RCR (mean UCLA score: 30.5 points) in patients older than 60 years of age, regardless of tear size, patient’s age, and type of suture repair. Interestingly, no differences in outcomes were observed when adjusting for preoperative tear size. These early results of arthroscopic repair were similar to those of open repair.

Djahangiri et al. (57) reported on five-year outcomes in patients older than 65 years after mini-open or arthroscopic operations. The authors found that a single tendon RCR resulted in high patient satisfaction and significant improvements of the Constant score. Furthermore, complete healing as determined by ultrasonography was documented in 70% of cases, and those who did heal had significantly better scores. The authors concluded, that mini-open and arthroscopic RCR had similar outcomes in patients older than 65 years when compared with their younger counterparts.

Verma et al. (58) arthroscopically treated 44 patients aged 70 years or older with FTRCTs (Figure 1) and showed significant improvement in pain and function at a mean follow-up of 36.1 months, with an ASES score of 87.5 points. None of the patients required revision surgery. The majority (94.3%) of their patients were satisfied with the results, and 94.1% would commit to doing the procedure again.

Interestingly, Fehringer et al. (59) demonstrated that similar outcome scores were achieved in surgically treated patients aged 65 and older with FTRCTs, compared to untreated patients with intact RCs, if the repairs healed. Additionally, patients with RCRs that healed had better function compared to patients with untreated tears. The healing rate as determined by ultrasonography was 78.5%, which is in line with the findings of other authors for this age group (48,49,57).

Bhatia et al. (60) conducted a study investigating the outcomes of 49 shoulders in 44 recreational athletes who were older than 70 years (mean age 73; range, 70–82 years). At a minimum follow-up of two years, the authors reported good outcomes following arthroscopic RCR in this active patient group of older individuals. Significant improvements in all outcome scores from pre- to postoperatively were demonstrated and no RCRs were revised. Furthermore, median patient satisfaction was 10 out of 10 and 77% of the patients were able to return to their sport at a similar level.

In a systematic review evaluating the treatment options for older individuals with RCTs tears published in 2012, the authors found insufficient evidence to suggest efficacy of operative over nonoperative treatment (61). However, their results showed possible favorable outcomes for repairs.

Most recently, a systematic review by Altintas et al. (2) demonstrated that RCR in patients 70 years or older resulted in high clinical success with good outcomes and pain relief. The authors emphasized that although the re-tear rate in this collective is high (27.1%), RCR offers a joint-preserving method with significant improvements in outcomes if patients are indicated for treatment appropriately, taking into account tear-specific (tear size, tear retraction, fatty atrophy of the RC muscles) and patient-specific characteristics (comorbidities, activity level, osteoarthritis, osteoporosis).

**Patch augmentation**

Various biologic and non-biologic augmentations exist, aiming to provide stability and improve healing capabilities of large and massive RCTs. In a recent systematic review and meta-analysis, graft augmentation provided significantly lower re-tear rates and higher ASES scores when compared to RCR alone (62). However, this may not be generalizable to the elderly, as the mean age of patients included in this study ranged from 48 to 67.3 years.

Flury et al. (63) investigated tendon integrity and shoulder function in patients aged 60 years and older following RCR of supraspinatus tears, with and without the use of a porcine dermis patch augmentation. No differences in outcome scores and re-tears were seen between the groups. Although results in younger patients have been promising, there is a paucity of literature specifically investigating the use of patch augmentation in the elderly.

**Predictors of success**

It is commonly believed that inferior outcomes following RCR are correlated with advanced age. However, current investigations have shown that chronological age alone might not be as important as previously thought.

Rhee et al. (47) reported that the re-tear rate following RCR increased significantly with preoperative tear size, but not with increasing age. In their study, no difference in re-tear rates was seen between patients younger and older than 70 years. Charouset et al. (64) reported that age alone was not correlated with poor results; however, the
size of the lesion was. They postulated that successful repairs can be achieved, particularly when the tear is limited to the supraspinatus tendon. In a more recent study, Gwark et al. (49) again corroborated that the most significant factor for re-tears was preoperative tear size rather than age.

One factor that might have led to the belief that age is an independent risk factor for failure is the circumstance that older patients possess a higher chance of having larger, irreparable RCTs (9). Additionally, age-dependent comorbidities such as osteoporosis have been identified as independent risk factors compromising RC healing (15). Although Ryu et al. (65) did not find a relationship between vitamin D levels and repair integrity or functional outcomes following RCR, an increased risk for postoperative surgical complications following arthroscopic RCR was observed by Harada et al. (66) Treatment of osteoporosis and vitamin D repletion prior to RCR is an emerging topic of interest; however, literature is scarce (66). Intraoperatively, osteoporotic bone may be managed with the use of larger anchors, broader sutures, medialization of the footprint to reduce tension, and increased points of fixation (16).

**Postoperative rehabilitation**

Postoperative rehabilitation is essential to successful outcomes after RCR. The goals of the postoperative period are to minimize pain, restore range of motion (ROM), and regain previous levels of functionality.

Superior tendon-to-bone healing has been associated with early immobilization during the immediate postoperative period (67). However, this comes with trade-offs; functional recovery may be delayed by suspending early motion, due to increased stiffness and muscle atrophy (68).

Houck et al. (69) performed a systematic review of seven meta-analyses comparing early passive motion, motion beginning within one week postoperatively, and delayed motion after immobilization for a minimum of 4–6 weeks. No clear conclusion was established in regard to superiority; however, many of the studies supported an increase in ROM and higher re-tear rates with early motion, as well as better healing with delayed motion. Additionally, many studies concluded that tear size played an important factor in protocol determination and success. Thomson et al. (70) conducted a systematic review that investigated the effects of early postoperative ROM exercise compared with delayed rehabilitation protocols. Two of the six studies included in the study reported that patients treated with early motion regained ROM more quickly; however, no statistically significant differences were noted between groups at one year postoperatively. The remaining four studies reported no statistically significant difference between rehab groups, suggesting that early rehabilitation following RCR surgery may not be detrimental.

Strong scientific evidence supporting a definitive postoperative rehabilitation protocol has yet to be established; therefore, the authors recommend a comprehensive approach that considers patient goals, surgical findings, tissue quality, tear size, and post-surgery risks, including stiffness and re-tear rate. Care must be taken to avoid over-stressing the repair during the post-operative window; thus, the authors prefer to immobilize the shoulder in a sling for 6 weeks, beginning with early pendulum and passive ROM exercises immediately postoperatively. At 4 to 6 weeks, active-assisted motion is begun with progression to full active motion as pain permits. Strengthening usually commences between 8 to 10 weeks, with a return to full activity without restrictions between 3 and 4 months.

**Conclusions**

In summary, healthy elderly patients without significant comorbidities who have the desire to return to an active lifestyle benefit equally from RCR as their younger counterparts. Chronological age does not seem to be an independent risk factor for failure; however, comorbidities associated with age may be. Therefore, patient selection is a crucial component dictating successful outcomes following RCR in the elderly.

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