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TECHNIQUE

Transosseous Anchor Double Knot (TOAK) Technique for Rotator Cuff Repair

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ABSTRACT

Numerous peer-reviewed publications have documented the improved functional outcomes in patients with successful, structurally intact repairs of the rotator cuff. This article details one of the biomechanically strongest techniques for rotator cuff repair using a unique combination of suture anchors and transosseous fixation: the Trans-Osseous Anchor Double Knot (TOAK) Technique.

HISTORICAL PERSPECTIVE

Since the time of Codman, surgeons have sought to provide a secure surgical construct for the repair of rotator cuff tears that allows both structural healing and improvement in function.[1–13] With advancements in suture materials and suturing techniques, numerous peer-reviewed reports have documented the improved outcomes in patients who maintain a diagnostically proven, structurally intact tendon repair at long term follow-up.[14–17] Gerber et al reported a significantly reduced failure rate in massive rotator cuff repairs, from 74% to 34%, with the use of modified Mason–Allen sutures and bone augmentation with a plate.[9,10]

Over a several year time period after the advent of suture anchors, the senior author has developed a biomechanically confirmed strong and secure cuff fixation that eliminates the potential risk for loose hardware in the subacromial space.[18] This open surgical technique, the Trans-Osseous Anchor Double Knot (TOAK) technique, utilizes a unique combination of single-row suture anchor fixation and concomitant transosseous sutures.

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INDICATIONS/ CONTRAINDICATIONS

The TOAK technique is indicated for any patient undergoing open rotator cuff repair, regardless of tendon size. Unfortunately, it is impossible to perform this procedure arthroscopically. It can be used in the context of a mini-open approach after an arthroscopic subacromial decompression and/or arthroscopic distal clavicle resection. There are no specific contraindications to this technique.

PREOPERATIVE PLANNING

As with any repair technique for the rotator cuff, preoperative evaluation generally includes an MRI or an MR arthrogram. The degree of retraction and trophicity of the involved rotator cuff musculature must be determined prior to undertaking rotator cuff repair. We agree with Burkhart et al that fatty infiltration of the cuff musculature (although perhaps irreversible) is not specifically a contraindication to rotator cuff repair, and does not necessarily portend a poor prognosis with regard to patient outcomes. The operating surgeon should be thoroughly familiar with mobilization techniques for the rotator cuff and appropriate handling/repair of the deltoid, which are beyond the scope of this manuscript.

SURGICAL TECHNIQUE

When the surgical procedure has reached the stage for final tendon-to-bone repair of the torn cuff, a very shallow (3 to 5 mm deep) but broad bony trough should be created from the sulcus to the tuberosity (Fig. 1A). The medial-lateral breadth of the trough should be approximately 10 mm. A deep trough into cancellous bone is not recommended, since the distal end of the tendon will ''kink'' and the footprint restoration will not be anatomic. The lateral edge of the articular cartilage should be ''beveled'' to make the transition from cartilage to bone smooth and allow anatomic recreation of the cuff footprint 3 to 5 mm below the top of the humeral head (Fig. 1B).

The senior author prefers the use of metallic suture anchors with double-loaded nonabsorbable sutures (5.0 mm Corkscrew with double-loaded Fiberwire suture, Arthrex, Naples, FL). However, suture anchors, regardless of type, are now inserted at an appropriate ''deadman's angle'' into the medial edge of the prepared bony trough (just medial to the cartilage bone junction) (Fig. 2). We use 1 anchor per centimeter of cuff tear in the sagittal plane (anterior to posterior) dimension. All suture strands from each anchor are then passed in a horizontal mattress fashion (inferior to superior) through the cuff tendon at a distance of 1 cm from the distal tendon edge. Once all sutures are passed, the sutures are tied, securing the tendon into the trough with these medial mattress stitches. The ends of the sutures are *not* cut above the knots, since the sutures will be ''reused'' through the lateral portion of the tendon (Fig. 3).

The greater tuberosity is now perforated for transosseous tunnels with any standard technique just lateral to the row of anchors and also on the lateral cortical margin of the tuberosity. We prefer to use either a small drill (1.8–2.0 mm) or a sharp awl. One limb from each of the suture pairs is now passed though the distal (lateral) portion of the torn tendon in a mattress fashion to begin a modified Mason–Allen stitch with 2 passes. That suture limb will now be on the superior portion of the tendon again after the 2 passes (Fig. 4A). The other suture limb is then passed from superior to inferior medial to the previous stitch—completing the Mason–Allen stitch (Fig. 4B). This limb will now be on the inferior portion of the tendon. Again, this should be performed for each of the suture pairs from each anchor (Fig. 4C).

The inferior limb from each suture pair is finally passed through the transosseous tunnels. A secure knot is tied on the lateral cortical margin of the greater tuberosity, and the cuff is securely restored to its anatomic footprint. The final repair construct demonstrates no prominence of the knots on the superior surface of the cuff—thereby preventing any ''knot impingement'' in the acromiohumeral articulation (Fig. 5).

■ POSTOPERATIVE CARE

Postoperative immobilization and protocol for progressive motion and resistance is the same that would be used for any rotator cuff repair per surgeon preference.

■ COMPLICATIONS

Suture breakage during knot tying was an infrequently encountered complication prior to the use of the current anchor/suture combination by the senior author. With the current materials, suture breakage has not been experienced.

■ BIOMECHANICAL TESTING OF THE TOAK TECHNIQUE

This technique has been tested both statically and dynamically against both single anchor mattress suture fixation and also against transosseous modified Mason–Allen suture fixation without anchors. Eighteen fresh-frozen cadaveric specimens with a mean age of 62 years were used in each limb of the biomechanical study. Specimens from elderly individuals were specifically

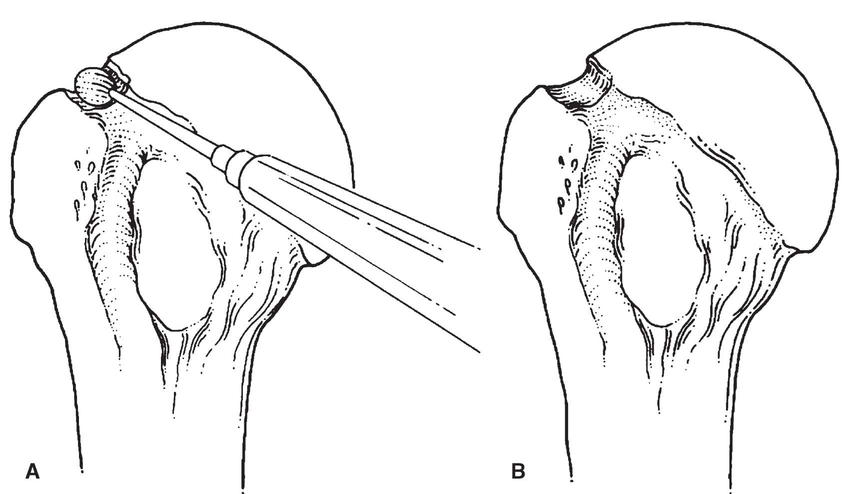

FIGURE 1. A, Hand burr used to prepare greater tuberosity. B, Final tuberosity preparation (3 to 5 mm below top of humeral head).

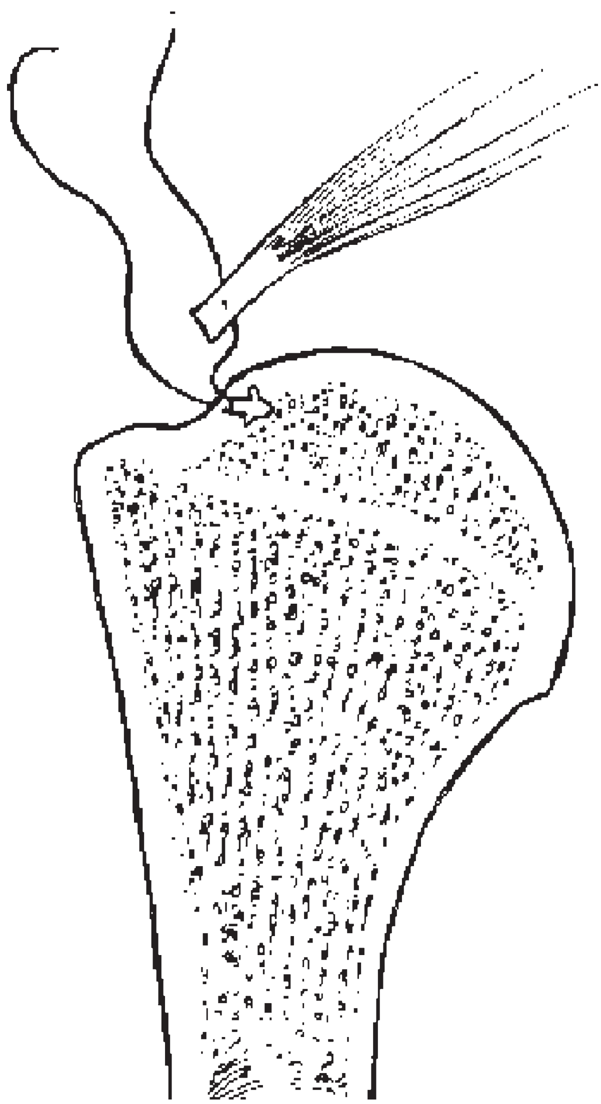

FIGURE 2. Insertion of suture anchors at medial edge of prepared trough using "deadman's angle."

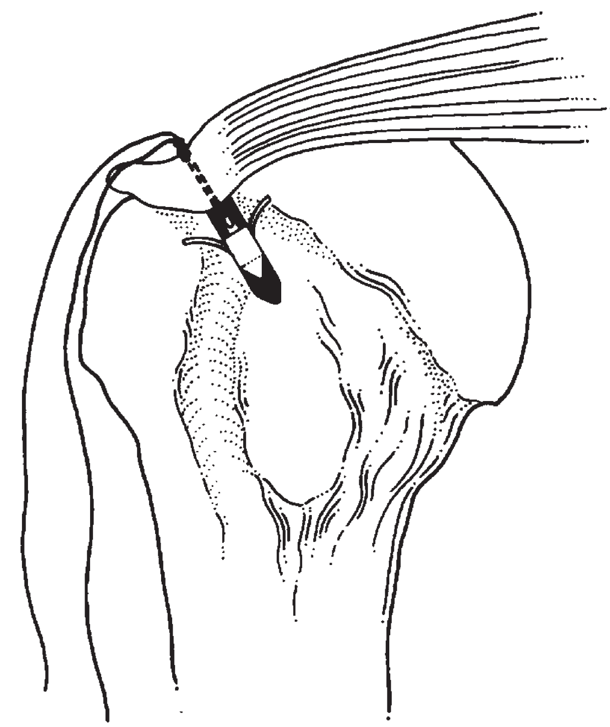

FIGURE 3. All suture strands are passed through cuff 1 cm medial to tendon edge. These horizontal mattress sutures are tied but ends are not cut.

selected because the relatively poor bone quality in this age group provided the initial impetus for the development of this surgical technique.

A simple, inexpensive radiographic densitometry method was used to help sort the specimens into groups for mechanical testing.[19] Standardized anterior-posterior roentgenograms were made of each specimen. The specimen was radiographed with an aluminum step wedge that consisted of 1.0 mm (±0.00) steps ranging from 6–14 mm. The supraspinatus muscle was dissected subperiosteally out of its fossa. With the exception of the supraspinatus muscle and its humeral insertion, all soft tissue from the proximal 20 cm of each humerus was also manually removed. Using sharp dissection, the supraspinatus tendon was then detached from its insertion into the greater tuberosity.

A ridged aluminum clamp was manufactured that allowed the musculotendinous junction and a large portion of the remainder of the supraspinatus muscle belly to be firmly grasped. Each of the 18 specimens was tested using an MTS servo-hydraulic test machine (Bionix 858, MTS Inc, Minneapolis, MN) with a 500 pound load cell. Roentgenographic densitometry measurements were made using a digital optical densitometer. The densitometric-determined mm determined for each bone location was then normalized by dividing this number by the anterior-posterior diameter of the humeral head (measured in the center). Consequently, these data can be used to approximate "bone quality" and hence load-carrying capacity.

A 6 cm long, 0.47 mm (3/16 inch) diameter threaded Steinmann pin was drilled transcortically in a transverse direction across the end of each bone. The cut end of the diaphysis was then potted 3 cm deep into a block of polymethyl methacrylate (PMMA) (Buehler Inc, Lake Bluff, IL) (Fig. 6). Using a 5 mm diameter power burr, a shallow trough was then fashioned in the area of the anatomic insertion of the supraspinatus. Specifically, the trough extended from 1 mm medial to the articular margin, across the sulcus, to the medial edge of the proximal greater tuberosity. The medial-lateral breadth of the trough was, therefore, approximately 10 mm. The trough was also deepened to just begin to expose cancellous bone. The detached supraspinatus tendon of each bone was reattached

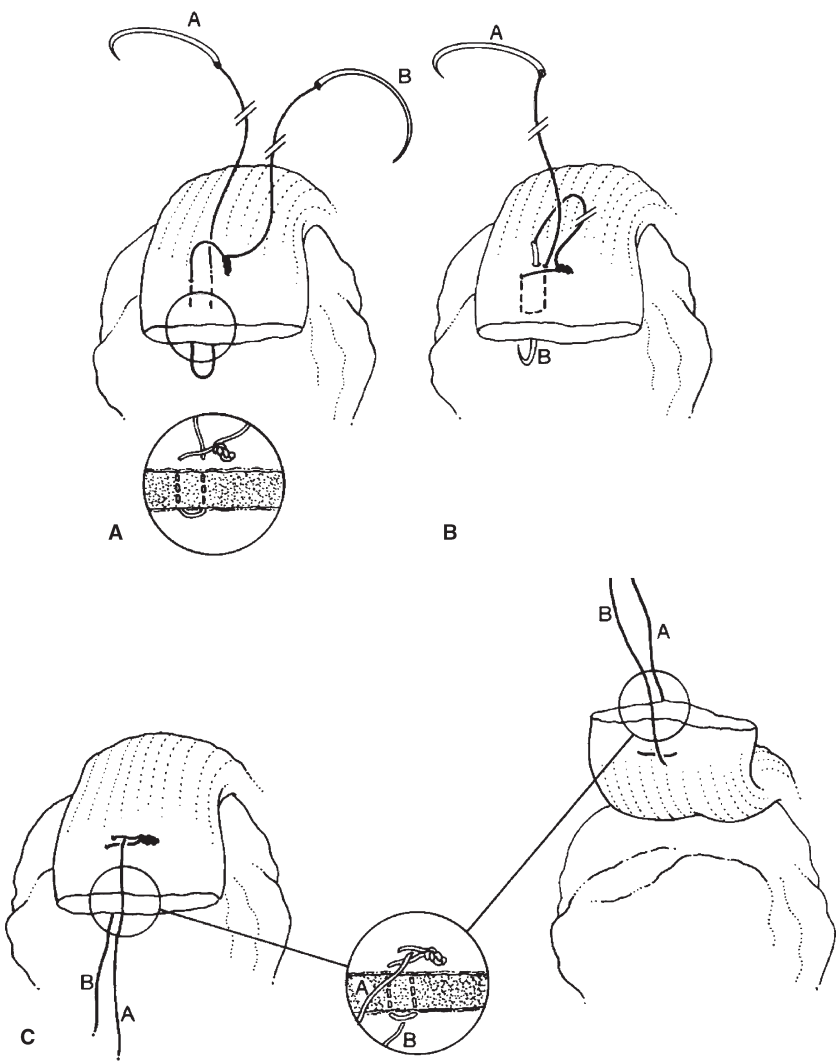

FIGURE 4. A, One suture limb (Limb A) from each pair of sutures is passed in a mattress fashion through the distal portion of the tendon. B, The second limb (Limb B) from each pair is now passed medial to the mattress suture from Limb A, completing the modified Mason-Allen stitch. C, Completed appearance of each pair of sutures after passing through distal portion of tendon.

according to the protocol defined for each group as outlined below. In all cases, #2 braided, nonabsorbable suture (Ethibond) (Ethicon Inc, Westwood, MA) was used.

Group 1: Trans-Osseous Suture, Single Knot Fixation

Using a 2 mm diameter drill bit and power drill, 3 holes were made in the sagittal plane in the central portion of the trough. Three corresponding drill holes were also made in the proximal aspect of the greater tuberosity at a distance of 1.0 cm lateral to the lateral edge of the trough. In each of these para-sagittal planes, adjacent holes were separated by 1 cm. Using a curved grasping clamp (surgical "towel clip"), a trans-osseous tunnel was made between each pair of holes. Three #2 Ethibond sutures were inserted into the tendon 1 cm from its lateral-most edge. These sutures were then weaved through the tendon using a modified Mason–Allen stitch. Each suture strand was tied with a consistent knot configuration.

Group 2: Bone/Suture Anchor, Single-Knot Fixation

Three Mitek GII bone/suture anchors (Depuy Mitek, a Johnson and Johnson company, Norwood, MA) with #2 Ethibond sutures were inserted into the medial edge of the trough (just medial to the cartilage-bone junction). Adjacent anchors were separated by 1 cm. Insertion was done using pre-drilled holes at a 45° angle to the supraspinatus. The 2 suture strands from each anchor were then passed directly superiorly through the supraspinatus tendon at a distance of 1 cm from its distal edge. The tendon was secured into the trough using a mattress stitch with a consistent knot configuration.

Group 3: Transosseous Anchor Double Knot (TOAK) Fixation

The tendons in this group were secured into the trough using a combination of the techniques used in Groups

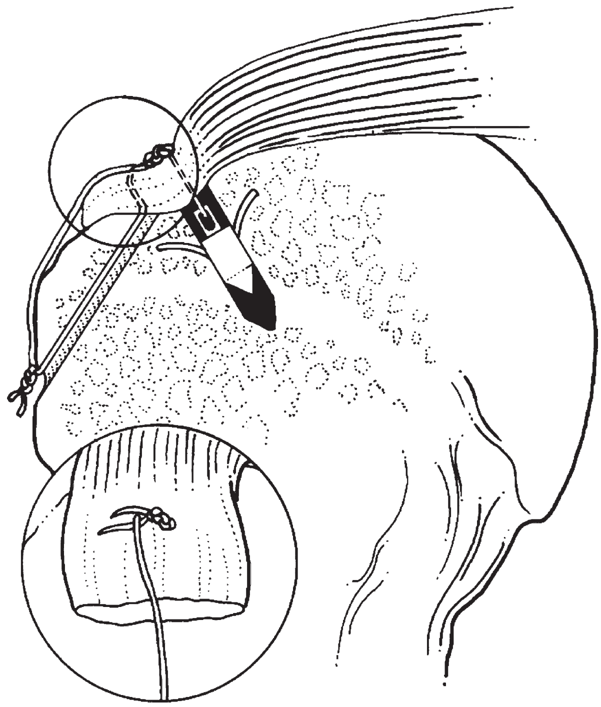

FIGURE 5. Inferior limb (Limb B) is now passed in a trans-osseous fashion. Knot is tied on lateral portion of greater tuberosity completing the TOAK technique.

1 and 2. Hence, drill holes for suture/bone anchors and corresponding trans-osseous tunnels were made. As was done in group 2 specimens, the suture strands from the anchors were passed directly in the superior direction through the tendon and tied securely using a mattress stitch. The suture strands were then weaved from this knot progressively toward the distal edge of the tendon using a modified Mason–Allen stitch.

Testing Protocol

Static Load-to-Failure Cadaveric Study. Each of the first 18 specimens was then loaded in tension to failure by pulling the tendon in the direction along the long axis of the humeral diaphysis using stroke control at a rate of 6 mm/min. The output of the load cell and cross head was plotted on a chart recorder as a load displacement curve, and the peak load prior to failure was determined. Failure of the cuff construct was considered to occur when a notable decrease in applied force was observed on the chart recorder. Mean peak failure loads were calculated for each group.

Using a commercially available microcomputer statistical program (NCSS 6.0, Number Cruncher Statistical Systems, Kaysville, UT), all data were screened for normality using several tests (Martinez–Iglewicz; Kolmogorov–Smirnov; and D'Agostino, Skewness, Kurtosis, and Omnibus). Differences between mean failure loads of the 3 groups were then statistically evaluated using the non-parametric Kurskal–Wallis Multiple-Comparison Z-Value Test. Results for each group are expressed as means ± 1 S.D. Statistical significance was set at $P < 0.05$.

Results. Results (Fig. 7) showed that group 1 (suture-only fixation) specimens failed at a mean force of 237.9 ± 68.1N (range 140–344.8N). Group 2 (anchor-only fixation) failed at a mean force of 215.2 ± 81.9N (range 116.8–333.6N). Mean failure forces between Groups 1 and 2 were not statistically different ($P > 0.1$). In group 3 (trans-osseous suture *plus* anchor fixation), 3 of the 6 specimens failed at the repair construct at a mean force of 382.6 ± 125.0N (range 309.0–527.0N). This failure force was substantially greater than the other groups (49% greater than suture-only group, $P = 0.055$; 61% greater than anchor-only group, $P < 0.01$) (Table 1).

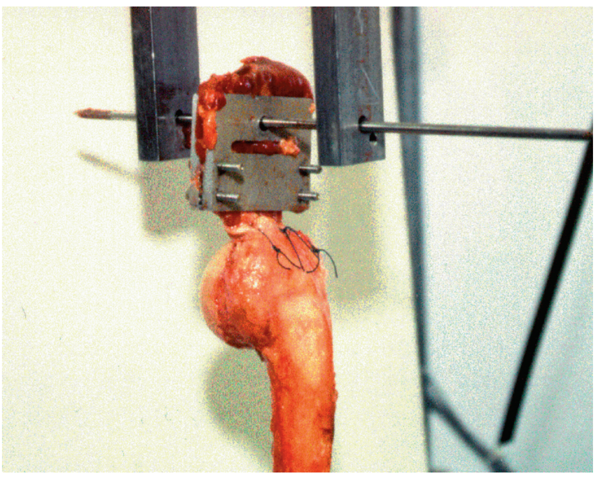

FIGURE 6. Testing apparatus for static and dynamic load studies.

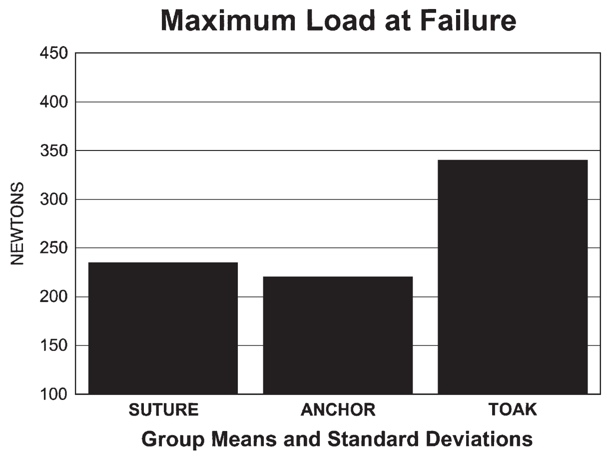

FIGURE 7. Bar graph demonstrating final load to failure for each group tested. TOAK technique demonstrated substantially greater load to failure.

Fig. 6 live 4/C

TABLE 1. *Inter-group comparisons for static pullout. Failure force of TOAK specimens statistically greater than either of the other 2 techniques*

	Maximum load (N)		Age		Relative bone density	
Comparison	% diff.	P value	% diff.	P value	% diff.	P value
Suture vs. anchor	10%	$P > 0.1$	3%	$P > 0.1$	5%	$P > 0.1$
TOAK vs. suture	61% (44%)†	$P = 0.055$*	4%	$P > 0.1$	3%	$P > 0.1$
TOAK vs. anchor	78% (58%)†	$P < 0.01$*	6%	$P > 0.1$	8%	$P > 0.1$

% diff. = percent difference between group means.
*Statistically significant (analysis includes all TOAK specimens, including the 3 specimens that did not fail at the tendon-bone construct.)
†Values in parentheses represent comparisons with only the 3 TOAK specimens that failed at the tendon-bone construct.

The remaining 3 specimens of group 3 also failed at relatively higher loads (300.8 ± 7.1N), but failed in the region of the musculotendinous junction and not at the suture/anchor construct. In these specimens, the tendon remained firmly attached to the reattachment site (Table 2). Analysis of age and relative bone density data showed no statistically significant differences in all possible inter-group paired comparisons ($P > 0.1$).

Dynamic Cyclic Failure Cadaveric Study. Loads were applied in a cyclic stepwise fashion. The first stage consisted of the application of an increasing force from 0 to 180 Newtons over a 5-second period across the rotator cuff repair. This was performed for 400 cycles, then the specimens went on to the next stage. During the next stage the maximum load was increased to 360 Newtons and cycled 400 times. The remaining parameters were kept constant, including the 5-second period for the load to increase from 0 to 360 Newtons. After 400 cycles at 360 Newtons, the specimens were then loaded at 540 Newtons keeping all other parameters constant. Failure was defined as a linear deviation of the stress/strain curve. The specimens were loaded to complete failure until there was no remaining contact between the humerus and scapula. This data point was entered into a spreadsheet. The mode of failure was also recorded.

An ANOVA test was used to compare the mean number of cycles at failure of the 3 groups. The Scheffé a posteriori test was used to analyze the data if a significant result was detected after ANOVA testing. Statistical significance was set at $P < 0.05$.

Results. The mean number of cycles of failure for each group was as follows: Tunnels 346, Anchor 678, and TOAK 663. All tunnel specimens failed by the suture cutting out of the greater tuberosity for the majority of the sutures placed in the specimen. Although some sutures broke, those remaining always sawed through the bone. There were no tendon ruptures prior to bone failure. In the anchor group, 3 specimens failed due to anchor pullout. The remaining 3 specimens had failure of the tendon or muscle. In the TOAK group, although there was failure of an anchor or suture in 2 specimens, the remaining sutures held until all tendons or muscles ruptured. In all TOAK specimens, a part of the tendon or muscle failed.

The results of the ANOVA test performed on the data reveal a significant difference among the 3 groups ($P = 0.023$). Analysis of these results using the Scheffé test demonstrated a difference between the tunnel repair group and the other 2 groups. There was no difference between the anchor and TOAK repairs when compared with each other. The bone density data revealed no significant difference of greater tuberosity bone density between the specimens of the 3 groups.

DISCUSSION

Clinically successful surgical repair of a full-thickness rotator cuff tear begins with firm reattachment of the enthesis.[2,4,7,10,14–16] The reattachment construct must remain intact and must be sufficiently strong so that biomechanical integrity is ultimately restored by tendon-to-bone healing. Since tendon-to-bone healing requires

TABLE 2. *Mode of failure for each group*

	Initial failure mode				Final (peak) failure mode			
Repair technique	Suture breakage	Bone cut-out	Anchor	Tendon	Suture breakage	Bone cut-out	Anchor	Tendon
Transosseous sutures (n = 6)	0	0	0	0	2*	5	0	0
Bone/suture anchors (n = 6)	0	0	0	0	1**	1	5	0
TOAK (n = 6)	0	1†	0	0	1	1††	2	3§

*One specimen failed by suture breakage and suture cut-out of bone.
**One specimen failed by suture cut-out of bone and anchor pull-out.
†One specimen was initially damaged by suture cut-out of bone with final (peak) failure by anchor pull-out.
††One specimen failed by suture cut-out of bone and anchor pull-out.
§These 3 specimens failed at the musculotendinous junction.

many weeks, the initial strength of surgical repair is an important determinant of the speed with which postoperative rehabilitation can be progressed.

The cyclic-loading results of this study indicate that repairs of the rotator cuff using anchors either alone or in combination with a bone tunnel seem to improve the ability of the repair to withstand cyclic loads. This data is similar to the results of a study by Burkhart et al, which demonstrated that anchors resisted cyclic loading better than bone tunnels.[3,5] Anchors seem to prevent cutting out of bone better than bone tunnels. When the tunnel-only specimens were observed during cyclic testing, the suture could be seen to move back and forth along the lateral cortex like a Gigli saw.

Deadman Theory and Vectorial Analysis of Forces

The static load-to-failure results of this study indicate that the TOAK technique demonstrates a substantially higher failure rate than either of the other 2 currently employed surgical techniques. A vectorial analysis of the forces involved at the site of tendon attachment may help to explain why the trans-osseous suture *plus* anchor double-knot technique is mechanically stronger than each of the other methods of single-knot fixation. Major forces involved include the force generated by the tendon (T) and the reaction forces of the suture (S) and anchor (A). As a first approximation for simplifying the vectorial analysis, the angular relationship of these forces is considered to remain unchanged, despite controlled shoulder motion. Component vectors of each of the major forces can be drawn as shown in Figure 8 and expressed in equation:

$$Tx = Ax + Sx$$

$$\text{or } Tsin = Acoso + Ssin \quad \text{Equilibrium}$$

$$Tx > Ax + Sx \quad \text{Failure}$$

Burkhart has described the "Deadman Theory" of suture anchors for the use of anchors in isolation (Fig. 8B). We believe that the TOAK is stronger than anchor-only or suture-only fixation because it better fits this analogy.

A force vector diagram shows that the tension applied through the cuff muscles is balanced by the component forces of the suture and anchor (Fig. 8C). As the shoulder moves dynamically, then as the angles change, the force applied to the anchors and sutures varies; as one increases the other will decrease, but as they act together they will always cumulatively be greater than either individually.

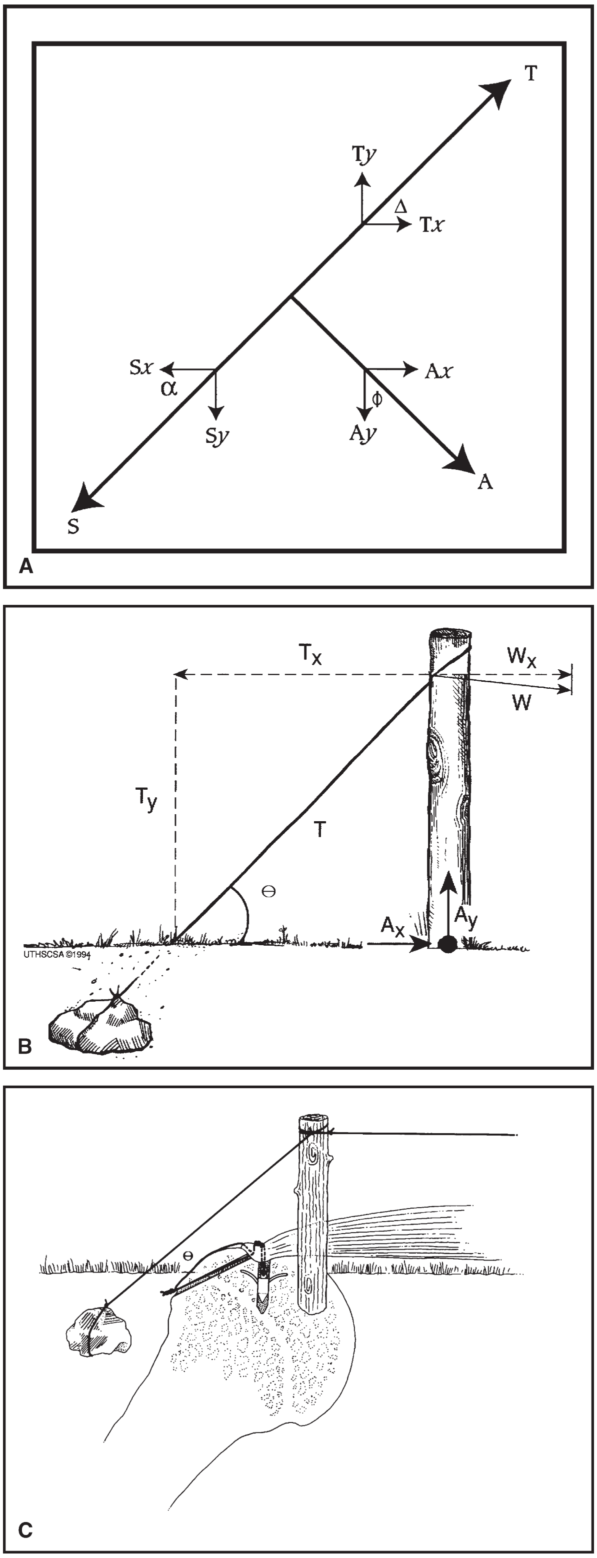

FIGURE 8. A, Vectorial analysis of forces at site of rotator cuff attachment. B, Theory of the "deadman's angle" for suture anchor insertion. C, Replication of the "deadman's analogy" with the TOAK technique.

■ FUTURE OF THE TECHNIQUE

The TOAK technique has not been compared with the recent use of "double-row" anchor fixation using all-arthroscopic methods. Also, the TOAK procedure

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could potentially be done arthroscopically if a stitching device could place a Mason–Allen stitch distal to an arthroscopically placed horizontal mattress suture. However, recent studies comparing arthroscopic and open rotator cuff repair still favor open repairs for tears greater than 3 cm.[2] Further investigations will focus on these parameters in an attempt to determine the ideal technique for rotator cuff repair.

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