Arthroscopic Rotator Cuff Repair

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Abstract

Arthroscopic rotator cuff repair is being performed by an increasing number of orthopaedic surgeons. The principles, techniques, and instrumentation have evolved to the extent that all patterns and sizes of rotator cuff tear, including massive tears, can now be repaired arthroscopically. Achieving a biomechanically stable construct is critical to biologic healing. The ideal repair construct must optimize suture-to-bone fixation, suture-to-tendon fixation, abrasion resistance of suture, suture strength, knot security, loop security, and restoration of the anatomic rotator cuff footprint (the surface area of bone to which the cuff tendons attach). By achieving optimized repair constructs, experienced arthroscopic surgeons are reporting results equal to those of open rotator cuff repair. As surgeons' arthroscopic skill levels increase through attendance at surgical skills courses and greater experience gained in the operating room, there will be an increasing trend toward arthroscopic repair of most rotator cuff pathology.

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The past decade has seen a major change in the way that rotator cuff surgery is performed. This change is the direct result of a paradigm shift in cuff repair. The paradigm shift itself is based on sound biomechanical principles coupled with a technological shift in the development of reliable, procedure-specific arthroscopic instrumentation. In a 2003 survey of 908 members of the Arthroscopy Association of North America (AANA) and the American Orthopaedic Society for Sports Medicine, the 700 surgeons who responded reported that they performed 24% of their rotator cuff repairs via an all-arthroscopic technique, whereas 5 years previously, they had performed only 5% of cuff repairs arthroscopically.[1] More recently, at the 2005 Annual Meeting of the American Academy of Ortho-paedic Surgeons, 167 orthopaedic surgeons attending a rotator cuff symposium session were polled electronically. In response to the question of how they would repair a mobile 3-cm rotator cuff tear, 62% answered that they would repair it arthroscopically.[2] These surveys demonstrate a substantial increase in the number of arthroscopic cuff repairs in just 7 years, and that rate is expected to accelerate during the next several years.

Thus, surgeons today are in the midst of a philosophical and technological paradigm shift that holds great promise for improving the well-being of patients who need rotator cuff surgery. To fully appreciate the scope of the changes requires understanding the current state of the art in arthroscopic rotator cuff repair, examining its development, and imagining its future.

Figure 1

$$\Sigma M_0 = O = C \times a - D \times A$$
$$D \times A = C \times a$$

$$\Sigma M_0 = O = I \times R - S \times r$$
$$\therefore I \times R = S \times r$$
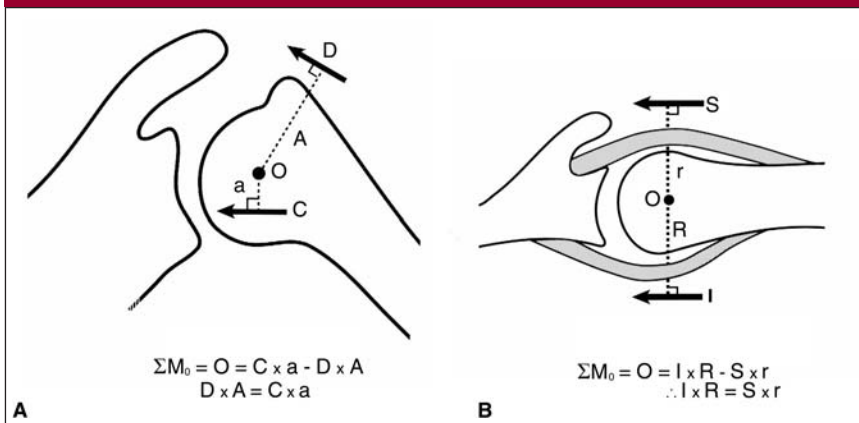
A, Coronal plane force couple. The inferior portion of the rotator cuff (below the center of rotation [O]) creates a moment that must balance the deltoid moment. **B,** Axillary view of transverse plane force couple. The subscapularis anteriorly is balanced against the infraspinatus and teres minor posteriorly. a = moment arm of the inferior portion of the rotator cuff, A = moment arm of the deltoid, C = resultant of rotator cuff forces, D = deltoid force, ΣM_0 = the sum of the moments about the center of rotation (O), I = infraspinatus, r = moment arm of the subscapularis, R = moment arm of the infraspinatus and teres minor, S = subscapularis

Figure 2

A, The transverse plane force couple (*left*) and the coronal plane force couple (*right*) are disrupted by a massive rotator cuff tear involving the posterior rotator cuff, infraspinatus, and teres minor. **B,** An alternative pattern of disruption of the transverse plane force couple. The transverse plane force couple is disrupted by a massive tear involving the anterior rotator cuff (ie, subscapularis). D = deltoid, I = infraspinatus, O = center of rotation, S = subscapularis, TM = teres minor

Biomechanical Function as a Predictor of Anatomic Structure

Form follows function. The human body is a prime example of this tenet of nature. When function is impaired, there is a derangement in form, or anatomy. Therefore, restoration of function requires solving the puzzle of how to restore the anatomy. The surgeon is presented with a structural disruption that can be repaired in one of several ways. The difficulty is in choosing the repair pattern (form) that will restore function, realizing that function is derived only from the proper application of the physical principles of biomechanics.
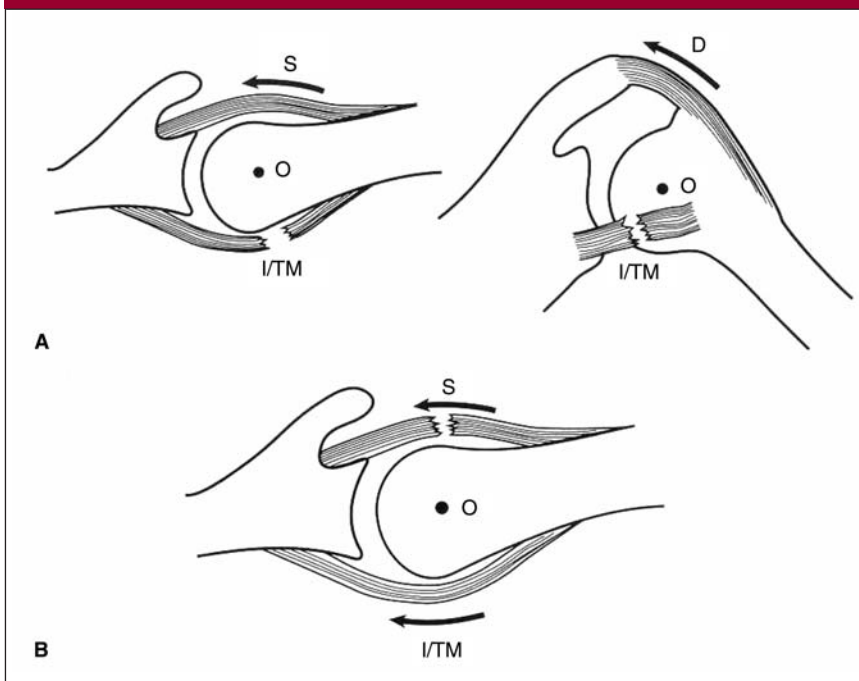
Recognizing the direct relationship between normal anatomy and normal biomechanics is the key to understanding how to properly repair disrupted tissue, whether by arthroscopic or open techniques. In the shoulder, as elsewhere in the body, biomechanical function is a consequence of the basic physiologic anatomic structure as well as of the interaction of tendons, muscles, and ligaments.

Balance of Force Couples

The intuitive solution to the problem of a torn rotator cuff is to "cover the hole." This can be done by techniques that disregard biomechanics (eg, subscapularis tendon transfer, freeze-dried allograft) to repair large rotator cuff defects. Unfortunately, the history of rotator cuff repair is filled with biomechanically unsound procedures.
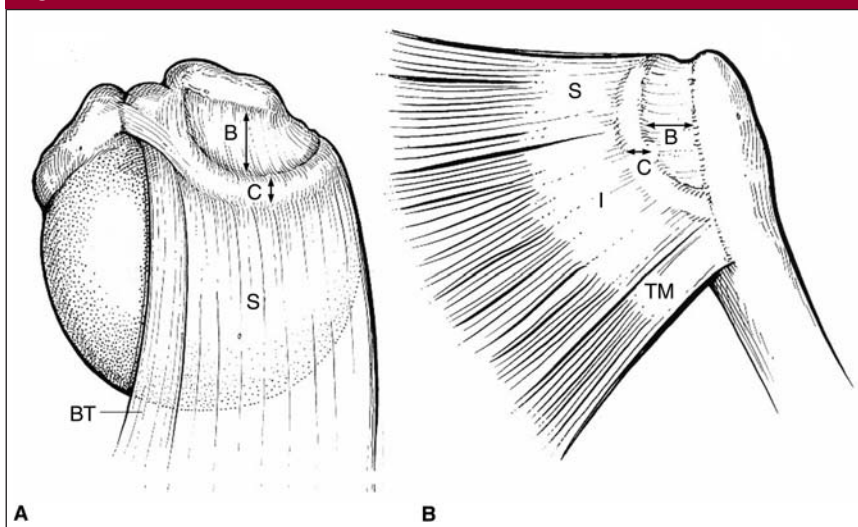
The muscles of the rotator cuff and the extrinsic shoulder muscles are positioned to create moments about the shoulder that will produce specific rotational motion. Furthermore, the shoulder can maintain a stable fulcrum of motion only when it maintains balanced force couples (ie, balanced moments) in both the coronal and transverse planes[3-5] (Figure 1). When these force couples are disrupted by a massive rotator cuff

Figure 3

Superior **(A)** and posterior **(B)** projections of the rotator cable and crescent. The rotator cable extends from the biceps tendon to the inferior margin of the infraspinatus, spanning the supraspinatus and infraspinatus insertions. B = mediolateral diameter of the rotator crescent, BT = biceps tendon, C = width of rotator cable, I = infraspinatus, S = supraspinatus, TM = teres minor

Figure 4
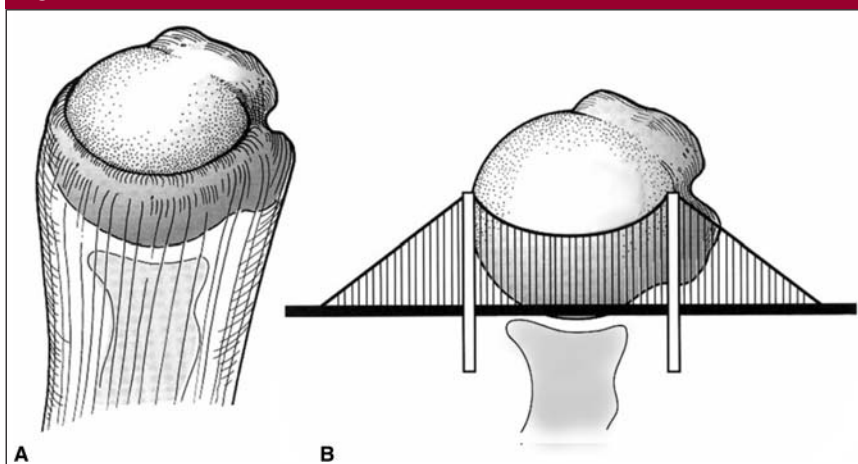
A, A rotator cuff tear can be modeled after a suspension bridge. **B,** The free margin corresponds to the cable, and the anterior and posterior attachments of the tear correspond to the supports at each end of the cable's span.

tear, the shoulder can no longer maintain a stable fulcrum, and active motion is lost (Figure 2). Thus, an overriding principle of cuff repair must be the restoration of balanced force couples. When rotator cuff repair restores the anterior and posterior forces so that the moments between the two are balanced, function will be restored, even in the presence of a persistent defect in the superior rotator cuff (supraspinatus).

The Rotator Cable

Another strong anatomic clue is related to the biomechanical function of the rotator cuff. The intact rotator cuff demonstrates an arching, cable-like thickening surrounding a thinner crescent of tissue that inserts into the greater tuberosity of the humerus; this is known as the cable-crescent complex.[6] This cable-like structure represents a thickening of the coracohumeral ligament and consistently is located at the margin of the avascular zone.[7] The rotator cable extends from its anterior attachment just posterior to the biceps tendon to its posterior attachment near the inferior border of the infraspinatus tendon (Figure 3). This rotator cable may function in a way that is analogous to a load-bearing suspension bridge. By this model, stress is transferred from the cuff muscles to the rotator cable as a distributed load, thereby stress-shielding the thinner, avascular crescent tissue, particularly in older individuals.

A rotator cuff tear similarly can be modeled after a suspension bridge, with the free margin of the tear corresponding to the cable and the anterior and posterior attachments of the tear corresponding to the supports at each end of the cable's span[8] (Figure 4). By this model, the supraspinatus muscle, even with a supraspinatus tendon tear, can still exert its compressive effect on the shoulder joint by means of its distributed load along the span of the suspension bridge configuration. Halder et al[9] confirmed the validity of this suspension bridge model in an in vitro biomechanical study.

Seeing and Reaching the Pathology

In general, if we can see the tear and reach it with arthroscopic instruments, we can repair it arthroscopically. Seeing the tear involves controlling bleeding, which requires a thorough understanding of fluid mechanics and turbulence control. To reach and repair the tear, the surgeon must possess an in-depth knowledge

Figure 5
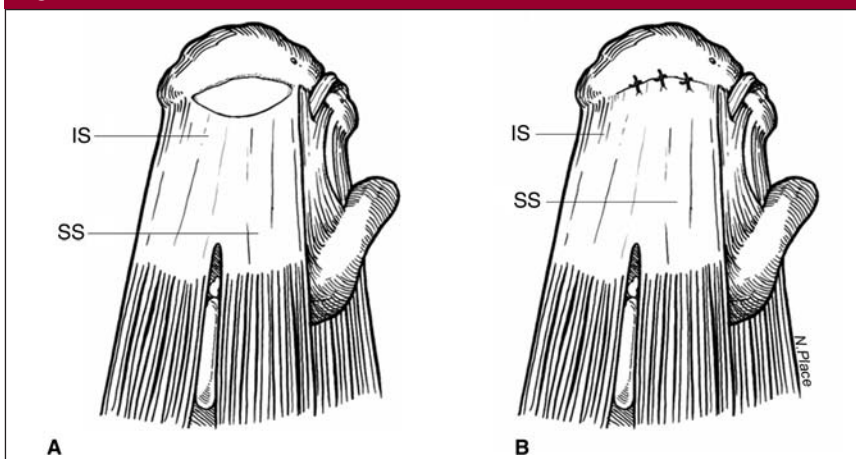
A, Superior view of a crescent-shaped rotator cuff tear involving the supraspinatus (SS) and infraspinatus (IS) tendons. **B,** Crescent-shaped tears demonstrate excellent mobility from a medial-to-lateral direction and may be repaired directly to bone.

of the anatomy of the shoulder to establish safe portals at an angle of approach that allows repair.

Seeing the Tear

There are four factors to consider in the control of bleeding: (1) patient blood pressure, (2) arthroscopic pump pressure, (3) rate of fluid flow, and (4) turbulence within the system. Generally, in the absence of medical contraindications, the patient's systolic blood pressure is maintained between 90 and 100 mm Hg. The arthroscopic pump pressure is run at 60 mm Hg; if bleeding impairs visualization, the pressure may be temporarily increased to 75 mm Hg for short periods (ie, 10 to 15 min). When possible, a dedicated separate 8-mm inflow cannula is used to maximize flow. It is best not to use arthroscopic instruments through the inflow cannula because they may create turbulence that hampers visualization.

The single most important (and least recognized) factor in controlling bleeding is turbulence control.[10] Turbulence results from rapid fluid flow out of the shoulder, which can occur through a skin portal that does not have a cannula. In such a situation, the Bernoulli effect creates a force at right angles to the streaming fluid that sucks the blood from the many capillaries in the subacromial space. Bleeding caused by turbulence can be controlled by obstructing fluid egress using simple digital pressure over the skin portals. This mechanism is separate from pressure distention of the subacromial space. In fact, increasing the pressure in the presence of turbulent flow makes the problem worse because it increases the speed of egress of the fluid from the skin portal, thereby increasing turbulence. Similarly, "chasing the bleeders" with electrocautery is counterproductive because the surgeon can never cauterize all of the bleeders as long as there is turbulence.

Reaching the Tear

To reach all parts of the cuff safely, the surgeon must be familiar with a variety of portals, including the modified Neviaser portal and the subclavicular portal.[11] Some surgeons prefer retrograde suture passage, with or without suture shuttles. When tissue quality is good, antegrade suture passage through a lateral portal is satisfactory. However, when tissue quality is suspect, the surgeon should perform retrograde suture passage to capture a larger bridge of tendon tissue for more secure fixation.

Tear Patterns

Open rotator cuff repair is performed through an anterolateral window (ie, incision). The surgeon must bring the cuff to that window to work on it; this spatial constraint can make it very difficult for the surgeon performing open cuff repair to properly evaluate and repair the tear. Furthermore, the anterolateral window has fostered a mindset of medial-to-lateral repair in surgeons performing open cuff repair.

Arthroscopy, however, frees the surgeon from spatial constraints. The surgeon may assess and approach the rotator cuff from several different angles to fully delineate the tear pattern and then repair it anatomically. Tear patterns are classified based on the shape and mobility of the tear margins. In our experience, most rotator cuff tears can be classified into four major categories: (1) crescent-shaped, (2) U-shaped, (3) L-shaped, and (4) massive, contracted, immobile tears.

Crescent-shaped tears are the classic standard tears, with excellent medial-to-lateral mobility, regardless of size (Figure 5, A). These tears may be repaired directly to bone with minimal tension (Figure 5, B).

U-shaped tears extend much farther medially than do crescent-shaped tears, with the apex of the tear adjacent to or medial to the glenoid rim (Figure 6, A). Recognizing this tear pattern is critical because attempting to medially mobilize and repair the apex of the tear to a lateral bone bed will result in extreme tensile stresses in the middle of the repaired cuff margin, causing tensile overload and subsequent failure. Sequential side-to-side suturing, from

Figure 6
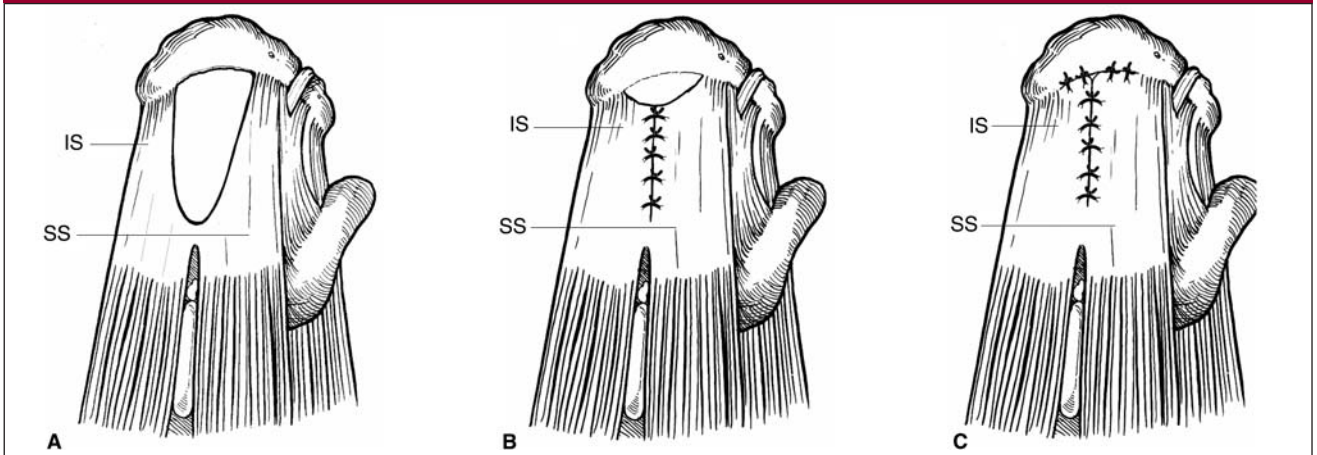
A, Superior view of a U-shaped rotator cuff tear involving the supraspinatus (SS) and infraspinatus (IS) tendons. **B,** The first step in repair is done with side-to-side sutures using the principle of margin convergence. **C,** The free margin is then repaired to bone in a tension-free manner.

Figure 7
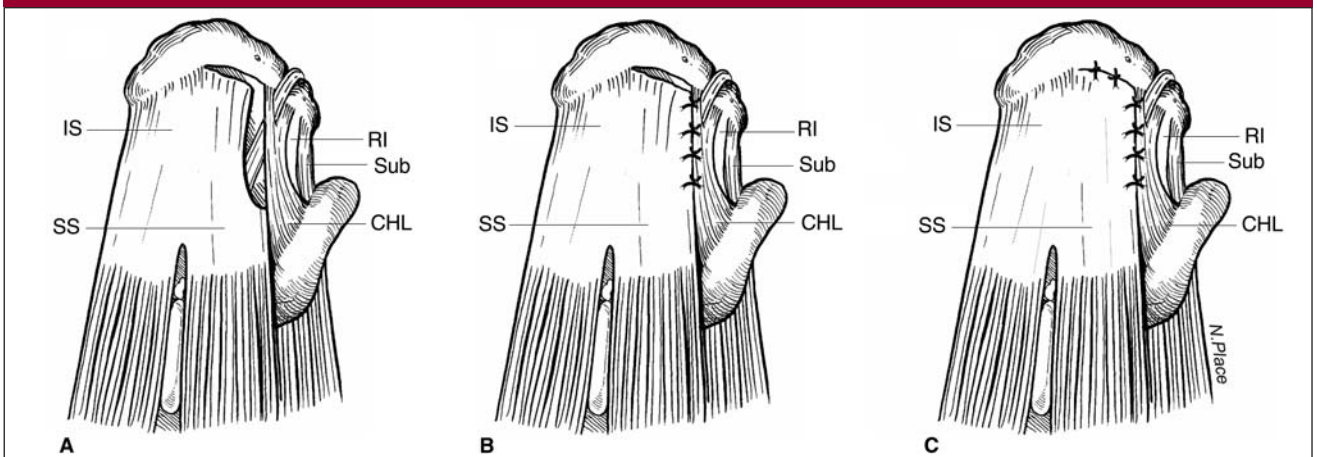
A, Superior view of an acute L-shaped rotator cuff tear involving the supraspinatus (SS) and rotator interval (RI). **B,** The acute L-shaped tear should be initially repaired along the longitudinal split. **C,** The converged margin is then repaired to bone. CHL = coracohumeral ligament, IS = infraspinatus, Sub = subscapularis

medial to lateral, of the anterior and posterior leaves of the tear causes the free margin of the rotator cuff to converge toward the bone bed on the humerus (Figure 6, B). The free margin of the rotator cuff can then be easily repaired to the bone bed in a tension-free manner (Figure 6, C). The technique of margin convergence not only allows repair of seemingly irreparable tears but also minimizes strain at the repair site, thereby providing an added degree of protection for the tendon-to-bone component of the repair.

L-shaped and reverse L-shaped tears are similar to U-shaped tears. However, in the L-shaped tear, one of the leaves is more mobile than the other leaf and can be more easily brought to the bone bed and to the other leaf (Figure 7, A). The apex of the L is identified, and the longitudinal split is sutured in a side-to-side manner (Figure 7, B), after which the converged margin is repaired to bone (Figure 7, C).

In the chronic L-shaped tear, the physiologic pull of the rotator cuff muscles posteriorly causes the tear to assume a more U-shaped configuration (Figure 8, A). It is imperative that the surgeon determine which

Figure 8
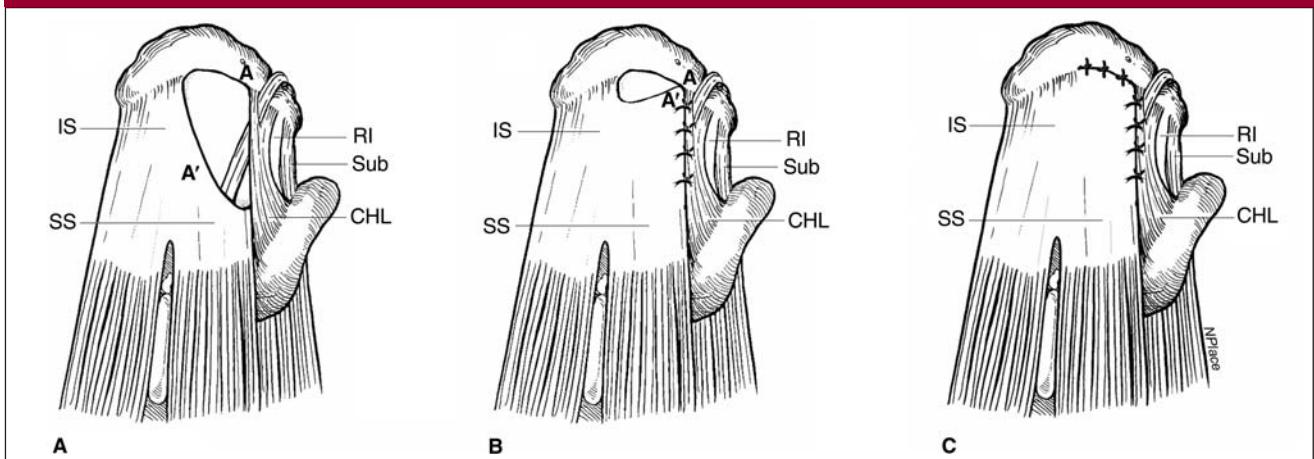
A, Superior view of a chronic L-shaped tear that has assumed a U-shaped configuration. **B,** L-shaped tear demonstrating excellent mobility from an anterior to posterior direction; however, one of the tear margins (usually the posterior leaf) is more mobile. The tear is initially repaired using side-to-side sutures (A' → A) via the principle of margin convergence. **C,** The converged margin is then repaired to bone in a tension-free manner. CHL = coracohumeral ligament, IS = infraspinatus, RI = rotator interval, SS = supraspinatus, Sub = subscapularis
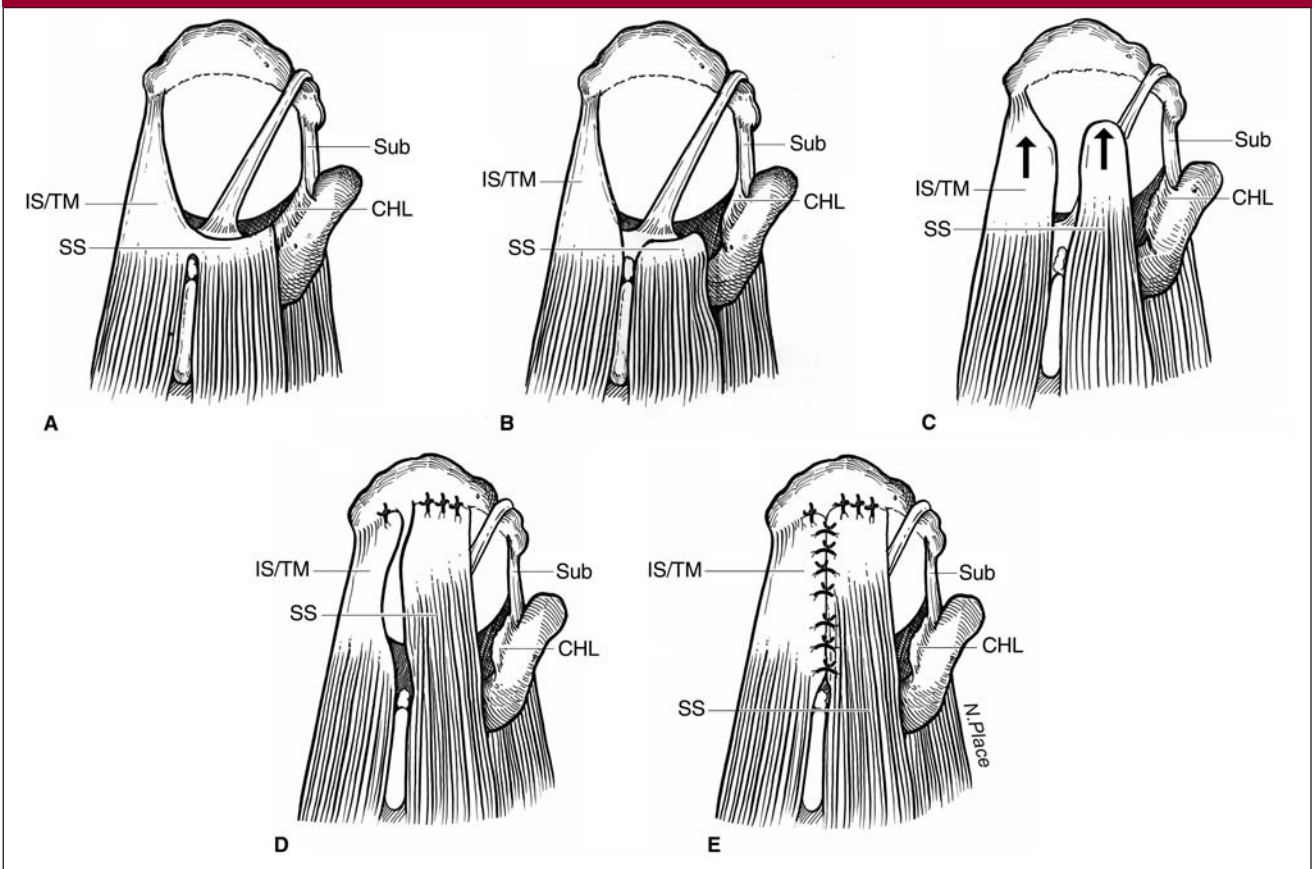
Figure 9
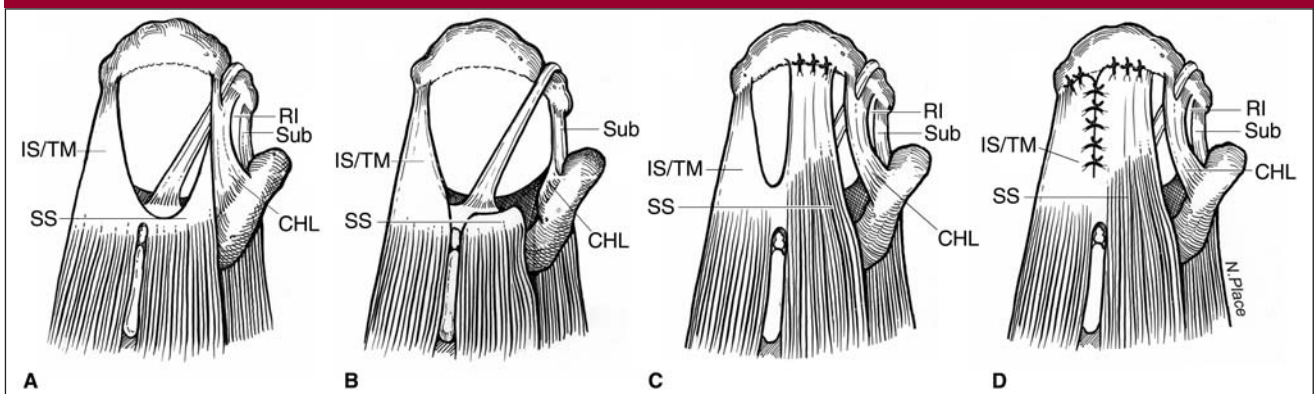
A, Superior view of a massive, contracted, immobile longitudinal rotator cuff tear. **B,** An anterior interval slide is performed, incising the interval between the supraspinatus tendon (SS) and the rotator interval (RI). **C,** The improved mobility from the release allows repair of the supraspinatus tendon to a lateral bone bed. **D,** The posterior leaf of the tear, consisting of the infraspinatus and teres minor (IS/TM), is then advanced superiorly and laterally, and the residual longitudinal defect is closed by side-to-side sutures. CHL = coracohumeral ligament, Sub = subscapularis

leaf is more mobile and where the "corner" of the L-shaped tear needs to be restored. First, a traction suture is placed at the corner to visually establish its location. Subsequently, side-to-side suture along the longitudinal split will accomplish margin convergence (Figure 8, B), followed by repair of the converged margin to bone (Figure 8, C).

In our experience, these first three tear patterns represent >90% of posterosuperior rotator cuff tears.[12] Using the principles outlined above, most rotator cuff tears, even massive ones, can be arthroscopically repaired without extensive mobilization. Repairing a tear according to its pattern can produce excellent results. However, the fourth tear pattern (ie, the massive, contracted, immobile rotator cuff tear) requires more sophisticated techniques.[12] These tears demonstrate no mobility from medial to lateral or from anterior to posterior; thus, they cannot be repaired directly to bone or side-to-side with margin convergence. Such massive, contracted, immobile cuff tears represent 9.6% of the massive

Figure 10

A, Superior view of a massive, contracted, immobile crescent rotator cuff tear. **B,** A double interval slide is performed, consisting first of an anterior interval slide followed by a posterior interval slide, releasing the interval between the supraspinatus (SS) and infraspinatus (IS) tendons. **C,** After release there is improved mobility (arrows) of the supraspinatus tendon and the infraspinatus/teres minor (IS/TM) posteriorly. **D,** The supraspinatus is then repaired to a lateral bone bed in a tension-free manner, and the infraspinatus/teres minor tendons are advanced laterally and superiorly. **E,** The residual defect is closed with side-to-side sutures. CHL = coracohumeral, Sub = subscapularis

tears in the senior author's referral-based practice and probably a much lesser percentage in most other practices.[12] They are difficult to manage because simple arthroscopic débridement typically does not result in any increase in strength, motion, or function, although pain relief may be achieved.[13]

These massive tears present in one of two patterns: massive contracted longitudinal (Figure 9) and massive contracted crescent (Figure 10). In massive contracted longitudinal tears, the "tongue" of supraspinatus tendon at the anterior margin of the tear is useful during repair after appropriate mobilization. In general, massive contracted crescent tears are wider in an anterior-to-posterior direction than the massive contracted longitudinal tears, making them more difficult to repair.

Although these two contracted immobile tear patterns were previously considered irreparable (a term that continues to be redefined), many large tears may now be repaired via advanced arthroscopic mobilization techniques. These advanced arthroscopic mobilization techniques are modifications of interval slide techniques performed during open surgery.[14-19]

The arthroscopic anterior interval slide, originally described by Tau-ro,[18] improves the mobility of the rotator cuff by releasing the interval between the supraspinatus tendon and the rotator interval, effectively incising the coracohumeral ligament, which becomes contracted in these tears. A cutting instrument is introduced through a lateral or accessory lateral portal, and the release is oriented toward the base of the coracoid (Figure 9, B). Using an anterior interval slide typically gains 1 to 2 cm of additional lateral excursion of the supraspinatus tendon. For massive contracted longitudinal tears, this is often adequate to allow tendon-to-bone repair of the supraspinatus (Figure 9, C), followed

Figure 11
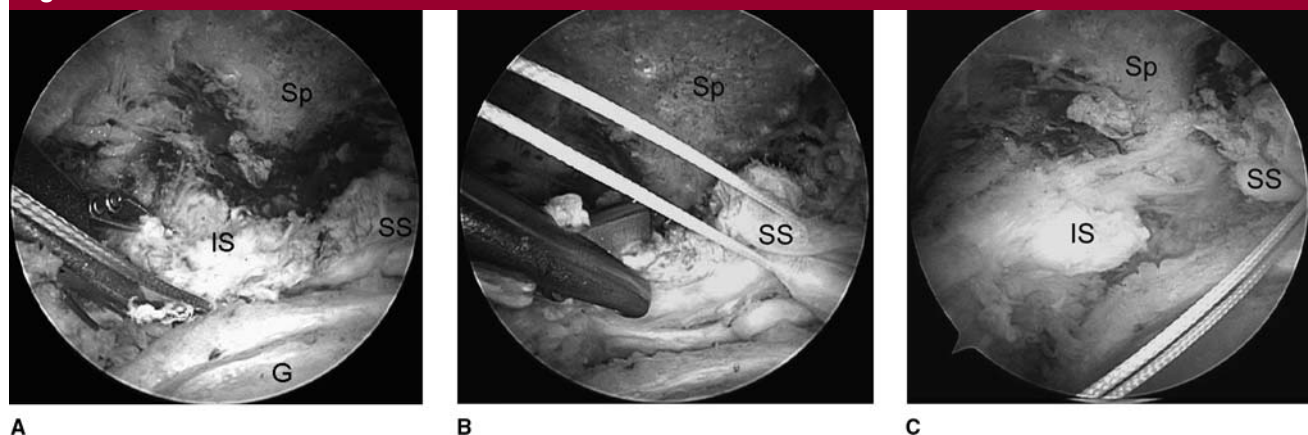
Arthroscopic images of the steps in a posterior interval slide. **A,** Arthroscopic view of a right shoulder from a lateral portal demonstrating the arching column of the scapular spine (Sp), which serves as a marker between the supraspinatus (SS) and infraspinatus (IS) tendons. A Viper suture passer (Arthrex, Naples, FL) is used to pass traction sutures into each tendon. **B,** Release of the posterior margin of the supraspinatus tendon from the infraspinatus using a basket punch. **C,** Completed posterior interval slide demonstrating complete release of the infraspinatus from the supraspinatus, revealing the scapular spine. Care is taken to avoid injury to the underlying suprascapular nerve. G = glenoid

by side-to-side suture plus advancement of the infraspinatus on the bone bed, if possible (Figure 9, D).

For massive contracted crescent tears, 1 to 2 cm of additional lateral excursion of the tendon usually is not enough to allow tendon-to-bone repair. In such cases, a double interval slide (ie, anterior interval slide plus posterior interval slide) often can achieve dramatic improvement in lateral excursion (up to 5 cm of additional lateral mobility of both the supraspinatus and the infraspinatus) (Figure 10). The posterior interval slide generally improves the lateral excursion of the infraspinatus tendon sufficiently to repair most or all of the infraspinatus to bone. Repair of at least the inferior half of the infraspinatus is critical because that amount of functional infraspinatus is necessary to restore the posterior moment, thereby balancing the transverse plane force couple to reestablish a normal glenohumeral fulcrum.

When performing a posterior interval slide, the scapular spine must be cleared of its surrounding subacromial fibroadipose tissue so that it can be clearly seen through a lateral viewing portal (Figure 11, A). When cleared of soft tissue, the scapular spine resembles the keel of a boat, and it serves as a marker between the supraspinatus and infraspinatus (Figure 11, B).

The suprascapular nerve is potentially at risk during the posterior interval slide. It curves tightly around the base of the scapular spine at its junction with the posterior glenoid neck, enveloped within a fat pad.[20] Care must be taken to lift the soft tissue away from the bone when cutting, avoiding the bone surfaces with the cutting instrument, and stopping the release when the fat pad at the base of the scapular spine is visible (Figure 11, C). After the release, if a complete repair is not possible, as much of a partial repair as is possible should be done.[21]

Patients with single- and double-interval slides have demonstrated marked improvement not only in pain, but also in active range of motion, strength, and overall shoulder function.[12] Because these results are far superior to débridement alone, we no longer perform arthroscopic débridement alone.

Biomechanics of Rotator Cuff Fixation

During the past 12 years, several biomechanical studies have been conducted with the collective intent of optimizing the strength of rotator cuff fixation.[22-28] As a result, current cuff fixation constructs are greatly superior to those of just a few years ago. Even so, the importance of tear pattern recognition must not be underestimated. An incorrectly repaired tear may have such large strains at the tear margin that a secure repair cannot be accomplished—for example, a U-shaped tear repaired strictly by medial-to-lateral fixation to bone, without margin convergence sutures.

For U- and L-shaped tears, side-to-side sutures that achieve margin convergence have the unique biomechanical property of significantly reducing strain at the tear margin.[29] Side-to-side closure of two thirds of a U-shaped tear reduces strain at the tear margin by a factor of six, thus dramatically enhancing the security of the fixation and safeguarding

against failure of the repair construct.

Under cyclic loads, transosseous rotator cuff repair constructs fail at low numbers of cycles because of cutting of the suture through bone.[22,23] Transosseous rotator cuff repair constructs were particularly susceptible to this mode of failure when the distal bone holes were made through metaphyseal bone rather than through thick cortical bone.

In contrast, under cyclic loads, rotator cuff repair constructs secured to bone by suture anchors did not fail at the bone-suture anchor interface but rather because the suture cut through the tendon. On average, these failures occurred at higher cycles than similar transosseous repairs. Thus, by using suture anchors, the weak link was effectively transferred from the bone to the rotator cuff tendon.[22]

After transferring the weak link to the suture-tendon interface, the next task was to optimize that weak link by finding the best way to minimize suture cutout through tendon. Doubling the number of fixation points of suture to tendon would reduce the load in each suture by 50%. The easiest way to do this was to double-load each suture anchor. Burkhart et al[24] confirmed the load reduction of this construct experimentally.

Optimization of the anchor pullout strength is desirable. It has been shown mathematically that the pullout angle (ie, deadman angle), which is the angle of insertion of the suture anchor, and the tension-reduction angle both should be ≤45° (Figure 12). A deadman angle ≤45° will significantly resist anchor pullout.[30]

A second factor in choosing an anchor relates to suture abrasion. Suture abrasion that primarily arises during arthroscopic knot tying can occur at the knot itself or as the suture slides through the anchor eyelet, abrades against bone, or slides through the knot pusher. Lo et al[25]

Figure 12
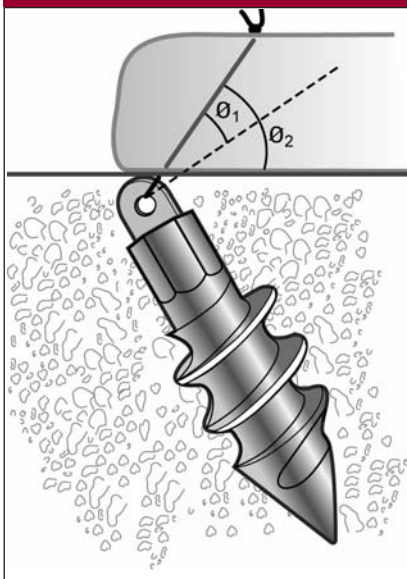
Proper anchor insertion at the deadman angle. θ_1 is the pullout angle for the anchor (angle the suture makes perpendicular to the anchor). θ_2 is the tension-reduction angle (angle the suture makes with the direction of pull of the rotator cuff). Ideally, θ_1 and θ_2 should both be ≤45°.

tested a variety of metal and biodegradable polymer anchors for suture abrasion and confirmed the findings of Bardana et al,[26] who showed that metal anchors demonstrate markedly more suture abrasion than do polymer biodegradable anchors. However, the results among various designs of biodegradable anchors were markedly different, as well. One common biodegradable anchor design incorporates a hole through the polymer body to form the suture eyelet (Panalok RC anchor and 3.5-mm Panalok; Mitek, Westwood, MA). This design failed by cutting of the Ethibond suture (Ethicon, Somerville, NJ) through the suture eyelet at low cycles (11.2 cycles to failure for the Panalok RC; 12.5 cycles to failure for the 3.5-mm Panalok). In another biodegradable suture anchor design, the eyelet consists of a flexible loop of no. 5 polyester suture that is insert-molded into the body

of the anchor (Biocorkscrew; Arthrex, Naples, FL). Cyclic abrasion testing demonstrated failure through the Ethibond suture rather than through the eyelet of the anchor, at significantly higher cycles than the other biodegradable anchor designs.

Many factors influence the choice of suture anchor. To be effective, the anchors must possess certain minimal strength characteristics. In general, nearly all commercially available suture anchors satisfy these minimal strength requirements.

Optimizing suture type for strength, abrasion resistance, and knot security was the next step in improving the strength of rotator cuff fixation. Lo et al[25] compared no. 2 Ethibond, the most commonly used suture in rotator cuff repair, with no. 2 Fiberwire (Arthrex). No. 2 Fiberwire is a recently introduced braided, nonabsorbable, polyblend suture with an ultimate strength to failure that is roughly equivalent to that of no. 5 Ethibond. Interestingly, no. 2 Fiberwire failed at notably higher cycles compared with no. 2 Ethibond under all tested abrasion conditions, even when using metallic anchors.[25] In fact, no. 2 Fiberwire failed at cycles 5 to 51 times higher than did no. 2 Ethibond and at cyclic loading levels at which abrasion from the suture eyelet is probably clinically irrelevant. Other high-strength sutures have recently become available and may be preferred by some surgeons.

The final component needed to optimize rotator cuff repair is the arthroscopic knot. The ideal knot must achieve the optimal balance of knot security and loop security. Knot security, which is the effectiveness of the knot at resisting slippage when load is applied, depends on three factors: friction, internal interference, and slack between throws. Loop security is the ability to maintain a tight suture loop around tissue as the knot is tied. Thus, it is possible for any knot to have good knot approximation and security but poor

Figure 13
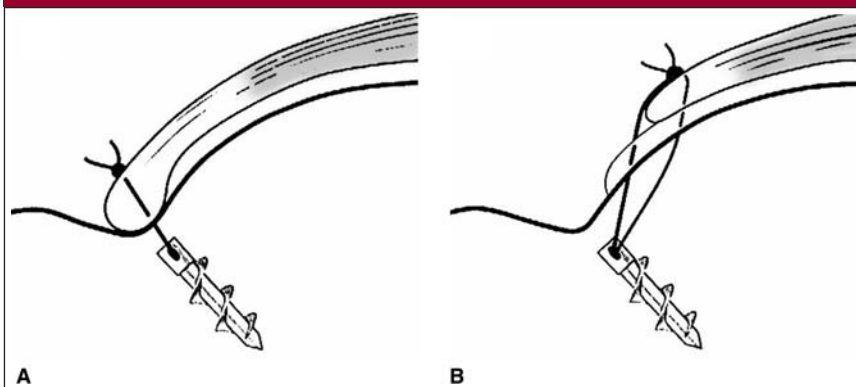
A, A tight suture loop holds the soft tissue tightly apposed to the prepared bone bed. **B,** A loose loop allows the soft tissue to pull away from the prepared bone bed, regardless of how securely the knot is tied.

Figure 14
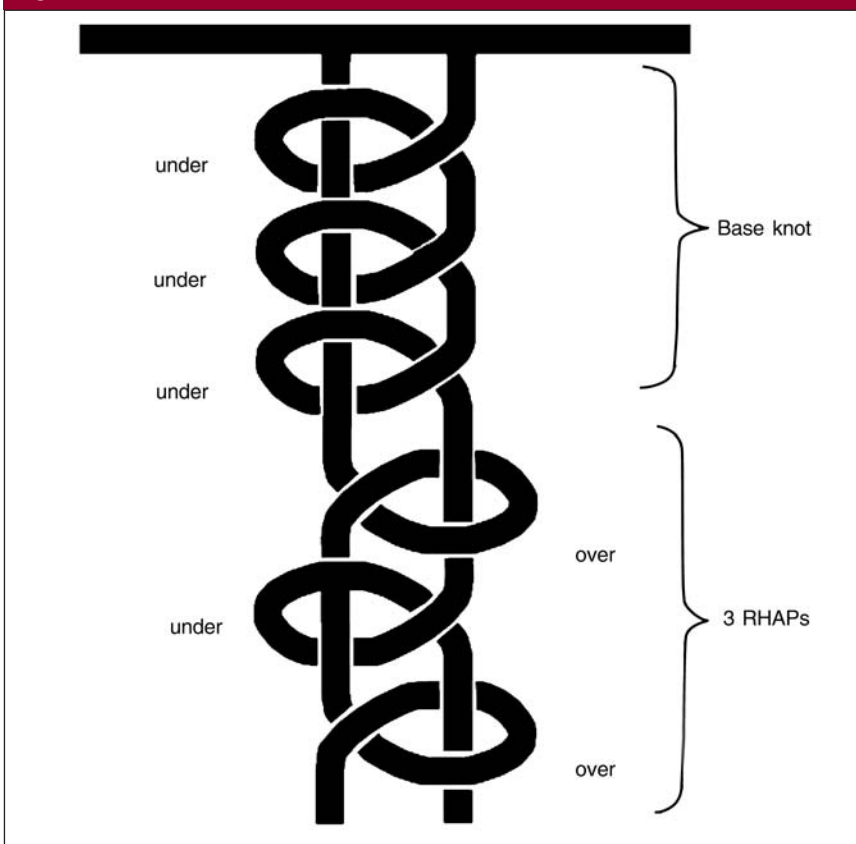
Static surgeon's knot. RHAPs = reversing half-hitches on alternating posts

loop security (eg, a loose suture loop) and, therefore, to be ineffective at approximating the tissue edges to be repaired (Figure 13).

The best combination of knot security and loop security is the arthroscopic surgeon's knot, which is a static (nonsliding) knot composed of a base knot of three half hitches in the same direction, followed by three reversing half-hitches on alternating posts (RHAPs)[27] (Figure 14). When a complex sliding knot is used, it is optimized and fully "locked" (ie, it will fail by breakage rather than slippage) only if the sliding knot is followed by three stacked RHAPs on top of it. Of 12 different sliding knots that were tested, the Roeder knot with three RHAPs provided the optimal balance of knot security and loop security.[27] Even so, the static arthroscopic surgeon's knot displayed even better characteristics of knot security and loop security than any of the sliding knots.

Burkhart et al[28] performed a biomechanical study comparing the loop security of various half-hitch combinations when tied with a standard single-hole knot pusher with the loop security of the same knots tied with the double-diameter knot pusher (Surgeon's Sixth Finger; Arthrex). The cannulated double-diameter knot pusher maintains loop security by means of pressure from the tip of the cannulated inner diameter tube against the first throw of the knot; subsequent throws are advanced with a sliding plastic outer-diameter tube (Figure 15). Thus, sequential half hitches may be secured without the suture loop becoming lax. The loop security of knots tied with the double-diameter knot pusher was superior to that of other methods.

Finally, restoration of the entire rotator cuff footprint, or tendon-to-bone contact area, will more effectively transmit rotator cuff forces to bone and may improve the potential for complete healing. A recent study by Galatz et al[31] showed a 94% incidence of recurrent rotator cuff defects after arthroscopic repair by a single-row medial-to-lateral technique.

The information on arthroscopic repair must be interpreted in the context of established results for open rotator cuff repair. Larger tear

Figure 15

The double-diameter knot pusher (Surgeon's Sixth Finger; Arthrex), consists of an inner (I) metallic tube with a sliding plastic outer (O) tube. A suture threader (T) is used to pass the suture limb through the inner metallic tube.

size is a predisposing factor for recurrence.[32-36] In fact, Harryman et al[33] showed by postoperative ultrasound that 68% of three-tendon cuff tears repaired by open surgery had recurrent defects. Many technical and biologic factors influence the results of rotator cuff repair.

The rotator cuff footprint may be completely reestablished arthroscopically by means of a double-row suture anchor repair, assuming that there is enough lateral excursion of the tendons to allow this. A medial row of anchors (one or two rows) is placed adjacent to the articular margin, and sutures are passed to secure the cuff with mattress sutures. Then a lateral row of anchors is placed, with simple sutures to secure the tendon edge.[37]

The Optimum Repair Construct

A series of studies was performed to determine the optimum rotator cuff repair construct.[22-25,27-30,37] The best construct would optimize suture-to-bone fixation, suture-to-tendon fixation, abrasion resistance of the suture, suture strength, knot security, and loop security. Research indicates that the optimized construct consists of doubly loaded biodegradable polymer suture anchors with insert-molded suture eyelets; no. 2 Fiberwire suture; and six-throw arthroscopic surgeon's knots with three RHAPs, tied with a double-diameter knot pusher.[22-25,27,28,30] When possible, a double-row repair may be used

in an attempt to optimize the footprint of the repaired rotator cuff. A medial row of suture anchors is placed at the articular margin of the bone bed, and the rotator cuff is secured with mattress sutures. In addition, a lateral row of suture anchors is placed on the greater tuberosity, securing the tendon edge with simple sutures.

Subscapularis Tendon Tears

Arthroscopic repair of the torn subscapularis tendon poses unique technical challenges. First, the available working space for arthroscopic instrumentation in this part of the shoulder is quite confined, so we typically repair the subscapularis first, before soft-tissue swelling compromises the space even further. Second, coracoid impingement with subcoracoid stenosis is frequently part of the problem, often necessitating arthroscopic coracoplasty.[38-40] Finally, subscapularis tears may be accompanied by medial subluxation of the biceps, requiring the surgeon to perform arthroscopic tenotomy or tenodesis of the long head of the biceps.[41]

With chronic retracted subscapularis tears, identification of the subscapularis tendon can be problematic. We have identified a consistent structure that appears arthroscopically as a comma-shaped arc of ligamentous tissue that is always located at the superolateral border of the subscapularis and can be used to locate that border. The comma sign is

Figure 16
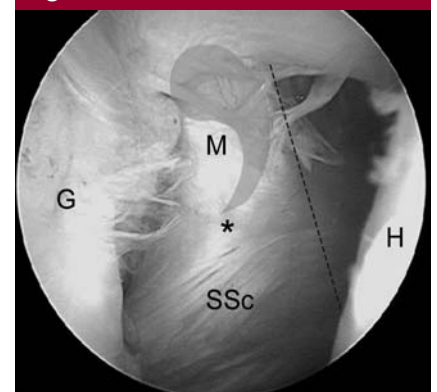
The comma sign is visible in this right shoulder with a retracted subscapularis tear, as viewed through a posterior portal. The comma is an arc-shaped structure adjoining the superolateral border of the subscapularis tendon (SSc). This structure is formed when the medial sling of the biceps tears away from its footprint on the lesser tuberosity of the humerus, directly adjacent to the footprint of the upper subscapularis. The lateral border of the comma defines the lateral border of the subscapularis (dotted line). G = glenoid, H = humerus, M = medial sling of biceps (comma), * = junction of medial sling and upper border of subscapularis muscle

formed by a portion of the superior glenohumeral/coracohumeral ligament complex that has torn away from the humerus[42] (Figure 16). This ligament complex, which functions as the medial sling of the biceps tendon before disruption, is consistently present as a guide to the subscapularis.

Figure 17
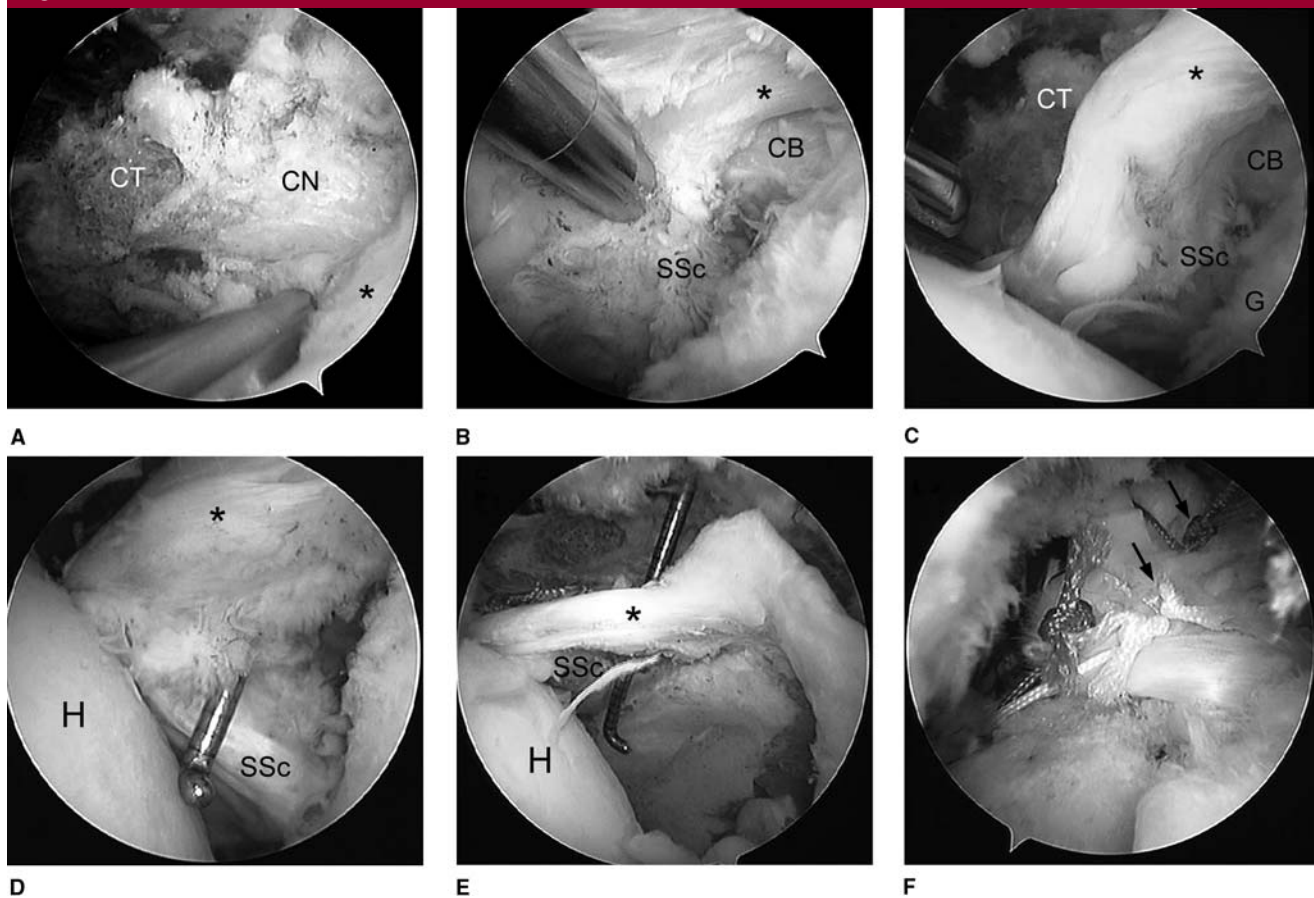
Interval slide in continuity. **A,** Arthroscopic lateral portal view of a left shoulder. A shaver is introduced through an accessory lateral portal and is used to dissect and expose the coracoid neck, in essence releasing and excising the origin of coracohumeral ligament from the lateral aspect of the coracoid. Here, a coracoplasty has been performed. **B,** Lateral portal view. A shaver is introduced through an accessory lateral portal and is used to excise the medial rotator interval while preserving an intact lateral bridge of rotator interval tissue containing the comma sign. The coracohumeral ligament is completely released and excised from the lateral aspect of the base of the coracoid. **C,** Posterior portal view demonstrating a completed interval slide in continuity. A lateral bridge of rotator interval tissue has been maintained, which contains the comma sign and leads to the superolateral aspect of the torn subscapularis tendon. The coracoid tip and coracoid base are visible on either side of the comma sign. **D,** A completed subscapularis repair. Posterior portal view using a 30° arthroscope demonstrating the intra-articular perspective. The comma sign is still intact. The hooked probe demonstrates the interval slide in continuity. **E,** Lateral portal view demonstrating a residual U-shaped posterosuperior rotator cuff defect, which can be closed with margin convergence. The intact lateral portion of the rotator interval serves as an anterior leaf that can be repaired to the posterior leaf of the rotator cuff. A hooked probe has been placed within the defect created by the interval slide in continuity. **F,** Lateral portal view following repair of a U-shaped rotator cuff tear. The intact lateral portion of the rotator interval, including the tissue of the comma sign, is incorporated into the side-to-side sutures (arrows). CB = coracoid base, CN = coracoid neck, CT = coracoid tip, G = glenoid, H = humerus, SSc = subscapularis tendon, * = comma sign

Massive, Contracted, Immobile Anterosuperior Rotator Cuff Tears

The arthroscopic approach to mobilizing contracted immobile tears must be different when the subscapularis tendon is chronically torn along with the supraspinatus and infraspinatus (anterosuperior tears) because the coracohumeral ligament has a propensity to rigidly shorten and tether the cuff medially. The interval slide in continuity is a useful technique in these complex cases.[43]

In this procedure, the coracohumeral ligament is released by dissecting it "in continuity" from the base of the coracoid, preserving an intact lateral bridge of rotator interval tissue containing the comma sign. This release generally produces enough additional lateral ex-

cursion of the subscapularis to permit its direct repair to its bone bed on the lesser tuberosity. The residual defect in the cuff is then closed according to standard principles. When margin convergence is indicated, the intact lateral portion of the rotator interval serves as an anterior leaf that can be repaired to the posterior leaf of the rotator cuff (Figure 17).

The Future

The future of arthroscopic rotator cuff repair can be discussed from two standpoints: educational initiatives in arthroscopic rotator cuff repair and refinements in technique. The AANA and the AAOS have both been active in providing hands-on cadaveric skills courses at the Orthopaedic Learning Center in Rosemont, Illinois. A twice-yearly course offered by the AANA to orthopaedic residents at a reduced price exposes surgeons-in-training to advanced skills at an early stage. Remote transmission of live arthroscopic rotator cuff surgery by the AANA to large meetings of surgeons allows interactive discussion between the shoulder surgeon and the audience as the case is being performed.

Refinement of technique is progressing rapidly. Already, the expert arthroscopic surgeon can achieve mechanically stable rotator cuff constructs that are as good as, or better than, those that are achievable by open means. Furthermore, these constructs produce excellent clinical and anatomic results. These results should not be surprising because mechanical stability always enhances biologic healing. Knotless fixation, although appealing, requires further development. Even if knotless anchors are developed that are as secure as those requiring knots, there will still be a frequent need for side-to-side sutures. Currently, side-to-side suture generally requires knots.

Summary

Arthroscopic rotator cuff repair has undergone dramatic refinements during the past few years. The surgeon who is accomplished in these techniques can now produce results that are as good as or better than those produced by open techniques. Achieving a biomechanically stable construct is critically important, and this can now be reproducibly accomplished via arthroscopic means. In the next 10 years, the trend toward all-arthroscopic rotator cuff repair will increase, and the results will demonstrate clinical effectiveness.

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Evidence-based Medicine: There are no level I or level II randomized controlled comparative studies referenced. Level III, IV, case reported, or case-controlled studies are presented along with several level V expert opinion referenced articles describing surgical techniques.

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