Fatty Infiltration and Rotator Cuff Atrophy

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Abstract

Moderate to severe fatty infiltration and rotator cuff atrophy are commonly associated with poor clinical outcomes and failed rotator cuff repair. Numerous animal and human studies have attempted to elucidate the etiology of fatty infiltration and rotator cuff atrophy. Mechanical detachment of the tendon in rotator cuff tears is primarily responsible. Suprascapular nerve injury may also play a role. CT, MRI, and ultrasonography are used to evaluate severity. The Goutallier staging system is most commonly used to evaluate fatty infiltration, and rotator cuff atrophy is measured using multiple techniques. The presence and severity of fatty infiltration have been associated with increasing age, tear size, degree of tendon retraction, number of tendons involved (ie, massive tears), suprascapular neuropathy, and traumatic tears. Fatty infiltration is irreversible and progressive if left untreated. Slight reversal of muscle atrophy has been noted after repair in some studies. Novel therapies are currently being evaluated that may eventually allow clinicians to alter the natural history and improve patient outcomes.

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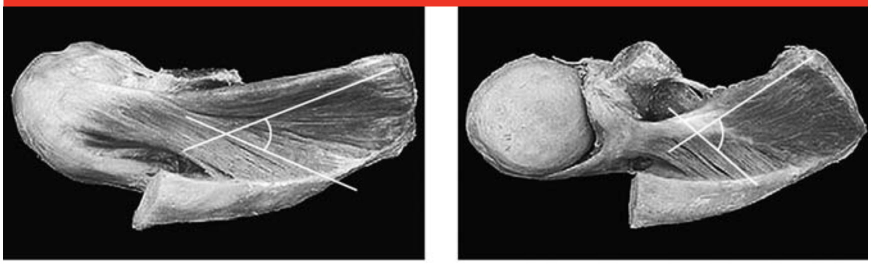
Goutallier et al[1] introduced the concept of fatty degeneration of the rotator cuff in 1989. They devised a staging system and noted that degeneration of the rotator cuff muscles was associated with rotator cuff tears (RCTs). Numerous natural history and outcomes studies published since then have noted progressively higher re-tear rates and poorer functional outcomes in patients with preoperative fatty infiltration and rotator cuff atrophy.[2-12]

The terms fatty degeneration, fatty infiltration, fatty change, and even fatty atrophy are often used interchangeably. Using histologic analysis in an ovine model, Meyer et al[13] noted infiltration of adipose cells, not muscle fiber degeneration. Currently, the term fatty infiltration is the most commonly used descriptor. Although rotator cuff atrophy and fatty infiltration are undoubtedly part of the same process, they have been found to be independent predictors of outcome.[10]

Poor interobserver correlation exists between orthopaedic surgeons when determining the degree of atrophy and fatty infiltration.[14-16] Although the Goutallier staging system is the most commonly used, many modifications have been developed. The description of rotator cuff atrophy also varies.[3,5,17]

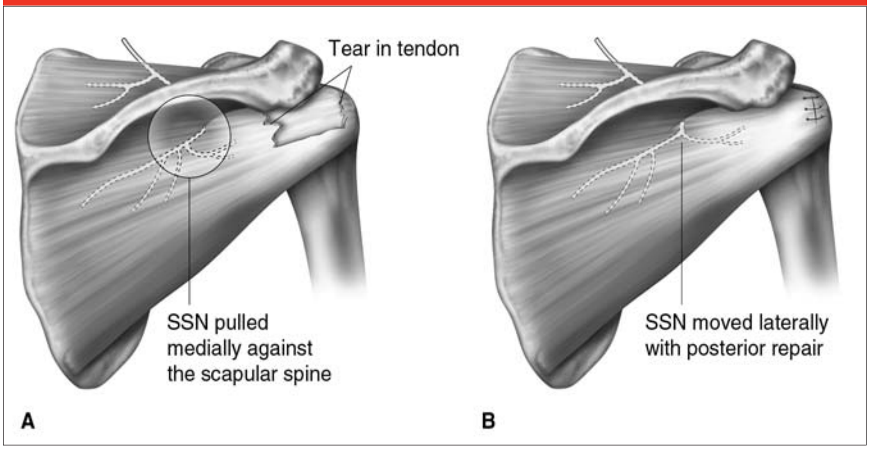
It is important to understand the original Goutallier staging system and its variations in order to apply them in clinical practice and to effectively review the literature. Greater understanding of the etiology of fatty infiltration and rotator cuff atrophy may ultimately lead to an improved understanding of management algorithms, outcomes, and prognosis.

Figure 1



Superior axial photographs of a normal intact supraspinatus muscle (**A**) and of a large retracted supraspinatus tear with muscle atrophy, fibrosis, and fatty infiltration (**B**) in a cadaver specimen. Note shortening of the muscle fibers and the increased pennation angle in panel B. (Adapted with permission from Tomioka T, Minagawa H, Kijima H, et al: Sarcomere length of torn rotator cuff muscle. *J Shoulder Elbow Surg* 2009;18[6]:955-959.)

Figure 2



A, Illustration of suprascapular nerve (SSN) traction injury at the base of the scapular spine due to medial and inferior retraction of a massive posterosuperior rotator cuff tear. **B,** Illustration of relief of traction on the SSN following repair of the rotator cuff tear.

Pathophysiology

The etiology of fatty infiltration and rotator cuff atrophy is complex and not fully understood. Along with increased connective tissue content and fibrosis, both atrophy and fatty infiltration decrease the elasticity and viability of the rotator cuff and impair healing.[9,18,19] Investigations are underway to discover the causative cellular and molecular processes.

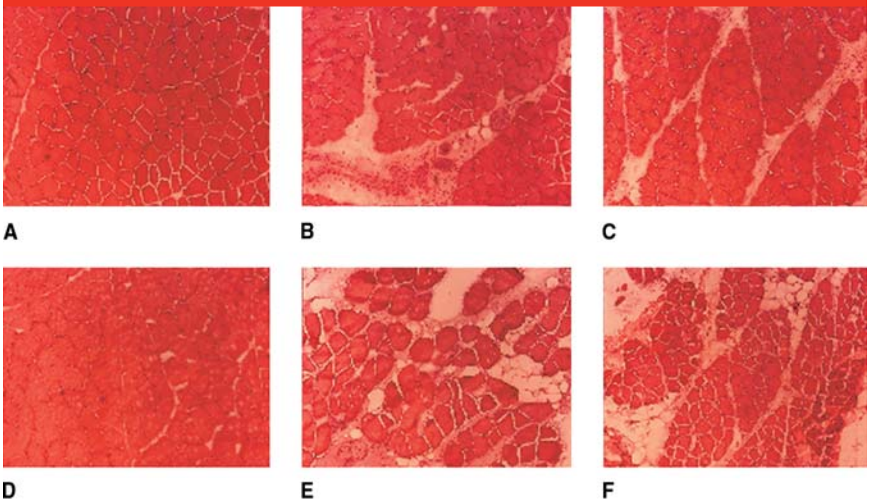
Both mechanical unloading and denervation likely play a role in the development of muscle atrophy and fatty infiltration. Mechanical unloading of the muscle has been shown to increase the pennation angle of muscle fibers[13] (Figure 1). Interstitial fat and fibrous tissue fills in the spaces between reoriented muscle fibers following musculotendinous retraction. The muscle fibers themselves do not degenerate.[13]

Using a sheep model, Gerber et al[18] studied the effect of muscle detachment on the composition of one rotator cuff muscle (ie, infraspinatus). CT, histologic analysis, and electron microscopy were used to evaluate the effect of tendon detachment over the course of 40 weeks, after which the effects of tendon repair were monitored for 35 weeks. Detachment did not alter vascular perfusion of the tendon or the composition of individual muscle fibers. It did, however, lead to increased muscle atrophy, inter- and intrafascicular fat content, and connective tissue content. These changes progressed over time, even after repair of the rotator cuff at 40 weeks. The severity of these findings was associated with the amount of retraction. The degree of muscle atrophy improved slightly 12 weeks after repair, but the amount of fatty infiltration did not.

Nerve injury has also been implicated in the development of rotator muscle atrophy and fatty infiltration. Retracted tears of the supraspinatus may increase tension on the suprascapular nerve (SSN) at the suprascapular notch.[20] Traction on the nerve can also occur at the scapular spine in combined supraspinatus/infraspinatus tears[21] (Figure 2). Mallon et al[22] found slowed SSN conduction velocity in patients with massive RCTs. Vad et al[23] reported a 28% rate of peripheral neuropathy in the axillary nerve and SSN associated with full-thickness RCTs and atrophy. Other studies have shown nerve recovery after repair of massive RCTs.[21]

Rowshan et al[24] found a decrease in muscle mass and cross-sectional area and an increase in fat content 6 weeks after tenotomy of rabbit subscapularis muscles. Rabbits subjected to transection of the subscapular nerve showed similar patterns of fat accumulation, both temporally and spatially (Figure 3). Histologic analysis showed wallerian degeneration, axonal demyelination, and myelin debris formation of the subscapular nerve in the tenotomy and nerve transection

Figure 3



Photomicrographs of cross-sectional rabbit subscapularis muscle stained with hematoxylin-eosin (original magnification ×200). Control (**A**), complete tenotomy (**B**), and subscapularis nerve transection (**C**) at 2 weeks. Control (**D**), complete tenotomy (**E**), and nerve transection (**F**) at 6 weeks. (Reproduced with permission from Gupta R, Lee TQ: Contributions of the different rabbit models to our understanding of rotator cuff pathology. *J Shoulder Elbow Surg* 2007;16[5 suppl]:S149-S157.)

Figure 4

Clinical photograph of infraspinatus atrophy noted on physical examination.

groups. Rabbits that underwent partial tenotomy had minimal change in muscle mass and fat content.

Kim et al[25] evaluated the effect of tenotomy and neurotomy on rodent rotator cuff muscles. Histologic analysis showed adipocytes, intramuscular fat globules, and intramyocellular fat droplets in both groups. Those authors noted that adipogenic and myogenic transcription factors were upregulated and that histologic changes increased over time. Rodents with both tenotomy and neurotomy had the most severe findings.

Overviews of the current knowledge of cellular- and molecular-level processes related to atrophy and fatty infiltration can be found elsewhere.[26,27]

Clinical Evaluation

History and Physical Examination

Clinical evaluation of patients with rotator cuff fatty infiltration and atrophy should follow the standard principles used for the evaluation of shoulder pathology. The history should contain a thorough discussion of the patient's shoulder pain and function, as well as the effect of that pain on work and activities of daily living. The patient's perceived level of shoulder function can be assessed using the Simple Shoulder Test, the Constant-Murley score, or the American Shoulder and Elbow Surgeons (ASES) shoulder score or an equivalent.[28]

In patients with suspected or known rotator cuff atrophy and fatty infiltration, a standard shoulder physical examination should be performed with special emphasis on a few key elements. Patients with severe rotator cuff disease often exhibit atrophy of the supraspinatus and/or infraspinatus muscles on visual surface examination (Figure 4). Mild to moderate atrophy of the supraspinatus can be masked by the overlying trapezius. Supraspinatus weakness may be evaluated subjectively or can be quantified with a dynamometer. Patients with massive RCTs and severe stage 3 or 4 fatty infiltration of the infraspinatus and teres minor may exhibit decreased or absent external rotation strength as well as a positive external rotation lag sign (infraspinatus) and a hornblower sign (teres minor)[29] (Figure 5). Persons with massive anterosuperior cuff tears and severe atrophy and fatty infiltration exhibit weak or absent findings on the belly press, lumbar lift-off, and bear hug tests.[30-32]

Injections of the glenohumeral joint, subacromial space, acromioclavicular joint, suprascapular notch, and biceps tendon may be of diagnostic and therapeutic benefit.[33] Patients with suspected suprascapular neuropathy can be evaluated using electromyography (EMG) and nerve conduction velocity (NCV) studies. The SSN must be specifically requested because it is not always routinely tested. It is important to note that overall sensitivity and specificity of EMG-NCV studies can be quite variable.[34]

Imaging

Standard shoulder radiographs should be evaluated. Narrowing of the acromiohumeral interval has been associated with increasing rotator cuff atrophy and fatty infiltration, and it is most pronounced with infraspinatus involvement.[35]

In the initial iteration of the Goutallier staging system, axial CT was used to evaluate the supraspinatus, subscapularis, and infraspinatus muscles.[1,2] The supraspinatus was evaluated on the axial image with the most muscle surface area (approximately 5 mm above the humeral head) (Figure 6). The subscapularis and infraspinatus were evaluated superiorly at the level of the tip of the coracoid and inferiorly at the level of the lower glenohumeral joint. The muscles were then assigned a stage (Table 1). The subscapularis and infraspinatus values were averaged individually. The mean value of all rotator cuff muscles together was then averaged to create a global fatty degeneration index (GFDI).[1,2]

Fuchs et al[36] modified the Goutallier staging system, using magnetic resonance arthrography to assess fatty infiltration (Table 2). All muscles were evaluated on the most lateral parasagittal image on which the scapular spine was in contact with the scapular body (Figure 7). Interobserver agreement improved in the evaluation of MRI and CT studies, although correlation was poor between MRI and CT.[36] Differences between the MRI and CT findings were likely related to the difficulty of distinguishing fibrous tissue from fat on CT scans and the variability in the image plane used between the two techniques.

Rotator cuff atrophy has generally been evaluated using either an occupation ratio as described by Thomazeau et al[4] or the tangent sign introduced by Zanetti et al.[17] The occupation ratio was defined as the surface area supraspinatus muscle/surface area supraspinatus fossa[4] (Figure 8) (Table 3). The tangent sign is negative if the supraspinatus crosses a line between the superior aspect of the coracoid and the supe-

Figure 5

Clinical photograph of a patient with a positive hornblower sign. When asked to bring both hands to her mouth, the patient was unable to do so on the affected (ie, right) side without abducting her right arm.

Table 1

Goutallier Staging System for Grading Fatty Infiltration Based on CT[1]

Stage	Rotator Cuff Fat Content
0	Normal muscle with no fatty streak
1	Some fatty streaks in the muscle
2	Fatty infiltration is present, but more muscle exists than fat
3	Equal amounts of fat and muscle
4	More fat than muscle

Adapted from Omid R, Lee B: Tendon transfers for irreparable rotator cuff tears. *J Am Acad Orthop Surg* 2013;21(8):492-501.

Figure 6

A, Axial CT scan demonstrating Goutallier stage 2 fatty infiltration of the supraspinatus muscle (SS). **B,** Superior axial cut demonstrating stage 1 fatty infiltration of the subscapularis (Sub) and infraspinatus (asterisk) muscles. **C,** Inferior axial cut demonstrating stage 2 fatty infiltration of the subscapularis and infraspinatus muscles. Note the black fatty streaks (arrows) within the muscle. (Adapted with permission from Goutallier D, Postel JM, Gleyze P, Leguilloux P, Van Driessche S: Influence of cuff muscle fatty degeneration on anatomic and functional outcomes after simple suture of full-thickness tears. *J Shoulder Elbow Surg* 2003;12[6]:550-554.)

rior border of the scapular spine. MRI evaluation is performed using the most lateral image where the scapular spine is in contact with the body of the scapula[17] (Figure 9). The grading system for rotator cuff atrophy proposed by Warner et al[5] includes the subscapularis as well as the supraspinatus (Figure 10).

Williams et al[37] studied 87 CT scans to determine the best plane for evaluating fatty infiltration of the supraspinatus on CT. Using both the Goutallier and Fuchs staging systems, they found the axial plane to be superior to the sagittal and coronal planes. Moreover, they found grade 3 fatty infiltration of the supraspinatus to be directly correlated with a positive tangent sign ($P < 0.0001$).

Rotator cuff atrophy and fatty infiltration have also been evaluated using ultrasonography. Benefits of ultrasonography include affordability, ease of use, dynamic evaluation of the rotator cuff, and patient benefits (eg, affordability, comfort, ability of the patient to view the study in real time). Drawbacks include availability and dependence on technician skill.[15,38,39] Khoury et al[15] evaluated 45 shoulders in 39 patients and determined occupation ratios with both MRI and ultrasonography. The correlation with MRI evaluation was 0.90. Fatty infiltration was also evaluated using ultrasonography. On ultrasonography, it was possible to differentiate between mild and severe fatty infiltration by grading echogenicity as mild or marked and to determine the status of the muscle pennation pattern (ie, normal, effaced, or absent). However, it is difficult to distinguish moderate from severe fatty infiltration using ultrasonography.[15]

Concerns about current grading systems include lack of agreement among clinicians and variability in images assessed. Given the spatial variation in fatty infiltration, single sagittal oblique images may not provide an accurate assessment of the whole rotator cuff musculature. Clinical studies performed after rotator cuff repair must be interpreted with caution. Lateralization of the supraspinatus muscle may falsely increase the occupation ratio and will change the portion of the muscle evaluated for fatty infiltration.

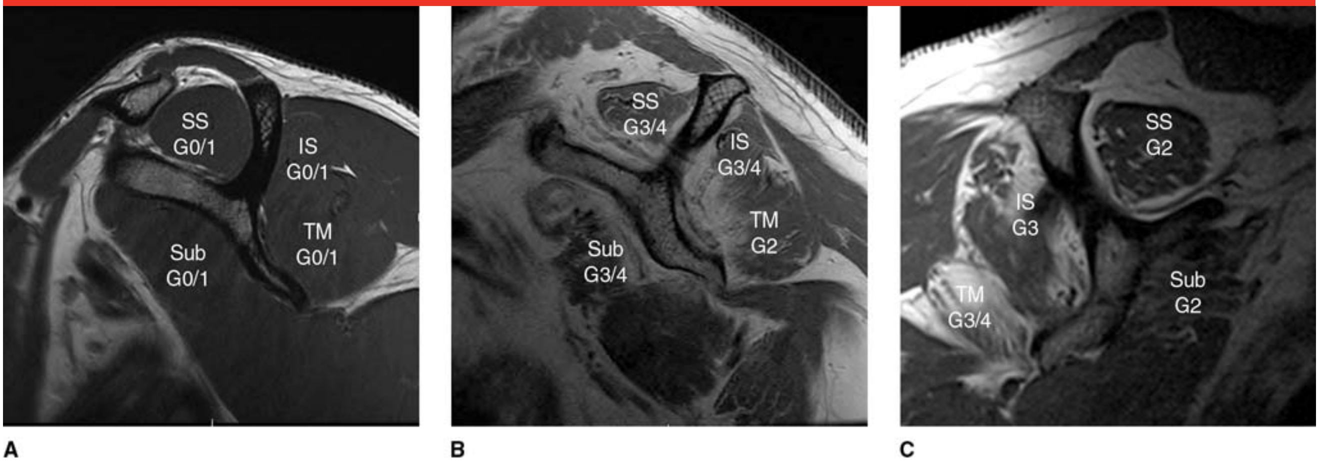
Recent investigations have called into question the reproducibility of the techniques used to assess rotator cuff atrophy and fatty infiltration. In an MRI study in which multiple findings were evaluated by 10 fellowship-trained orthopaedic surgeons who specialize in the shoulder,

Table 2

Fuchs System of Grading Fatty Infiltration on MRI[36]

Grade	Rotator Cuff Fat Content
Goutallier stages 0 and 1 (minimal)	No fat to minimal fat
Goutallier stage 2 (moderate)	More muscle than fat
Goutallier stages 3 and 4 (severe)	Equal amounts fat and muscle or more fat than muscle

Figure 7



T1-weighted sagittal oblique magnetic resonance images of the shoulder demonstrating the Fuchs method of determining fatty infiltration of muscle. **A,** Normal rotator cuff musculature in a healthy young person. **B,** Severe Goutallier (G) stage 3/4 fatty infiltration of the supraspinatus (SS), subscapularis (Sub), and infraspinatus (IS) muscles in an elderly patient. The teres minor (TM) demonstrates moderate Goutallier stage 2 fatty infiltration. **C,** Severe Goutallier stage 3/4 fatty infiltration of the external rotators of the IS and TM, stage 3 infiltration of the IS, and stage 2 fatty infiltration of the Sub and SS muscles in a middle-aged patient.

Figure 8

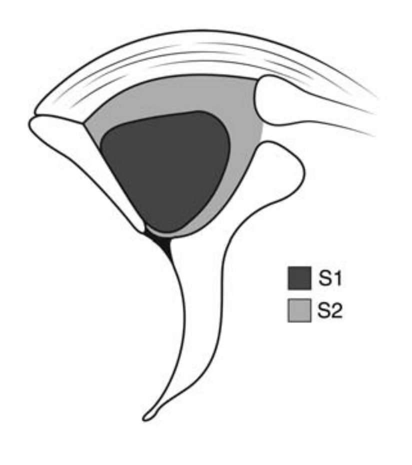


Illustration of the elements involved in the Thomazeau method of calculating the occupation ratio based on a sagittal oblique view. S1 = surface of the supraspinatus muscle, S2 = entire supraspinatus fossa

Table 3

Thomazeau Grading System of Rotator Cuff Atrophy[4]

Grade	Atrophy Status	Occupation Ratio
I	Normal/slight	0.6–1.0
II	Moderate	0.4–0.6
III	Severe	<0.4

Figure 9

Coronal magnetic resonance image of a shoulder demonstrating a negative (almost positive) tangent sign (black line). IS = infraspinatus muscle, SS = suprascapular muscle, Sub = subscapularis muscle, TM = teres minor

Spencer et al[14] reported interobserver agreement of 0.36 with the Goutallier grading system. Interobserver agreement for the tangent sign was 0.59.

Oh et al[16] evaluated both CT scans and magnetic resonance images of 75 shoulders using both the Goutallier and the Fuchs classifications. Two musculoskeletal radiologists and three fellowship-trained orthopaedic surgeons who specialize in the shoulder were noted to have slightly better interobserver agreement on MRI (interclass correlation coefficient [ICC], 0.6 to 0.72) than on CT (ICC, 0.43 to 0.6). No difference was noted between the Goutallier and Fuchs grading systems. Interobserver agreement was significantly better among radiologists (ICC, 0.58 to 0.78) than orthopaedic surgeons (ICC, 0.32 to 0.68).

Several applications are being investigated in an effort to make the evaluation of rotator cuff atrophy and fatty infiltration more objective and clinically practical. For example, multidetector CT has been used to determine occupation ratios using Y views of the supraspinatus fossa. High intra- and interobserver correlation was found between multidetector CT and T1- and T2-weighted MRI (range, 0.89 to 0.98; $P < 0.001$).[40] Proton magnetic resonance spectroscopy programs have been developed to quantify the fat content of muscle.[41] The technology that gains the greatest acceptance and widespread use must be easy to use, inexpensive, and readily available.

Natural History

In general, the natural history of fatty infiltration is one of progression. In a retrospective review of 1,688 shoulder MRI and CT studies, Melis et al[12] found moderate supraspinatus fatty infiltration (Goutallier stage 2) an average of 3 years after onset of shoulder symptoms (traumatic tears, $P = 0.04$). Onset of moderate fatty infiltration was noted earlier in traumatic RCTs than in chronic tears (34.8 mo [$P = 0.04$] and 54.1 mo [$P = 0.003$], respectively). Severe infiltration was noted an average of 57.7 months after traumatic tears ($P = 0.04$) and 83.9 months after chronic progressive tears ($P = 0.003$). Patients had a positive tangent sign indicating severe atrophy at an average of 4.5 years after symptom onset ($P = 0.001$). Fatty infiltration of the supraspinatus was associated with increasing patient age, delay between symptom onset and diagnosis, and the number of tendons involved. Degree of muscle atrophy was influenced by fatty infiltration, the number of tendons involved, delay between symptom onset and diagnosis, and patient age. The authors of the study concluded that rotator cuff repair should be performed before Goutallier stage 2 fatty infiltration or the development of a positive tangent sign.

Maman et al[42] retrospectively evaluated 59 shoulders in patients who were diagnosed with RCT on MRI evaluation and who elected to undergo nonsurgical treatment. Partial-thickness tears did not exhibit atrophy, and only one had fatty infiltration. Fatty infiltration was present or advanced in 70% of patients whose tear size increased dur-

Figure 10

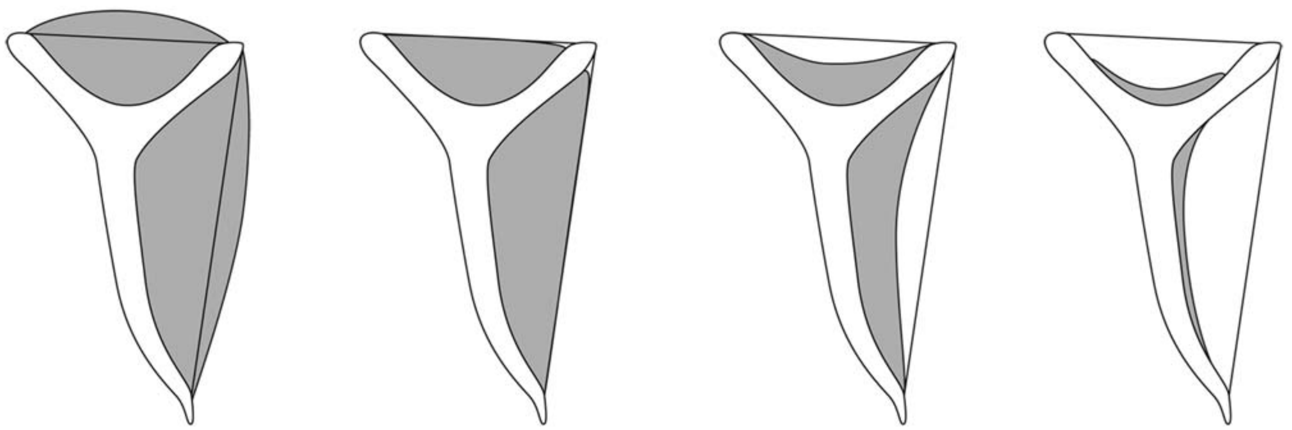


Illustration of the Warner method of evaluating rotator cuff atrophy based on T1-weighted sagittal oblique magnetic resonance images.[5] The grade is determined by the amount of muscle above or below a line drawn from the edge of the coracoid to the tip of the scapular spine. The Zanetti tangent line extends from the superior aspect of the coracoid to the superior border of the scapular spine.

ing the course of the study (P = 0.0089). By contrast, 24% of shoulders without new fatty infiltration or advancement of existing fatty infiltration developed progressive tears (P = 0.0089). In addition, the increase in overall tear size was significantly larger for patients with fatty infiltration than for those without infiltration (P = 0.0089). The authors also noted that 17% of tears progressed in patients aged ≤60 years compared with 54% in patients older than 60 years (P = 0.007). The authors concluded that factors associated with progressive RCT include age >60 years, full-thickness tears, and fatty infiltration.

Kim et al[43] used ultrasonography to evaluate both shoulders in 262 patients and noted that tear length and width were significantly greater in shoulders with fatty degeneration (P < 0.0001). The location of the supraspinatus tears was more important than tear size or retraction in the degree of fatty degeneration. The odds of having fatty degeneration decreased significantly the farther the tear was from the biceps tendon. The anterior region of the supraspinatus insertion near the biceps tendon is the site of attachment of the rotator cable, and the authors speculated that it is under greater load than other portions of the muscle. Infraspinatus fatty degeneration was more closely associated with tear size and retraction.

Melis et al[35] reported on the natural history of fatty infiltration of the infraspinatus. They noted that infraspinatus fatty infiltration increased significantly in the presence of infraspinatus tendon tear and when multiple tendons were torn (P < 0.0005). Likewise, they noted worse fatty infiltration with increasing age (P < 0.0005). Other studies have shown that the infraspinatus can develop fatty infiltration even when it is not torn.[44] This finding has been noted in patients with large anterosuperior tears.[1,44] It may be attributed to a traction injury of the SSN caused by retraction of the anterosuperior cuff. It is also possible that tears of the infraspinatus have been mistaken as tears of the supraspinatus. Mochizuki et al[45] noted the insertion of the infraspinatus to be far more anterior than previously thought. Infraspinatus degeneration is speculated to upset the anterior-posterior glenohumeral force couple and to lead to proximal humeral migration and further degradation of the supraspinatus.[35] Goutallier et al[1] noted that infraspinatus lesions were associated with poorer functional outcomes and external rotation.

The natural history of massive RCTs is paradoxical. Zingg et al[46] retrospectively evaluated the natural history of fatty infiltration in 19 shoulders with massive RCTs at an average of 48 months after diagnosis. They noted a significant increase in tear size (P = 0.003) and glenohumeral arthritis (P = 0.014) as well as decreased acromiohumeral distance (P = 0.005). Fatty infiltration increased by approximately one stage in all three muscles (P = 0.001). Even so, patients maintained satisfactory shoulder function (ie, mean Constant score of 83). Four of eight tears, however, became irreparable (ie, acromiohumeral distance <7 mm and Goutallier stage 3 or greater).

Outcomes

Outcomes diminish as rotator cuff atrophy and fatty infiltration worsen. Using preoperative CT scans as well as follow-up CT scans and magnetic resonance images obtained an average of 3 years after repair, Goutallier et al[6] evaluated 220 open RCTs repaired with sutures through bone tunnels. GFDI values were tabulated for each shoulder before surgery and at follow-up. The overall re-tear rate was 36% ($P < 0.001$). All shoulders with a GFDI ≥2 exhibited evidence of recurrent tear ($P < 0.001$). A GFDI <0.5 was required for a re-tear rate <25%. Constant scores improved from 46 to 70 in the group of patients with recurrent tear and from 46 to 78 in the patients with intact repairs ($P < 0.0001$). A higher preoperative GFDI was associated with a lower postoperative Constant score ($P < 0.001$).

Fuchs et al[7] evaluated 32 one-tendon open rotator cuff repairs preoperatively and at an average of 38 months after repair. They noted a 13% re-tear rate, all of which were distinctly smaller than the original tear. The average Constant score improved from 63.9% preoperatively to 94.5% postoperatively ($P < 0.0001$). Muscular atrophy did not decrease significantly after tendon repair. Fatty infiltration of the supraspinatus and infraspinatus increased significantly despite repair ($P < 0.0053$ and $P < 0.003$, respectively). Rotator cuff atrophy was significantly worse in patients with re-tears than in those with intact repairs ($P < 0.049$).

In a study published in 2009, Goutallier et al[11] retrospectively evaluated patients with a GFDI ≤2 with intact repairs 1 year after surgery and at an average of 9 years after surgery. They found functional outcomes to be related to GFDI at baseline and last follow-up. Constant scores improved significantly for 2 years after surgery and then remained stable, with an average final Constant score of 77 (range, $P < 0.0001$ to 0.0002). In general, patients with a GFDI ≤2 had excellent results and intact rotator cuff repairs. These results were maintained over time.

Gladstone et al[10] evaluated 38 open and arthroscopic rotator cuff repairs with MRI studies obtained before repair and 1 year after surgery. Rotator cuff atrophy and fatty degeneration, specifically of the infraspinatus, had a negative effect on functional assessment scores, strength, and the integrity of the rotator cuff repair. Using a regression analysis model, fatty infiltration and rotator cuff atrophy of the infraspinatus were found to be the only preoperative variables that predicted poorer ASES and Constant scores. There was no relation between the quality of the rotator cuff muscles and patient pain levels. Both fatty infiltration and atrophy progressed during the study, even in successful repairs. Reruptured rotator cuffs developed a greater degree of fatty infiltration and atrophy than did successful repairs. Based on the results of this study, Gladstone et al[10] agreed with the prior suggestion that there might be a so-called point of no return when the muscles are irreversibly damaged.

Liem et al[47] retrospectively evaluated 53 consecutive patients who underwent arthroscopic repair of isolated supraspinatus tears. They obtained MRI studies on all patients at an average of 26.4 months postoperatively and noted a re-tear rate of 25%. Constant scores improved dramatically regardless of integrity of the rotator cuff. Preoperative stage 2 fatty infiltration was a positive predictor of recurrent tear, and older age was associated with re-tear. In patients with intact repairs, fatty infiltration and atrophy did not progress. In those with recurrent tear, fatty infiltration and atrophy worsened significantly; these patients had inferior functional results.

Gerber et al[3] studied 29 patients who had undergone open repair to manage massive RCT and noted a 34% re-tear rate. Re-tears were more likely in patients with traumatic RCTs ($P < 0.05$). Supraspinatus atrophy was mildly reversed after repair. Infraspinatus atrophy worsened even after successful repairs. Fatty infiltration was not reversible but progressed less in patients with intact repairs. As found in other studies, the Constant score improved significantly even in patients with re-tears, from 49% to 85% ($P = 0.0024$). Range of motion improved and pain decreased.

Warner et al[5] evaluated the open repair of combined subscapularis and supraspinatus (anterosuperior) tears and noted significantly worse Constant scores in patients with severe fatty infiltration and atrophy. The average postoperative Constant score was 79 for patients with stage 1 fatty infiltration compared with 31 in patients with stage 4 fatty infiltration ($P < 0.05$).

Arthroscopic repair of massive RCTs has demonstrated promising results. Burkhart et al[48] evaluated 22 patients with massive RCTs with Goutallier stage 3 and 4 fatty infiltration of the infraspinatus. At an average of 39.3 months after surgery, they noted significant improvement in range of motion; strength; University of California, Los Angeles (UCLA) score; and Constant score. Of patients with Goutallier stage 3 or 4 fatty infiltration, those with 50% to 75% fatty infiltration had significantly better results than did those with >75% fatty infiltration. Burkhart et al[48] speculated that their improved outcomes were associated with patient selection, tear recognition, and surgical technique.

Future Directions

At best, current interventions (eg, successful rotator cuff repair) can halt the progression of fatty infiltration. They cannot reverse it. Although rotator cuff atrophy may improve, the musculature will not fully return to normal. Most rotator cuff basic science studies have focused on tendon-to-bone healing. Consistently successful repairs cannot be expected if the rotator cuff muscle itself is unhealthy. Our knowledge of the pathophysiology of rotator cuff atrophy and fatty infiltration is improving. Investigations into the cellular and molecular pathogenesis of these conditions offer the hope of creating new management techniques that will halt or reverse the progression of fatty infiltration and rotator cuff atrophy.[26,27]

Gerber et al[19] evaluated indirect improvement of the local environment by studying the effect of slow continuous traction on torn retracted rotator cuff muscles in sheep. They postulated that tension created when repairing chronic retracted RCTs in one-stage procedures is harmful to the muscle, whereas slow continuous traction would allow normalization of the muscle architecture. They elongated the infraspinatus musculotendinous unit 1 mm per day and noted partial reversal of atrophy and normalization of the rotator cuff muscle architecture histologically. Fatty infiltration did not progress in sheep managed with traction, and atrophy decreased to 78% of the muscle square area of the contralateral side ($P = 0.0001$). In sheep in which traction failed, fatty infiltration increased, but not to a statistically significant degree ($P = 0.144$).

In a study published 2 years later, Gerber et al[49] evaluated the effect of anabolic steroids on fatty infiltration and atrophy in rabbits with chronic RCTs. They noted that nandrolone decanoate administered either locally or systemically inhibited the development of fatty infiltration and partially preserved muscle function.

Our understanding of gene expression patterns and complex molecular pathways continues to evolve. Ultimately, the goal is to find ways to prevent the differentiation of mesenchymal stem cells into adipose cells. Investigators hope to determine ways to slow or halt the progression of fibrosis that often occurs after injury and restore the ability of the muscle to regain normal architecture.[26,27]

Summary

Increased fatty infiltration and rotator cuff atrophy are associated with increased re-tear rates as well as poorer functional outcomes following rotator cuff repair. Most studies indicate that fatty infiltration does not decrease after successful repair. It increases, however, in patients with failed repair. In some studies, atrophy has been shown to improve only partially after successful repair. Risk factors for progression of fatty infiltration include size and location of the tear, degree of retraction, age, and time from onset of symptoms to diagnosis. Infraspinatus fatty infiltration predicts a poorer prognosis and functional outcome following rotator cuff repair. This is most likely due to disruption of the anterior-posterior glenohumeral force couple.

Management options are wide-ranging. There are currently no evidence-based guidelines for the treatment of patients with fatty infiltration and rotator cuff atrophy. Understanding the degree of pain and functional deficits in the context of the patient's everyday life is essential to developing a treatment plan.

Historically, interobserver correlation among orthopaedic surgeons has been poor. In addition, significant variation exists in the techniques used to determine Goutallier stage and degree of muscle atrophy. Outcome studies must be read carefully to understand the technique used. Our understanding of fatty infiltration and rotator cuff atrophy will improve as methods of evaluation become more objective and include analysis of the involved muscle as a whole and the entire rotator cuff as a functional unit.

References

Evidence-based Medicine: Levels of evidence are described in the table of contents. In this article, references 10, 19, and 40 are level II studies. References 4, 11, 14-16, 36, 37, and 39 are level III studies. References 2, 3, 5-9, 12, 18, 21, 22, 35, 42, 44, and 46-48 are level IV studies. References 33 and 34 are level V expert opinion.

References printed in **bold type** are those published within the past 5 years.

1. Goutallier D, Bernageau J, Patte D: Assessment of the trophicity of the muscles of the ruptured rotator cuff by CT scan [French]. *Rev Chir Orthop Repar Appar Mot* 1989;75:126-127.
2. 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.
3. Gerber C, Fuchs B, Hodler J: The results of repair of massive tears of the rotator cuff. *J Bone Joint Surg Am* 2000;82(4):505-515.
4. Thomazeau H, Boukobza E, Morcet N, Chaperon J, Langlais F: Prediction of rotator cuff repair results by magnetic resonance imaging. *Clin Orthop Relat Res* 1997;(344):275-283.
5. Warner JJ, Higgins L, Parsons IM IV, Dowdy P: Diagnosis and treatment of anterosuperior rotator cuff tears. *J Shoulder Elbow Surg* 2001;10(1):37-46.
6. Goutallier D, Postel JM, Gleyze P, Leguilloux P, Van Driessche S: Influence of cuff muscle fatty degeneration on

anatomic and functional outcomes after simple suture of full-thickness tears. *J Shoulder Elbow Surg* 2003;12(6):550-554.

7. Fuchs B, Gilbart MK, Hodler J, Gerber C: Clinical and structural results of open repair of an isolated one-tendon tear of the rotator cuff. *J Bone Joint Surg Am* 2006;88(2):309-316.

8. Jost B, Pfirrmann CW, Gerber C, Switzerland Z: Clinical outcome after structural failure of rotator cuff repairs. *J Bone Joint Surg Am* 2000;82(3):304-314.

9. Gerber C, Schneeberger AG, Hoppeler H, Meyer DC: Correlation of atrophy and fatty infiltration on strength and integrity of rotator cuff repairs: A study in thirteen patients. *J Shoulder Elbow Surg* 2007;16(6):691-696.

10. Gladstone JN, Bishop JY, Lo IK, Flatow EL: Fatty infiltration and atrophy of the rotator cuff do not improve after rotator cuff repair and correlate with poor functional outcome. *Am J Sports Med* 2007;35(5):719-728.

11. **Goutallier D, Postel JM, Radier C, Bernageau J, Zilber S: Long-term functional and structural outcome in patients with intact repairs 1 year after open transosseous rotator cuff repair. *J Shoulder Elbow Surg* 2009;18(4):521-528.**

12. **Melis B, DeFranco MJ, Chuinard C, Walch G: Natural history of fatty infiltration and atrophy of the supraspinatus muscle in rotator cuff tears. *Clin Orthop Relat Res* 2010; 468(6):1498-1505.**

13. Meyer DC, Hoppeler H, von Rechenberg B, Gerber C: A pathomechanical concept explains muscle loss and fatty muscular changes following surgical tendon release. *J Orthop Res* 2004;22(5):1004-1007.

14. Spencer EE Jr, Dunn WR, Wright RW, et al; Shoulder Multicenter Orthopaedic Outcomes Network: Interobserver agreement in the classification of rotator cuff tears using magnetic resonance imaging. *Am J Sports Med* 2008;36(1): 99-103.

15. Khoury V, Cardinal E, Brassard P: Atrophy and fatty infiltration of the supraspinatus muscle: Sonography versus MRI. *AJR Am J Roentgenol* 2008; 190(4):1105-1111.

16. **Oh JH, Kim SH, Choi JA, Kim Y, Oh CH: Reliability of the grading system for fatty degeneration of rotator cuff muscles. *Clin Orthop Relat Res* 2010; 468(6):1558-1564.**

17. Zanetti M, Gerber C, Hodler J: Quantitative assessment of the muscles of the rotator cuff with magnetic resonance imaging. *Invest Radiol* 1998; 33(3):163-170.

18. Gerber C, Meyer DC, Schneeberger AG, Hoppeler H, von Rechenberg B: Effect of tendon release and delayed repair on the structure of the muscles of the rotator cuff: An experimental study in sheep. *J Bone Joint Surg Am* 2004;86(9):1973-1982.

19. **Gerber C, Meyer DC, Frey E, et al: Neer Award 2007: Reversion of structural muscle changes caused by chronic rotator cuff tears using continuous musculotendinous traction: An experimental study in sheep. *J Shoulder Elbow Surg* 2009;18(2):163-171.**

20. Albritton MJ, Graham RD, Richards RS II, Basamania CJ: An anatomic study of the effects on the suprascapular nerve due to retraction of the supraspinatus muscle after a rotator cuff tear. *J Shoulder Elbow Surg* 2003;12(5):497-500.

21. Costouros JG, Porramatikul M, Lie DT, Warner JJ: Reversal of suprascapular neuropathy following arthroscopic repair of massive supraspinatus and infraspinatus rotator cuff tears. *Arthroscopy* 2007;23(11):1152-1161.

22. Mallon WJ, Wilson RJ, Basamania CJ: The association of suprascapular neuropathy with massive rotator cuff tears: A preliminary report. *J Shoulder Elbow Surg* 2006;15(4):395-398.

23. Vad VB, Southern D, Warren RF, Altchek DW, Dines D: Prevalence of peripheral neurologic injuries in rotator cuff tears with atrophy. *J Shoulder Elbow Surg* 2003;12(4):333-336.

24. **Rowshan K, Hadley S, Pham K, Caiozzo V, Lee TQ, Gupta R: Development of fatty atrophy after neurologic and rotator cuff injuries in an animal model of rotator cuff pathology. *J Bone Joint Surg Am* 2010;92(13):2270-2278.**

25. **Kim HM, Galatz LM, Lim C, Havlioglu N, Thomopoulos S: The effect of tear size and nerve injury on rotator cuff muscle fatty degeneration in a rodent animal model. *J Shoulder Elbow Surg* 2012;21(7):847-858.**

26. **Kang JR, Gupta R: Mechanisms of fatty degeneration in massive rotator cuff tears. *J Shoulder Elbow Surg* 2012; 21(2):175-180.**

27. **Laron D, Samagh SP, Liu X, Kim HT, Feeley BT: Muscle degeneration in rotator cuff tears. *J Shoulder Elbow Surg* 2012;21(2):164-174.**

28. **Smith MV, Calfee RP, Baumgarten KM, Brophy RH, Wright RW: Upper extremity-specific measures of disability and outcomes in orthopaedic surgery. *J Bone Joint Surg Am* 2012;94(3):277-285.**

29. Walch G, Boulahia A, Calderone S, Robinson AH: The 'dropping' and 'hornblower's' signs in evaluation of rotator-cuff tears. *J Bone Joint Surg Br* 1998;80(4):624-628.

30. Gerber C, Krushell RJ: Isolated rupture of the tendon of the subscapularis muscle: Clinical features in 16 cases. *J Bone Joint Surg Br* 1991;73(3):389-394.

31. Gerber C, Hersche O, Farron A: Isolated rupture of the subscapularis tendon. *J Bone Joint Surg Am* 1996;78(7):1015-1023.

32. Barth JR, Burkhart SS, De Beer JF: The bear-hug test: A new and sensitive test for diagnosing a subscapularis tear. *Arthroscopy* 2006;22(10):1076-1084.

33. **Gerber C, Wirth SH, Farshad M: Treatment options for massive rotator cuff tears. *J Shoulder Elbow Surg* 2011; 20(2 suppl):S20-S29.**

34. **Boykin RE, Friedman DJ, Higgins LD, Warner JJ: Suprascapular neuropathy. *J Bone Joint Surg Am* 2010;92(13):2348-2364.**

35. **Melis B, Wall B, Walch G: Natural history of infraspinatus fatty infiltration in rotator cuff tears. *J Shoulder Elbow Surg* 2010;19(5):757-763.**

36. Fuchs B, Weishaupt D, Zanetti M, Hodler J, Gerber C: Fatty degeneration of the muscles of the rotator cuff: Assessment by computed tomography versus magnetic resonance imaging. *J Shoulder Elbow Surg* 1999;8(6):599-605.

37. **Williams MD, Lädermann A, Melis B, Barthelemy R, Walch G: Fatty infiltration of the supraspinatus: A reliability study. *J Shoulder Elbow Surg* 2009;18(4):581-587.**

38. Strobel K, Hodler J, Meyer DC, Pfirrmann CW, Pirkl C, Zanetti M: Fatty atrophy of supraspinatus and infraspinatus muscles: Accuracy of US. *Radiology* 2005;237(2):584-589.

39. Ziegler DW: The use of in-office, orthopaedist-performed ultrasound of the shoulder to evaluate and manage rotator cuff disorders. *J Shoulder Elbow Surg* 2004;13(3):291-297.

40. **Tae SK, Oh JH, Kim SH, Chung SW, Yang JY, Back YW: Evaluation of fatty degeneration of the supraspinatus muscle using a new measuring tool and its correlation between multidetector computed tomography and magnetic resonance imaging. *Am J Sports Med* 2011;39(3):599-606.**

41. Pfirrmann CW, Schmid MR, Zanetti M, Jost B, Gerber C, Hodler J: Assessment of fat content in supraspinatus muscle with proton MR spectroscopy in asymptomatic volunteers and patients

with supraspinatus tendon lesions. *Radiology* 2004;232(3):709-715.

42. **Maman E, Harris C, White L, Tomlinson G, Shashank M, Boynton E: Outcome of nonoperative treatment of symptomatic rotator cuff tears monitored by magnetic resonance imaging. *J Bone Joint Surg Am* 2009;91(8):1898-1906.**

43. **Kim HM, Dahiya N, Teefey SA, Keener JD, Galatz LM, Yamaguchi K: Relationship of tear size and location to fatty degeneration of the rotator cuff. *J Bone Joint Surg Am* 2010;92(4):829-839.**

44. **Cheung S, Dillon E, Tham SC, et al: The presence of fatty infiltration in the infraspinatus: Its relation with the condition of the supraspinatus tendon. *Arthroscopy* 2011;27(4):463-470.**

45. Mochizuki T, Sugaya H, Uomizu M, et al: 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):962-969.

46. Zingg PO, Jost B, Sukthankar A, Buhler M, Pfirrmann CW, Gerber C: Clinical and structural outcomes of nonoperative management of massive rotator cuff tears. *J Bone Joint Surg Am* 2007;89(9):1928-1934.

47. Liem D, Lichtenberg S, Magosch P, Habermeyer P: Magnetic resonance imaging of arthroscopic supraspinatus tendon repair. *J Bone Joint Surg Am* 2007;89(8):1770-1776.

48. Burkhart SS, Barth JR, Richards DP, Zlatkin MB, Larsen M: Arthroscopic repair of massive rotator cuff tears with stage 3 and 4 fatty degeneration. *Arthroscopy* 2007;23(4):347-354.

49. **Gerber C, Meyer DC, Nuss KM, Farshad M: Anabolic steroids reduce muscle damage caused by rotator cuff tendon release in an experimental study in rabbits. *J Bone Joint Surg Am* 2011;93(23):2189-2195.**