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Arthroscopic rotator cuff repair: Scientific rationale, surgical technique, and early clinical and functional results of a knotless self-reinforcing double-row rotator cuff repair system

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Background: Rotator cuff repair has shown to improve shoulder function and reduce pain experienced by patients. Successful repairs should have high fixation strength, allow minimal gap formation, maintain stability, and restore normal anatomy and function of the supraspinatus footprint. The purpose of this study is to describe our preferred method for rotator cuff repair using a knotless self-reinforcing double-row system, and to cite biomenchanical data rationalizing its use.
Methods and material: Seventeen of 22 patients were identified as undergoing primary rotator cuff repair with minimum follow-up of 1 year (mean, 535 days; range, 370-939). The average age was 63 (range, 43-79). Data collected included average pain today, average worst pain, Single Assessment Numeric Evaluation (SANE), and patient satisfaction.
Results: For all patients, average pain today and average worst pain decreased and functional scores (SANE) increased. Patient satisfaction was 9.8 out of 10 (range, 7-9). The patients also began rehabilitation earlier and returned to full activities at 4 months.
Conclusion: These results indicate that the knotless self-reinforcing double-row repair system is a viable option in treating rotator cuff tears. This system provides improved contact area and restores the native footprint of the tendon leading to better outcomes.
Level of Evidence: Level IV, Case Series, Treatment Study.

Keywords: Double-row rotator cuff repair; minimize tendon gap formation; improve contact area for rotator cuff repair

Rotator cuff repair has provided patients with reliable pain relief and improved function in those who have failed nonoperative management. The long-term integrity of the repair is key to improving success and influences the ultimate outcome. While short term results show functional improvements and most patients experience less pain, in some series, there have been trends towards deteriorating clinical results with longer follow-up, and this seems related to the structural healing of the repair.[1,3,10,12,19,24,27]

The ideal repair should have high initial fixation strength, allow minimal gap formation, and maintain mechanical stability until healing is achieved.[22] In addition to these qualities, it should also restore the normal anatomy and function of the native supraspinatus footprint.

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Focus has, therefore, shifted from simple re-approximation of the torn rotator cuff to bone accomplished by single-row techniques to anatomic double-row methods. Most recently, double-row constructs with sutures that span and interconnect across anchors have been utilized as a hybrid fixation model that combines the benefits of double row and transosseous fixation and produces improved contact area and pressure.

In this review, we describe current trends in arthroscopic double-row rotator cuff repair and illustrate a unique method utilizing a knotless system with footprint restoration that incorporates 2 rows of anchors, suture interconnectivity, self-reinforcement, and suture tape for improved strength. We also report on our short-term clinical experience with this type of double-row fixation method. The advantages of this technique lie in its uncomplicated operative procedure, strength of fixation and self-reinforcing characteristics, and footprint restoration.

Rationale for double-row repair

The dimensions of the native supraspinatus tendon insertion have been described to be between 350 to 432 mm^2.[2,13] One of the criticisms of single-row repair techniques is the inability to reliably restore the anatomic supraspinatus footprint.

Meier[36] used a 3-dimensional digitizer to evaluate the repair of simulated rotator cuff tears in a cadaveric model. Their study showed that 100% of the original supraspinatus footprint was restored with double row repair, whereas the single-row suture anchor fixation and transosseous simple suture techniques reproduced only 46% and 71% of the insertion site, respectively.

Park et al[43] later compared standard double row suture anchor fixation to transosseous equivalent (TOE) fixation techniques (medial row – suture anchor, lateral row – suture bridge/biotenodesis screw construct) using pressure-sensitive film to measure pressurized contact area. The mean pressurized contact area between the tendon and insertion was significantly greater for the suture bridge technique utilizing four strands (124.2 mm^2, 77.6% footprint) compared with the double-row technique (63.3 mm^2, 39.6% footprint). Furthermore, the 4 strand suture bridge repair showed greater tendon on footprint pressures than double-row repair (0.27 MPa vs 0.9 MPa).

Numerous papers have been published comparing the biomechanical properties evaluating single- and double-row techniques in cadaveric models. Many of these publications have been inspired due, in large part, to recent reports citing postoperative failure of repaired rotator cuff tendons.[1,3,10,12,19,24,27] Multiple publications have documented improved biomechanical properties for double-row repair techniques compared to single-row repair constructs. These include superior ultimate loads to failure, gap formation, and cyclic loading.[26,33-35,47,52]

In a direct comparison between standard double-row anchor fixation and TOE (medial row – suture anchor, lateral row – suture bridge/biotenodesis screw construct), Park et al[44] measured gap formation, ultimate load to failure, and stiffness. Gap formation and stiffness were not statistically different between the 2 groups, but ultimate load to failure was. Ultimate load to failure in the TOE group was 443 N and 299 N in the double row technique. Because the distal fixation points in the TOE construct are placed on the lateral aspect of the proximal humerus, the supraspinatus force vector is 90° in reference to this. This configuration serves to increase the load to failure.

Recently, Burkhart et al[7] described a knotless system utilizing anchors and a suture chain technique (Arthrex, Naples, FL) to perform an interconnected, spanning double-row repair. The key to this system is its intrinsic self-reinforcing quality derived from 3 different mechanisms. The authors first note that as the tensile load increases, the force perpendicular to the bone surface (normal force) increases, thereby increasing the frictional resistance to failure. Second, as tension in the tendon increases, the angle between the sutures and bone decreases. This serves to wedge the tendon more tightly against the bone. Lastly, a wider suture provides increased contact surface area for compression of tendon to bone.

This knotless, self-reinforcing technique was compared to standard double row fixation in cadaveric biomechanical testing (7 paired specimens). Results showed that yield load and ultimate load were higher for this system compared to standard double-row repair in 6 of 7 pairs; but these values were not significant. Ultimate load to failure was 538.7 N compared to 511.3 N, compared to standard double-row repair. The authors attribute the lack of significance to a small sample size and to 1 cadaveric pair, which was a statistical outlier that produced contrary results to all of the other models. If this specimen was excluded, the difference in results was considered statistically significant. There was also no difference, with respect to cyclic displacement, between the 2 groups. Lastly, the authors pointed out that the difference between the yield and ultimate loads was lower in the knotless, self-reinforcing group. This means that the construct does not reach its yield point until it is close to complete failure – attributing this quality to the system's self-reinforcing nature.

Evolution of rotator cuff repair

Treatment of impingement syndrome and rotator cuff tears has undergone drastic changes over the past decade starting with formal open and mini-open repairs. Even today, mini-open (arthroscopically assisted) rotator cuff repair is still the benchmark to which all new techniques are compared. Optimal results were obtained when a limited deltoid splitting approach was combined with arthroscopic subacromial decompression and joint inspection. Reproducible and reliable outcomes were obtained with this treatment with success rates greater than 80-90%.[4,8,20,30,31,45] With the advent of suture anchor fixation, the mini-open technique was then combined with double-row fixation.[17]

When investigators were able to demonstrate superior results and faster return to function with arthroscopic versus open subacromial decompression for impingement syndrome,[16,29,40,51] surgeons were encouraged to attempt all arthroscopic rotator cuff repairs. Benefits of an all-arthroscopic technique include avoiding violation of deltoid fibers and preservation of deltoid origin, decreased morbidity and quicker return to function, and improved cosmesis. As surgeons became more experienced and confident with arthroscopic techniques, results of all arthroscopic rotator cuff repair were shown to be equivalent to those of mini-open repairs with the additive benefit of superior range of motion.[5,6,21,39,46,53] Furthermore, postoperative evaluation examining cuff healing showed comparable results with an all arthroscopic technique.[5,31]

Despite satisfactory results with arthroscopic single-row reconstruction, multiple studies have shed light on the failure of the repaired rotator cuff to heal, some as high as 94%.[1,3,10,12,19,24,27] Even though patients experienced good pain relief, functional results have been shown to deteriorate with time. Furthermore, the absence of healing has been correlated with inferior strength.[5] Attention was, therefore, turned towards improving healings rates by trying to restore the anatomic relationship of the torn supraspinatus tendon to its footprint on the greater tuberosity. The next step in the evolution of rotator cuff repair took the form of arthroscopic double-row fixation.

The benefits of double-row suture anchor fixation include improved footprint restoration, additional points of fixation which increase the strength of the overall construct, and decrease in load and stress that each anchor must resist.[2,26,32,33,35,36,47,48,51] Research has shown that initial load to failure of a rotator cuff repair may be increased by increasing the number of suture anchors, the number of sutures per anchor, or using suture patterns that grab more adjacent tendon fibers.[14]

The next advancement in rotator cuff repair for the senior author came with the development of the mattress double anchor technique.[34,37] The strategy behind this model is a hybrid construct incorporating both the transosseous suture configuration and the modified Mason-Allen tissue-grasping technique. After placement of a medial anchor, a second lateral anchor with a suture loop is used to create a mattress suture pattern between the 2 anchors (from medial to lateral). This suture mattress serves to compress the tendon onto the tuberosity, thus creating a broad footprint (Figure 1). In principle, this construct served as the foundation for future transosseous equivalent repair models. It was the first of its kind to take advantage of the suture length between the medial and lateral anchors, to restore the anatomic footprint, and maximize tendon to bone compression. In a subsequent biomechanical study,[37] the senior author with his colleagues found the MDA technique was as strong as traditional single-row techniques, with better restoration of surface area and less chance for bone failure.

Transosseous equivalent (TOE) double-row repair was validated in large part by Park et al in their 2-part study evaluating its contact characteristics and biomechanical properties.[43,44] Their construct comprised of two 6.5-mm Bio-Corkscrew anchors (Arthrex, Naples, FL) for medial row fixation. A limb from each medial row anchor was then secured in a 4-suture bridge construct 1 cm distal to the lateral edge of the footprint using a Bio-Tenodesis screw (Arthrex) (Figure 2). Modifications of this technique have been described using knotless anchors instead of bio-tenodesis screws for lateral fixation.

In addition to the structural and biomechanical qualities of this construct mentioned earlier, multiple other advantages have been explained.[15,42] As noted by Park et al, the TOE technique does not depend on the lateral most tissue of the torn cuff which is often deficient in nature. Second, a 4-bar construct exists that provides interconnectivity to the system. This allows the load to be shared between all 4 fixation points via the suture-bridge, especially during rotational movements. As opposed to standard double-row fixation, which secures the tendon only at suture anchor fixation points, TOE allows compression of the tendon to bone about the entire length of suture from medial to lateral fixation. This provides greater footprint restoration and a barrier from synovial fluid for the healing zone.

The most recent versions of the TOE technique include the system described earlier by Burkhart et al,[8] and the knotless system that we have been using, which is illustrated in this paper.

Clinical experience with double-row repair

As double-row repair is becoming more popular, there are increasing reports of clinical outcome studies being published.

Sugaya et al[49] presented their experience with a cohort of 86 patients who underwent standard double-row rotator cuff repair with suture fixation. Average American Shoulder and Elbow Surgeon (ASES) score was 94.3 postoperatively at 31 months. Follow-up MRI at an average 14 months after surgery showed a re-tear rate of 5% in small and medium sized tears and a 40% re-tear rate in massive tears. Furthermore, patients who were found to have a major discontinuity in the repaired tendon on postoperative MRI had inferior functional outcomes and strength. This once again supports the idea that patients who go on to heal their rotator cuff tears postoperatively have clinically better results.

Lafosse et al[28] followed a similar cohort of 105 patients and found analogous results. Postoperative repair integrity was primarily evaluated by CT arthrogram performed at a mean 23 months postoperatively. This demonstrated a re-tear rate of 11% (12 patients). Paralleling results published by Sugaya et al[49] intact rotator cuff repairs were associated with significantly increased strength and active range of

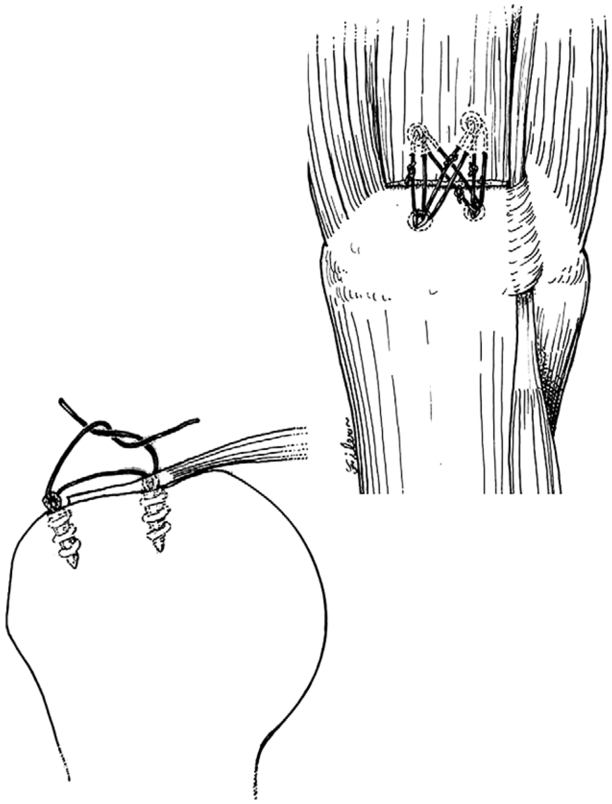

Figure 1 Early double-row interconnected technique. The suture linked between 2 anchors is then secured using standard arthroscopic knot tying techniques. The tendon is compressed onto the tuberosity and a broad footprint is recreated. In the coronal view, the configuration is similar to that achieved with transosseous techniques. (Reprinted with permission from: Millett PJ, Mazzocca A, Guanche CA. Mattress double anchor footprint repair: A novel, arthroscopic rotator cuff repair technique. Arthroscopy 2004;20:875-879.)

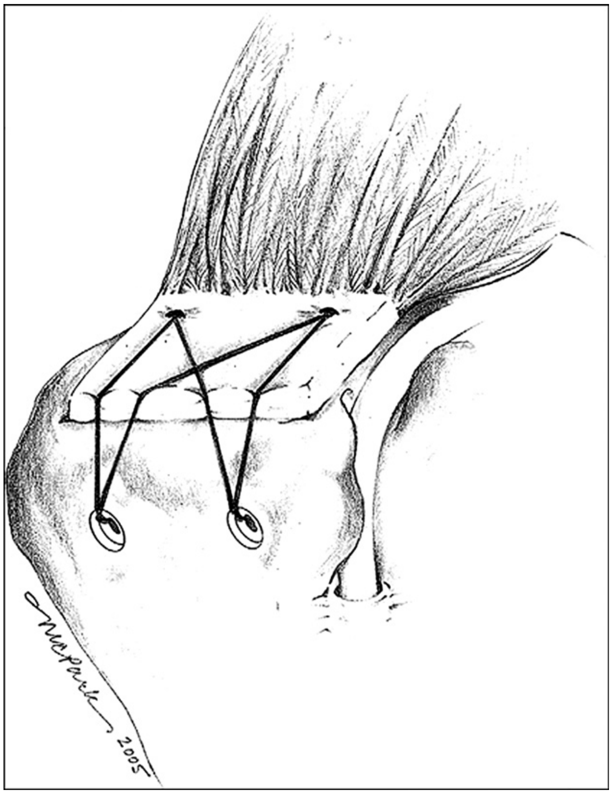

Figure 2 Transosseous-equivalent rotator cuff repair with 4 suture bridges. (Reprinted with permission from: Park MC, ElAttrache NS, Tibone JE, Ahmad CS, Jun BJ, Lee TQ. Part I: Footprint contact characteristics for a transosseous-equivalent rotator cuff repair technique compared with a double-row repair technique. J Shoulder Elbow Surg 2007;16:461-8.)

motion. Failure rates in these 2 studies are significantly lower than those previously published for open and arthroscopic repair. [1,3,10,12,19,24,27]

Huijsmans et al[25] showed similar results in a cohort of 210 patients who underwent standard double-row fixation. Ultrasonography performed at a minimum of 12 months demonstrated an intact rotator cuff in 83% of all shoulders. These authors reported a postoperative tear rate of 53% (17 patients) in massive tears and 22% (9 patients) in patients with a large tear. This can be compared to the study by Galatz et al[19] documenting a 94% re-tear rate of large and massive rotator cuff tears repaired by arthroscopic single row fixation at a minimum of 12 months by ultrasound.

Charousset et al[11] evaluated rotator cuff healing 6 months after single (35 patients) and double-row (31 patients) repair via CT arthrograms. They noted no differences in clinical outcomes between the 2 groups with respect to Constant score. However, rotator cuff healing was rated as anatomic and watertight in 19 patients with double-row fixation and in 14 patients with single-row fixation ($P = .03$).

Millett et al found significant pain relief and functional improvement in a group of 131 patients who underwent double-row suture anchor rotator cuff repair.[38] Pain scores improved from a mean of 9 preoperatively to 1.7 postoperatively. ASES scores increased from 30 preoperatively to 80.7 after surgery. 98.6% of patients reported that they were satisfied with their shoulder function and 95.5% reported that they would have this surgery again.

Park et al[41] compared 2 groups of patients undergoing either single-row or double-row suture anchor repair. Single-row fixation was used in the first 40 consecutive patients and double-row fixation in the next consecutive 38 patients. The authors found that when large tears were considered (>3 cm), ASES and Constant scores were all significantly better in the double-row group.

Franceschi et al[18] performed one of the first randomized clinical trial evaluating a total of 60 patients assigned to either single- or double-row suture anchor fixation. At 2-year follow-up, these authors found no difference with respect to the University of California, Los Angeles (UCLA) score and range of motion. Follow-up MRI at 2 years showed 18 patients had an intact rotator cuff in the double row group as opposed to 14 in the single-row group. These results were not statistically significant; however, as no power analysis was performed, it is difficult to assess the validity of these findings.

Figure 3 Four strand knotless double-row construct utilizing suture tape. (Reprinted with permission from Arthrex, Naples, FL.)

Burks et al[9] also performed a randomized controlled study comparing single- and double-row repair with 20 patients in each group. In addition to functional evaluation with UCLA, Constant, WORC, SANE, ASES scores, range of motion and strength, MRI evaluation was performed preoperatively and at 6 weeks, 3 months, and 1 year after repair. No significant differences were found with respect to any of these parameters. This study has been criticized for excluding large size tears and being under-powered (re-tear rate assumed to be 20% for double-row repair). Furthermore, an unbalanced diamond shaped double-row configuration was used, with fewer anchors medially then laterally.

In another prospective study, Grasso et al[23] evaluated a total of 80 (final data on 72) patients randomized to either single- or double-row repair. With a mean follow-up of 24.8 months, they found no difference with respect to Disabilities of the Arm, Shoulder and Hand (DASH) and Work-DASH self-administered questionnaires, normalized Constant score, or strength measurement. These authors noted their overall numbers were too small to allow for stratification, preventing further examination of larger tears. Furthermore, no postoperative radiographic studies evaluating healing rate were performed.

Author's preferred operative technique

For large and massive rotator cuff tears, we prefer to employ a knotless technique using bio-absorbable anchors and a braided suture tape (SwiveLock; FiberTape Arthrex, Naples, FL) to create a 4-bar interconnected construct. We believe this method combines the benefits of both double row fixation and transosseous repair techniques, while, at the same time, adhering to the principle of self-reinforcement and remains technically easy.

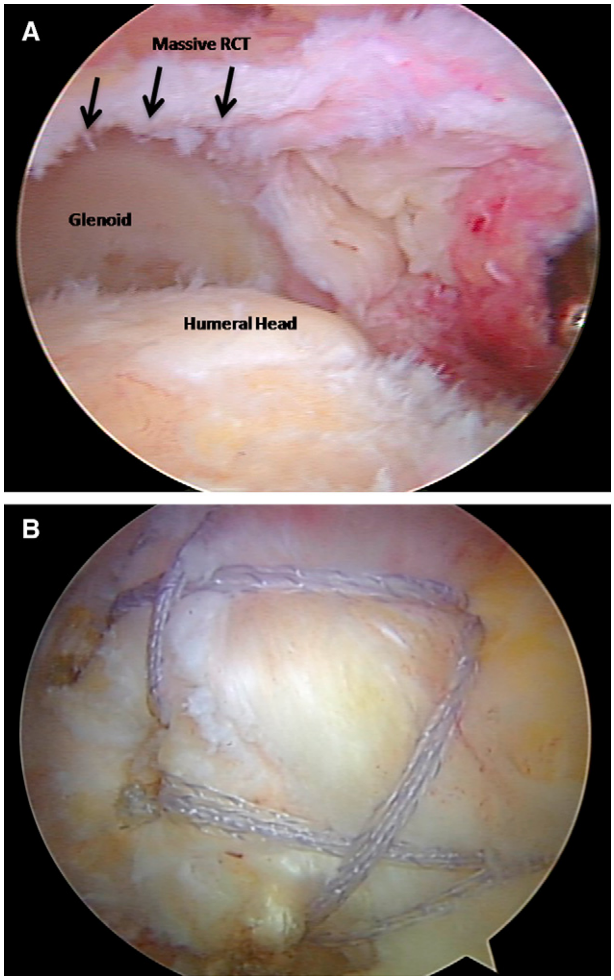

Figure 4 (**A**) Arthroscopic view of a massive rotator cuff tear. (**B**) Arthroscopic view of extended 6-strand, 6-anchor, knotless, self-reinforcing double-row repair of a massive tear of the rotator cuff tear (extended speed bridge).

Another benefit with this construct is the lack of suture at the tendon bone interface. As most of the healing in rotator cuff repair comes from the bone, it is the authors' opinion that having the tendon in direct contact with the bone with compression, is desirable and should facilitate healing.

After induction of general anesthesia, the patient is placed in beach chair position using a SPIDER arm holder (Tenet Medical Engineering, Inc., Calgary, Alberta, Canada). Standard posterior, posterolateral, anterolateral, and anterior portals are established. Routine diagnostic arthroscopy is performed and any intra-articular glenohumeral pathology addressed.

Attention is then turned to evaluation of the torn rotator cuff tendon from the subacromial space. Subacromial bursectomy and acromioplasty are performed with release of the coracoacromial ligament in all but massive, irreparable tears. Debridement and arthroscopic release are performed as necessary to achieve adequate mobilization of the cuff to allow re-approximation to the lateral aspect of the native supraspinatus footprint. The footprint is prepared with

Table Outcome data from Author's double row rotator cuff repairs

	Preoperative data	Postoperative data
Mean pain today (Scale 0-10)	2.7 (range, 0-5)	0.2 (range, 0-1)
Mean worst pain (Scale 0-10)	5.3 (range, 3-8)	2.6 (range, 0-10)
Single Assessment Numeric Evaluation (SANE) Scale (0-100)		88 (range, 40-100)
Patient satisfaction with Surgical Outcome Scale (0-10)		9.8 (range, 7-10)

removal of soft tissue and abrasion of the bone using an arthroscopic burr. The cortical rim is preserved, as this is the strongest bone for anchor fixation and the anchors used have threads that are designed to gain purchase in the cortex.[50]

Two anchors pre-loaded with 2-mm suture tape are used medially. Medial anchors are placed 1-2-mm lateral to the articular margin after bone sockets are prepared using a punch through a lateral portal. The first anchor is placed anteriorly. The anchor is advanced with a mallet until the anchor body makes contact with bone. The anchor is then advanced by clockwise rotation of the anchor driver handle until the anchor body is flush with bone. Each tail of the suture tape is passed through the tendon anterior and posterior to the anchor fixation site using any preferred suture shuttling or direct passing device. About a 15-mm bite of tendon should be obtained, as this determines how much tendon will be pulled over the tuberosity. Furthermore, any delaminations in the tendon should be incorporated into the repair to ensure the tear is anatomically reduced. Both suture tape tails from each anchor are maintained in the posterior portal. These steps are then repeated for the posteromedial anchor. Care should be taken to spread the medial anchors at least 1 cm in the anteropostero direction to prevent fracture and also to avoid excessive suture strangulation of the tissue. For very large tears, 3 anchors can be used medially in an expanded type repair.

At this point, 1 suture tape tail from each medial anchor is retrieved out the lateral portal. The suture tapes are then loaded into the eyelet of another knotless anchor that will be used for lateral fixation. These sutures are retrieved through a 6-mm cannula and are then loaded into the anchor. A total of 2 additional anchors are placed for lateral row fixation, 1 anteriorly and 1 posteriorly. Ideal placement of these anchors is approximately 5-10 mm lateral to the edge of the greater tuberosity, where the bone quality improves.[50] The anterior anchor is placed first in a manner similar to the medial set of anchors. It is important to tension each limb from the medial row prior to complete seating of the lateral anchor. These steps are then repeated for the posterolateral anchor. A 4-strand self-reinforcing interconnected construct is thus created (Figure 3).

Alternately, medial row fixation with knots can also be achieved with this system. The anchors come pre-loaded with a #2 high strength suture. This can be passed through the medial aspect of the torn cuff in mattress fashion and tied down for added medial row security.

For larger tears (Figure 4, *A*), an extended 6-anchor construct is utilized: 3 anchors medially and 3 anchors laterally. Each limb from the center medial anchor is secured to the most anterior and posterior lateral anchors. One limb from the medial anterior and posterior anchors is secured to the center lateral anchor. The remaining limbs from each medial anterior and posterior anchor are secured to their respective counterpart anchors laterally (Figure 4, *B*).

The rigid fixation achieved through this system allows us to initiate early range of motion without fear of compromising the repair. Our postoperative rehabilitation protocol includes initial immobilization in an abduction sling for 4 weeks. Passive range of motion is initiated from week 2 to week 6, followed by active-assist and active motion. The majority of patients return to unrestricted activity by 4 months.

Author's experience with knotless double-row repair technique

A series of 22 patients with minimum 1-year follow-up (IRB approved) were identified who underwent primary rotator cuff repair utilizing the above described technique. Seventeen patients were available for follow-up (average 535 days; range, 370-939). There were 15 men and 7 women with a mean age of 63 (range, 43-79). One patient had a gentle manipulation under anesthesia while undergoing a contralateral shoulder rotator cuff repair for a nagging pain and sharp painful twinges with overhead activities at 0.3 months postoperatively. For those patients that did not progress to another surgery, average pain today decreased and functional scores increased (Table). Overall, all patients said they would have surgery again. There were no additional complications. These early results show that patients obtain reliable pain relief and increased functional results after rotator cuff repair. Because of the improved biomechanics of this type of repair, we allowed earlier rehabilitation which minimized convalescence. A sling was used for only 5 weeks in most cases. For all patients undergoing a double row repair, routine postoperative protocol cleared patients to return to full activities at 4 months.

Conclusion

Surgical treatment of rotator cuff pathology has undergone drastic changes in a short 10 years time. This is due, in part, to novel ideas, recent biomechanical research, and new technological innovation. The current state of arthroscopic rotator cuff repair focuses on anatomic reconstruction of the supraspinatus footprint. Regardless of good pain relief, experience has shown that if the rotator cuff does not heal, functional results are suboptimal.

In an effort to provide the most favorable conditions for tendon healing, recent attention has shifted to double row constructs. Multiple studies have shown that this fixation method results in improved contact area and footprint restoration compared to traditional single-row repair and standard double-row suture anchor repairs. In addition, contact pressure required for tendon to bone healing has also been shown to be greater for this system. Single-row repairs have been shown to have the lowest load to failure and are most vulnerable to gap formation at the repair site. Standard double-row fixation does provide improved ultimate load to failure, but fails to restore contact area and pressure as well as double row constructs that incorporate interconnectivity.

Some recent prospective studies have failed to show differences in outcome between single- and double-row repair.[9,18,23] However, differences may only be obvious when examining large or massive tears, which these studies failed to evaluate in large numbers. Other investigators have shown improved tendon healing rates with double-row fixation compared to historical single-row controls.[25,28,49] These differences are apparent especially when examining large and massive tears. These improved healing rates have been associated with improved functional results.

We believe that double-row fixation currently offers the best option for a structurally sound rotator cuff repair and it allows earlier rehabilitation. As Park et al[43,44] and Burkhart et al[7] have explained, this construct has multiple advantages. In addition to its multiple biomechanical characteristics mentioned above, the system's interconnectivity and self-reinforcement qualities are its strongest attributes. We believe that the principles outlined in this technique should be applied to rotator cuff repairs. Specifically, rigid fixation must be achieved in order to allow early range of motion without fear of compromising the repair. We believe the approach outlined in this article allows the surgeon to realize all of these goals.

The technique outlined in this article possesses these advantages combined with the simplicity and time conservation of a knotless procedure. The self-reinforcement nature of the repair converts detrimental tensile forces into beneficial compressive ones, much like a tension-band construct. Not only does the interconnectivity provided by the 4-bar construct afford compression about the entire length of the construct, it provides rotational stability as well.

Early clinical results of this repair technique are encouraging. In order to assess the true effectiveness of this technique, longer follow-up with comparative studies are needed—especially those evaluating patients with large and massive rotator cuff tears.

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Supplementary data

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References

1. Anderson K, Boothby M, Aschenbrener D, van Holsbeeck M. Outcome and structural integrity after arthroscopic rotator cuff repair using 2 rows of fixation: minimum 2-year follow-up. Am J Sports Med 2006;34:1899-905.
2. Apreleva M, Ozbaydar M, Fitzgibbons PG, Warner JJP. Rotator cuff tears: The effect of the reconstruction method on three-dimensional repair site area. Arthroscopy 2002;18:519-26.
3. Bishop J, Klepps S, Lo IK, Bind J, Gladstone JN, Flatow EL. Cuff integrity after arthroscopic versus open rotator cuff repair: A prospective study. J Shoulder Elbow Surg 2006;15:290-9.
4. Blevins FT, Warren RF, Cavo C, Altchek DW, Dines D, Palletta G, et al. Arthroscopic assisted rotator cuff repair: results using a mini-open deltoid splitting approach. Arthroscopy 1996;12:50-9.
5. Boileau P, Brassart N, Watkinson DJ, Carles M, Hatzidakis AM, Krishnan SG. Arthroscopic repair of full-thickness tears of the supraspinatus: does the tendon really heal? J Bone Joint Surg Am 2005;87:1229-40.
6. Buess E, Steuber KU, Waibl B. Open versus arthroscopic rotator cuff repair: a comparative view of 96 cases. Arthroscopy 2005;21:597-604.
7. Burkhart SS, Adams CR, Burkhart SS, Schoolfield JD. A biomechanical comparison of 2 techniques of footprint reconstruction for rotator cuff repair: The SwiveLock-FiberChain construct versus standard double-row repair. Arthroscopy 2009;25:274-81.
8. Burkhart SS, Nottage WM, Ogilvie-Harris DJ, Kohn HS, Pachelli A. Partial repair of irreparable rotator cuff tears. Arthroscopy 1994;10:363-70.
9. Burks RT, Crim J, Brown N, Fink B, Greis PE. A prospective randomized clinical trial comparing arthroscopic single and double-row rotator cuff repair magnetic resonance imaging and early clinical evaluation. Am J Sports Med 2009;37:674-82.
10. Calvert PT, Packer NP, Stoker DJ, Bayley JI, Kessel L. Arthrography of the shoulder after operative repair of the torn rotator cuff. J Bone Joint Surg Br 1986;68:147-50.
11. Charousset C, Grimberg J, Duranthon LD, Bellaiche L, Petrover D. Can a double-row anchorage technique improve tendon healing in arthroscopic rotator cuff repair? A prospective, nonrandomized, comparative study of double-row and single-row anchorage techniques

with computed tomographic arthrography tendon healing assessment. Am J Sports Med 2007;35:1247-57.
12. Cole BJ, Alford JW, Hayden K, Pylawka T, Lewis PB. Arthroscopic rotator cuff repair: Prospective evaluation at minimum 2-year follow-up. J Shoulder Elbow Surg 2007;16:e22.
13. Cole BJ, ElAttrache NS, Anbari A. Arthroscopic rotator cuff repairs: An anatomic and biomechanical rationale for different suture-anchor repair configurations. Arthroscopy 2007;23:662-9.
14. Cummins CA, Appleyard RC, Strickland S, Haen PS, Chen S, Murrell GA. Rotator cuff repair: an ex vivo analysis of suture anchor repair techniques on initial load to failure. Arthroscopy 2005;21:1236-41.
15. ElAttrache NS, Park MC, Tibone JE, Ahmad CS, Bong JJ, Lee TQ. Arthroscopic ''Transosseous equivalent'' rotator cuff repair, http://www.arthrex.com/myarthrex/videos/index.cfm?myURL=1085_01FF&Bandwidth=Auto&VideoID=55&sortfeature=title&sort=asc&specialty=SURG-11#55; DVD-1085; downloaded 08/21/09.
16. Esch JC, Ozerkis LR, Helgager JA, Kane N, Lilliott N. Arthroscopic subacromial decompression: Results according to the degree of rotator cuff tear. Arthroscopy 1988;4:241-9.
17. Fealy S, Kingham TP, Altchek DW. Mini-open rotator cuff repair using a two-row fixation technique: outcomes analysis in patients with small, moderate, and large rotator cuff tears. Arthroscopy 2002;18:665-70.
18. Franceschi F, Ruzzini L, Longo UG, Martina FM, Zobel BB, Maffulli N, et al. Equivalent clinical results of arthroscopic single-row and double-row suture anchor repair for rotator cuff tears: A randomized controlled trial. Am J Sports Med 2007;35:1254-60.
19. Galatz LM, Ball CM, Teeley SA, Middleton WD, Yamaguchi K. The outcome and repair integrity of completely arthroscopically repaired large and massive rotator cuff tears. J Bone Joint Surg Am 2004;86:219-24.
20. Gartsman GM. Arthroscopic management of rotator cuff disease. J Am Acad Orthop Surg 1998;6:259-66.
21. Gartsman G, Khan M, Hammerman S. Arthroscopic repair of full-thickness tears of the rotator cuff. J Bone Joint Surg 1998;80A:832-40.
22. Gerber C, Schneeberger AG, Beck M, Schlegel U. Mechanical strength of repairs of the rotator cuff. J Bone Joint Surg 1994;76:371-80.
23. Grasso A, Milano G, Salvatore M, Falcone G, Deriu L, Fabbriciani C. Single-row versus double-row arthroscopic rotator cuff repair: A prospective randomized clinical study. Arthroscopy 2009;25:4-12.
24. Harryman DT, Mack LA, Wang KY, Jackins SE, Richardson ML, Matsen FA III. Repairs of the rotator cuff. Correlation of functional results with integrity of the cuff. J Bone Joint Surg 1991;73:982-9.
25. Huijsmans PE, Pritchard MP, Berghs BM, van Rooyen KS, Wallace AL, de Beer JF. Arthroscopic rotator cuff repair with double-row fixation. J Bone Joint Surg Am 2007;89:1248-57.
26. Kim DH, Elattrache NS, Tibone JE, Jun BJ, DeLaMora SN, Kvitne RS, et al. Biomechanical comparison of a single-row versus double-row suture anchor technique for rotator cuff repair. Am J Sports Med 2006;34:407-14.
27. Knudsen HB, Gelineck J, Sojbjerg JO, Olsen BS, Johannsen HV, Sneppen O. Functional and magnetic resonance imaging evaluation after single-tendon rotator cuff reconstruction. J Shoulder Elbow Surg 1999;8:242-6.
28. Lafosse L, Brozska R, Toussaint B, Gobezie R. The outcome and structural integrity of arthroscopic rotator cuff repair with use of the double-row suture anchor technique. J Bone Joint Surg Am 2007;89:1533-41.
29. Lazarus MD, Chansky HA, Misra S, Williams GR, Iannotti JP. Comparison of open and arthroscopic subacromial decompression. J Shoulder Elbow Surg 1994;3:1-11.
30. Levy HJ, Uribe JW, Delaney LG. Arthroscopic assisted rotator cuff repair: Preliminary results. Arthroscopy 1990;6:55-60.
31. Liu SH, Baker CL. Arthroscopically assisted rotator cuff repair: Correlation of functional results with integrity of the cuff. Arthroscopy 1994;10:54-60.
32. Lo IKY, Burkhart SS. Double-row arthroscopic rotator cuff repair: Re-establishing the footprint of the rotator cuff. Arthroscopy 2003;19: 1035-42.
33. Ma CB, Comerford L, Wilson J, Puttlitz CM. Biomechanical evaluation of arthroscopic rotator cuff repairs: double-row compared with singlerow fixation. J Bone Joint Surg Am 2006;88:403-10.
34. Mazzocca AD, Millett PJ, Guanche CA, Santangelo SA, Arciero RA. Arthroscopic single-row versus double-row suture anchor rotator cuff repair. Am J Sports Med 2005;33:1861-8.
35. Meier SW, Meier JD. The effect of double-row fixation on initial repair strength in rotator cuff repair: a biomechanical study. Arthroscopy 2006;22:1168-73.
36. Meier SW, Meier JD. Rotator cuff repair: The effect of double-row fixation on three-dimensional repair site. J Shoulder Elbow Surg 2006; 15:691-6.
37. Millett PJ, Mazzocca A, Guanche CA. Mattress double anchor footprint repair: A novel, arthroscopic rotator cuff repair technique. Arthroscopy 2004;20:875-9.
38. Millett PJ, Warner JJ, Johnston TL. Clinical results of double-row arthroscopic rotator cuff repair. Unpublished data.
39. Morse K, Davis AD, Afra R, Kaye EK, Schepsis A, Voloshin I. Arthroscopic versus mini-open rotator cuff repair: a comprehensive review and meta-analysis. Am J Sports Med 2008;36:1824-8.
40. Norlin R. Arthroscopic subacromial decompression versus open acromioplasty. Arthroscopy 1989;5:321-3.
41. Park JY, Lhee SH, Choi JH, Park HK, Yu JW, Seo JB. Comparison of the clinical outcomes of single- and doublerow repairs in rotator cuff tears. Am J Sports Med 2008;36:1310-6.
42. Park MC, ElAttrache NS, Ahmad CS, Tibone JE. ''Transosseous-equivalent'' rotator cuff repair technique. Arthroscopy 2006;22:1360.e1-e5.
43. Park MC, ElAttrache NS, Tibone JE, Ahmad CS, Jun BJ, Lee TQ. Part I: Footprint contact characteristics for a transosseous-equivalent rotator cuff repair technique compared with a double-row repair technique. J Shoulder Elbow Surg 2007;16:461-8.
44. Park MC, Tibone JE, ElAttrache NS, Ahmad CS, Jun BJ, Lee TQ. Part II: biomechanical assessment for a footprint-restoring arthroscopic transosseous-equivalent rotator cuff repair technique compared with a double-row technique. J Shoulder Elbow Surg 2007;16:469-76.
45. Paulos LE, Kody MH. Arthroscopically enhanced ''miniapproach'' to rotator cuff repair. Am J Sports Med 1994;22:19-25.
46. Severud EL, Ruotolo C, Abbott DD, Nottage WM. All-arthroscopic versus mini-open rotator cuff repair: A long-term retrospective outcome comparison. Arthroscopy 2003;19:234-8.
47. Smith CA, Alexander S, Hill AM, Huijsmans PE, Bull AMJ, Amis AA, et al. A biomechanical comparison of single and double-row fixation in arthroscopic rotator cuff repair. J Bone Joint Surg Am 2006;88:2425-31.
48. Snyder SJ. Single vs. double row suture anchor fixation rotator cuff repair. Presented at the American Orthopaedic Society for Sports Medicine Specialty Day at the 75th Annual Meeting of the American Academy of Orthopaedic Surgeons 2007 Mar 8; San Francisco, CA.
49. Sugaya H, Maeda K, Matsuki K, Moriishi J. Repair integrity and functional outcome after arthroscopic double-row rotator cuff repair: a prospective outcome study. J Bone Joint Surg Am 2007;89:953-60.
50. Tingart MJ, Apreleva M, Lehtinen J, Zurakowski D, Warner JJ. Anchor design and bone mineral density affect the pull-out strength of suture anchors in rotator cuff repair: which anchors are best to use in patients with low bone quality? Am J Sports Med 2004;32:1466-73.
51. Van Holsbeeck E, DeRycke J, Declercq G, Martens M, Verstreken J, Fabry G. Subacromial impingement: Open versus arthroscopic decompression. Arthroscopy 1992;8:173-8.
52. Waltrip RL, Zheng N, Dugas JR, Andrews JR. Rotator cuff repair: a biomechanical comparison of three techniques. Am J Sports Med 2003;31:493-7.
53. Warner JJ, Tetreault P, Lehtinen J, Zurakowski D. Arthroscopic versus mini-open rotator cuff repair: a cohort comparison study. Arthroscopy 2005;21:328-32.