Technical Note

Margin Convergence: A Method of Reducing Strain in Massive Rotator Cuff Tears

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Summary: Increased security of fixation in rotator cuff repair is usually achieved by increasing the strength of fixation. Paradoxically, the problem can be approached by techniques that decrease the strain at the margins of the tear so that weaker fixation will still be adequate. Such techniques provide greater safety tolerances for the strength characteristics of suture, tendon, and bone. The principle of margin convergence can be applied to rotator cuff repair as a means to enhance the security of fixation by decreasing the mechanical strain at the margins of the tear. This strain reduction should also contribute to pain reduction by virtue of decreased stimulation of mechanoreceptors in the rotator cuff. The cliché *no pain, no strain* can be converted to a paradigm by reversal of its components to *no strain, no pain.* **Key Words:** Rotator cuff—Rotator cuff repair—Strain—Shoulder pain.

Much has recently been written and presented about the strength and security of rotator cuff repair.[1-5] A successful result demands a technique with fixation strong enough to hold the repair and prevent extension of the tear. It is equally logical to approach the problem of tissue fixation security from a diametrically opposite and paradoxical viewpoint. Instead of emphasizing stronger fixation methods, one can identify and use techniques that reduce the strain along the cuff margin so that weaker tissue fixation will still be adequate. In this way, we are more likely to have sufficient safety tolerances for the strength characteristics of suture, tendon, and bone, making suture breakage, tendon failure, and bone failure less likely. Instead of roping the bull, we harness the ox.

STRAIN CONSIDERATIONS IN ROTATOR CUFF REPAIRS

The engineering definition of axial strain (ϵ) is change in length (ΔL) per initial length (L) of a material that undergoes a uniaxial deforming force.

The strain in a rotator cuff tear can be seen to be the change in the medial-to-lateral dimension of the tear divided by the initial (preload) medial-to-lateral dimension of the tear ($\Delta L/L$). The load in this case would be the resultant longitudinal force caused by contraction of the rotator cuff musculature acting across the tear (Fig 1). For the sake of simplicity, assume that the rotator cuff consists of an elastic, isotropic, homogeneous material, which is subjected to infinitesimal strain. Also assume that the cross-sectional area remains constant along the tear length. The strain is related to the length of the tear and the cross-sectional area of intact tissue according to the formula[6]:

$$\epsilon \text{ (strain)} = \frac{\Delta L}{L} = \frac{F}{AE}$$

where
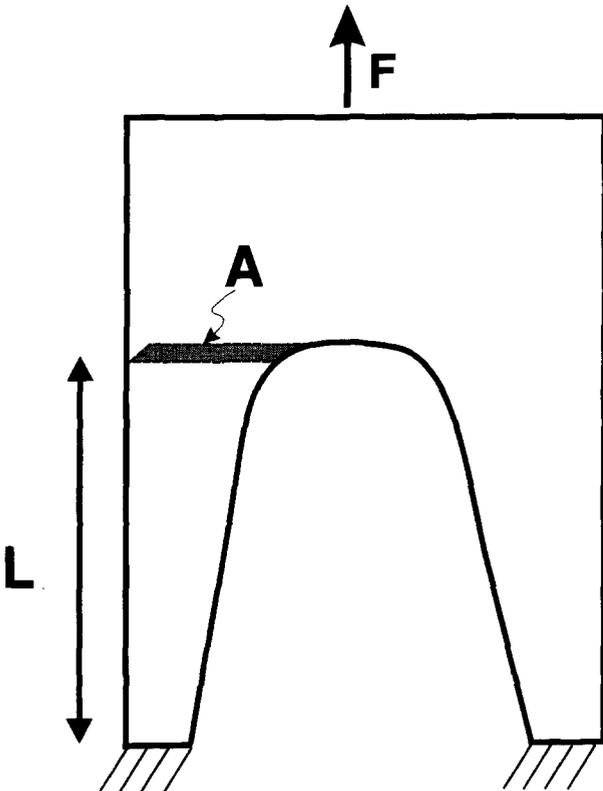
FIG 1. Diagrammatic representation of linear strain and elongation. A force (F) applied to a rotator cuff tear of length L will cause an elongation of the tear (ΔL). Elongation is related to strain according to the formula

$$\epsilon \text{ (strain)} = \frac{\Delta L}{L} = \frac{F}{AE}$$

where A = cross-sectional area of intact cuff at level of strain measurement and E = modulus of elasticity (Young's modulus).

L = Medial-to-lateral dimension of cuff tear
A = Cross-sectional area of intact cuff at level of strain measurement
F = Resultant longitudinal rotator cuff force
E = Modulus of elasticity (Young's modulus)

It is not uncommon for rotator cuff tears to extend medially to the glenoid. In such cases, it is often not possible to pull the free margin of the tear all the way over to the greater tuberosity for direct repair to bone. However, many of these U-shaped tears can be partially closed in a side-to-side manner. But does this side-to-side repair improve the mechanical characteristics of the cuff tear sufficiently to justify this technique? A simple mechanical analysis will lead us to the answer.

Strain Reduction in Side-to-Side Repairs

Consider the case of a large U-shaped rotator cuff tear. Such a tear can be converted to a smaller crescent-shaped tear by side-to-side repair, effecting a "margin convergence" of the tear toward the greater tuberosity (Fig 2). This technique shifts adjacent tissue into the defect, increasing the cross-sectional area (A). It also shortens the medial-to-lateral dimension of the defect, decreasing L. Both of these factors can significantly decrease the strain in the rotator cuff.

One can easily show the strain reduction in the rotator cuff by converting a U-shaped tear (Fig 3) to a crescent-shaped tear. Consider the hypothetical case in which the tear is closed side-to-side along two thirds of its length. In this case, $L_1 = 3L_2$; that is, the residual cuff defect after partial repair is one third the length of the original defect. Assume that the cross-sectional area (A_2) after repair is twice the prerepair area (A_1), so that $A_2 = 2A_1$. The resultant rotator cuff force (F) acting on both areas does not change ($F_1 = F_2 = F$). So,

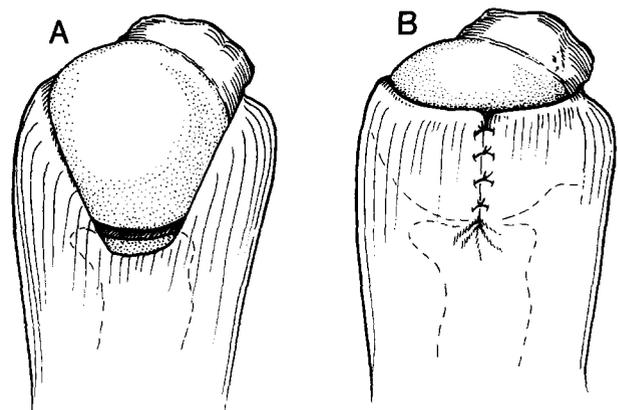$$\Delta L_1 = \frac{F_1 L_1}{A_1 E}$$
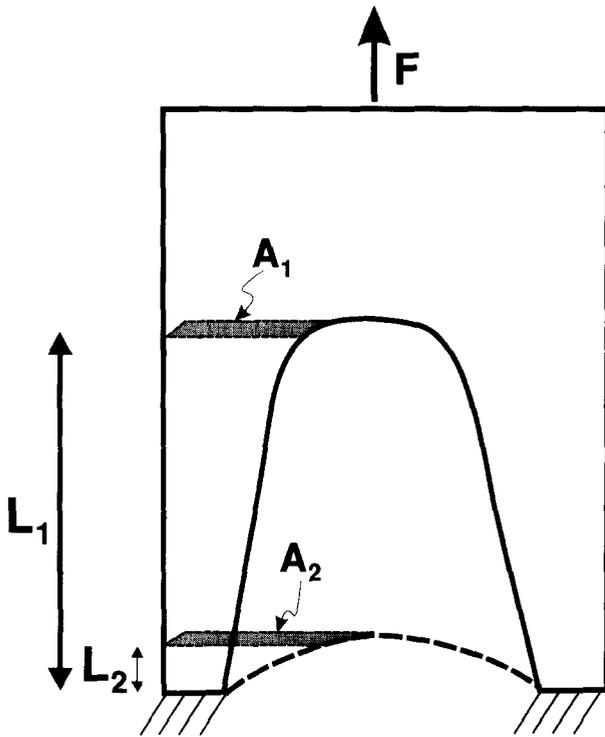
and

$$\Delta L_2 = \frac{F_2 L_2}{A_2 E}$$

Substituting the above relationships into the equations:

$$\frac{\Delta L_1}{\Delta L_2} = \frac{L_1 A_2}{L_2 A_1} = \frac{(3L_2)(2A_1)}{L_2 A_1} = 6$$

Therefore $\Delta L_1 = 6\Delta L_2$

FIG 2. (A) U-shaped rotator cuff tear. (B) Partial side-to-side repair causes a "margin convergence" of the tear toward the greater tuberosity. This increases the cross-sectional area and decreases the length of the tear, thereby decreasing strain.

FIG 3. Free body diagram showing the mechanical conditions before and after partial side-to-side repair. The length of the tear has been reduced from L_1 to L_2, and the cross-sectional area of the cuff tissue at the apex of the margin of the tear has been increased from A_1 to A_2. These changes decrease the elongation of the tear and decrease the strain at the tear margin.

This means that the fiber elongation in the repaired configuration is only one sixth the elongation in the prerepair configuration, giving a sixfold reduction in elongation (ΔL) by simple side-to-side repair. Of course, it should be borne in mind that, even after side-to-side repair, a significant stress concentration will still remain in the rotator cuff due to the interruption of uniformity of the cuff's cross-sectional area. These high stresses around the edge of the defect will nevertheless still be substantially smaller than those in the prerepair configuration.

Margin Convergence

One would anticipate that the strain reduction shown in the example above would be protective in two ways:

(1) It should be protective against suture failure as well as propagation of the tear if the cuff is left in the crescent-shaped configuration; and

(2) it should be protective of a repair of the free margin to bone, should the surgeon elect to repair the re-configured crescent-shaped free margin to bone.

Since we have shifted (converged) the free margin of the rotator cuff closer to its anatomic insertion on the greater tuberosity by side-to-side repair, we have called this margin-shift phenomenon "margin convergence" (Fig. 2).

No Strain, No Pain

Connective tissue has been shown to be highly endowed with free nerve endings that act as pain receptors.[7-10] A recent biochemical assay study[11] has shown, a large number of pain receptors in the subacromial space, both in the tendons and in the bursa.

Decreased strain should produce decreased stimulation of pain receptors in the shoulder[12] in the same way that decreased strain causes decreased stimulation of mechanoreceptors in the knee.[8] If so, this effect could enhance function; a less painful shoulder would naturally be a more functional shoulder.

No pain, no strain. This cliché can be converted to a paradigm by reversal of its components to *no strain, no pain.*

CONCLUSIONS

Side-to-side repair of large rotator cuff tears produces the phenomenon of margin convergence, or shift of the free margin of the tear toward the greater tuberosity. Such a repair can provide significant reductions in rotator cuff deformation, even without repair of the tear margins to bone. The associated strain reductions may be a significant factor in protecting side-to-side rotator cuff repairs against failure. Strain reduction should also be effective in protecting against suture failure as well as propagation of the tear if the cuff margin is not repaired to bone. If the cuff margin is repaired to bone, after partial side-to-side repair, the strain reduction afforded by the side-to-side repair should be protective of the repaired margin to bone. In a cuff tear that cannot be completely repaired, the surgeon should consider a partial side-to-side repair to take advantage of the strain reduction. It is possible that the reduced strain can enhance function indirectly by decreased mechanical stimulation of pain receptors in the rotator cuff, because deformation of these receptors should decrease as the strain decreases.

REFERENCES

1. France EP, Paulos LE, Harner CD, Straight B. Biomechanical evaluation of rotator cuff fixation methods. *Am J Sports Med* 1989;17:176-181.
2. Sward L, Hughes JS, Amis A, Wallace WA. The strength of

surgical repairs of the rotator cuff. A biomechanical study on cadavers. *J Bone Joint Surg Br* 1992;74:585-588.

3. Gerber C, Schneeberger AG, Beck M, Schlegel U. Mechanical strength of repairs of the rotator cuff. *J Bone Joint Surg Br* 1994;76:371-380.

4. Craft DV, Moseley JB II. Fixation strength of rotator cuff repairs with third-generation suture anchors versus the transosseous suture technique. Presented at the 62nd Annual Meeting of the American Academy of Orthopaedic Surgeons, Orlando, FL, February 18, 1995.

5. Caldwell GL II, Warner JJP, Miller MD, Towers J, Debski RE. Transosseous rotator cuff fixation: The weak link? A biomechanical investigation. Presented at the 62nd Annual Meeting of the American Academy of Orthopaedic Surgeons, Orlando, FL, February 18, 1995.

6. Riley WF, Zachary LW. Axial loading: Applications and pressure vessels. In: *Introduction to mechanics.* New York: John Wiley, 1989:87-89.

7. Leeson TS, Leeson CR. Histology. Ed 4. Philadelphia: WB Saunders, 1981:538-541.

8. Schultz RA, Miller DC, Kerr CS, Micheli L. Mechanoreceptors in human cruciate ligaments. *J Bone Joint Surg Am* 1984;66: 1072-1076.

9. Kelly DD. Central representations of pain and analgesia. In Kandell ER, Schwartz JH, eds. *Principles of neural science.* Ed 2. New York: Elsevier, 1985:330-343.

10. Assimakopoulos AP, Katonis PG, Agapitos MV, Exarchou EI. The innervation of the human meniscus. *Clin Orthop* 1992;275: 232-236.

11. Saifer TB, Levy HJ, Saifer FM, Kleinbart F, Vigorita V, Bryk E. Neurohistology of the subacromial space. Presented at the 61st Annual Meeting of the American Academy of Orthopaedic Surgeons, New Orleans, LA, February 1994.

12. Ochs S. Receptors and effectors. In Selkurt EE, ed. *Physiology.* Ed 3. Boston: Little, Brown, 1971:59-66.