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A Biomechanical Comparison of Single and Double-Row Fixation in Arthroscopic Rotator Cuff Repair

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Investigation performed at Imperial College, London, United Kingdom

Background: The optimal method for arthroscopic rotator cuff repair is not yet known. The hypothesis of the present study was that a double-row repair would demonstrate superior static and cyclic mechanical behavior when compared with a single-row repair. The specific aims were to measure gap formation at the bone-tendon interface under static creep loading and the ultimate strength and mode of failure of both methods of repair under cyclic loading.

Methods: A standardized tear of the supraspinatus tendon was created in sixteen fresh cadaveric shoulders. Arthroscopic rotator cuff repairs were performed with use of either a double-row technique (eight specimens) or a single-row technique (eight specimens) with nonabsorbable sutures that were double-loaded on a titanium suture anchor. The repairs were loaded statically for one hour, and the gap formation was measured. Cyclic loading to failure was then performed.

Results: Gap formation during static loading was significantly greater in the single-row group than in the double-row group (mean and standard deviation, 5.0 ± 1.2 mm compared with 3.8 ± 1.4 mm; $p < 0.05$). Under cyclic loading, the double-row repairs failed at a mean of 320 ± 96.9 N whereas the single-row repairs failed at a mean of 224 ± 147.9 N ($p = 0.058$). Three single-row repairs and three double-row repairs failed as a result of suture cut-through. Four single-row repairs and one double-row repair failed as a result of anchor or suture failure. The remaining five repairs did not fail, and a midsubstance tear of the tendon occurred.

Conclusions: Although more technically demanding, the double-row technique demonstrates superior resistance to gap formation under static loading as compared with the single-row technique.

Clinical Relevance: A double-row reconstruction of the supraspinatus tendon insertion may provide a more reliable construct than a single-row repair and could be used as an alternative to open reconstruction for the treatment of isolated tears.

The objective of rotator cuff repair is to restore the anatomical configuration and mechanical performance of the tendon-bone insertion sufficiently to sustain loading associated with functional activity. Most open and arthroscopic repair techniques have depended on a single row of either transosseous sutures or suture anchors combined with simple sutures or grasping sutures through the tendon[1,2]. It has been shown that adding a second row of sutures increases the repair strength significantly[3-5]. More recently, the concept of "footprint reconstruction" has emerged, in which the two rows of fixation are used not only to increase strength but also to increase the surface area of contact between the humeral tuberosity and the repaired tendon[6,7].

The hypothesis of the present study was that a double-row repair would demonstrate superior static and cyclic mechanical behavior when compared with a single-row repair. The specific aims were to measure gap formation at the bone-tendon interface under static creep loading and the ultimate strength and mode of failure of each method of repair under cyclic loading.

Materials and Methods

Twenty-three fresh-frozen cadaveric shoulder specimens from donors who had been forty-seven to seventy years old at the time of death were obtained according to local and national ethical guidelines. Each shoulder was thawed at room

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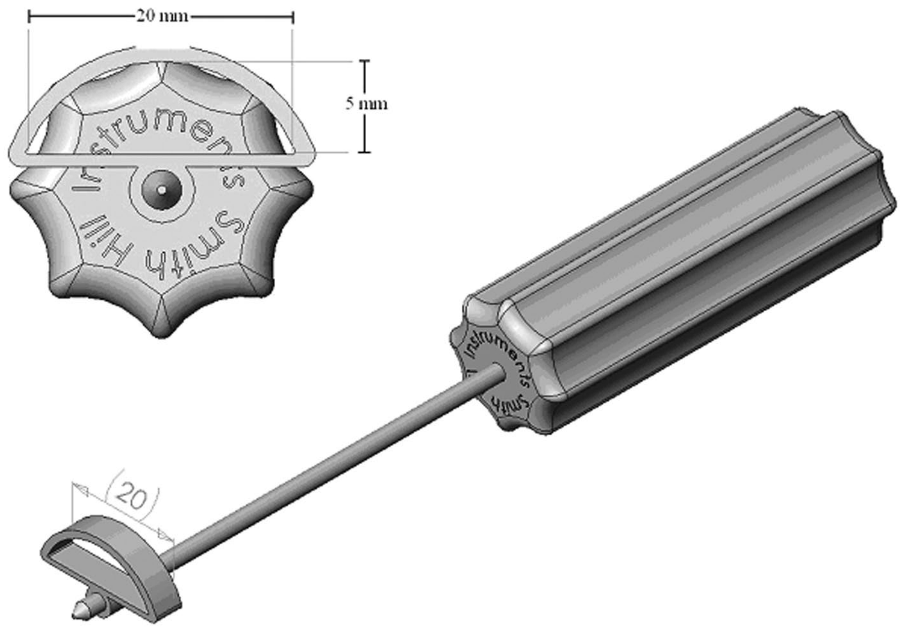

Fig. 1
Schematic illustration of the custom-made metal template for cutting the defect in the supraspinatus tendon.

temperature for twenty-four hours prior to use, and the scapula of each specimen was clamped onto a rig to approximate the normal beach-chair position of a patient undergoing shoulder arthroscopy.

Each shoulder was assessed arthroscopically for any associated rotator cuff abnormalities, and any shoulder that was found to have a degenerative cuff or a cuff tear was withdrawn from the study. On the basis of this examination, sixteen specimens were found to be suitable for testing. These specimens were randomized to treatment with a single-row repair (eight specimens) or a double-row repair (eight specimens). There was no difference between the groups with regard to the age of the donors (p = 0.4).

A lateral deltoid-splitting mini-open incision was used to allow direct visualization of the superior surface of the supraspinatus tendon. A custom-designed template was placed on the supraspinatus tendon to allow a standardized defect to be created and removed at the insertion on the greater tuberosity. The template had a width of 20 mm, with a maximum depth of 5 mm. A metal spike allowed accurate placement of the template onto the greater tuberosity, with the anterior edge immediately adjacent to the biceps tendon (Fig. 1). The deltoid and skin incisions were repaired with a continuous 4.0 Prolene suture (Ethicon, Johnson and Johnson, Edinburgh, Scotland). The defect was then assessed arthroscopically to ensure consistency.

The repairs were performed with use of a standardized all-arthroscopic approach by two surgeons (A.L.W., J.F.deB.). The first two repairs of each type were performed with both surgeons present to ensure a standardized technique. Thereafter, both surgeons performed an equal number of the single and double-row repairs. The greater tuberosity was prepared with a powered burr to lightly decorticate the bone surface. TwinFix 5.0-mm titanium suture anchors loaded with two #2 Durabraid sutures (Smith and Nephew Healthcare, Cambridge, United Kingdom) were inserted at the "deadman angle"[8] of 45° to the bone surface. Therefore, the single-row repair involved the use of a single anchor with two sutures and

Fig. 2
Schematic illustration of a single-row repair.

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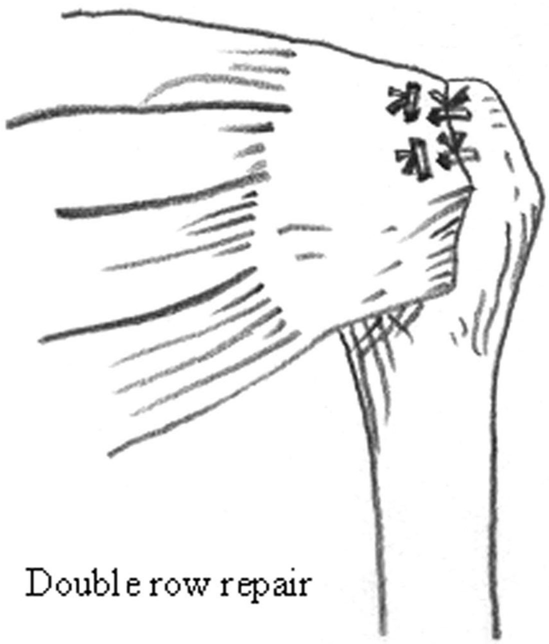

Fig. 3

Schematic illustration of anchor placement for a double-row repair, with mattress sutures placed at the musculotendinous junction and simple sutures placed at the lateral edge of the tendon footprint.

the double-row repair involved the use of two anchors with a total of four sutures. In the single-row repairs, an anchor was placed at the midpoint between the articular margin and the lateral tip of the greater tuberosity, and two simple loop sutures were placed through the tendon margin with use of a penetrating suture grasper (Fig. 2). In the double-row repairs, the first anchor was placed medially at the margin of the humeral articular cartilage and was tied with two mattress sutures placed adjacent to the musculotendinous junction of the supraspinatus (Fig. 3). The lateral anchor was inserted just lateral to the highest tip of the greater tuberosity, and two single loop sutures were tied to produce a firm attachment of the lateral aspect of the tendon to the footprint. All sutures were tied arthroscopically with use of a locking sliding knot (Nicky knot[9]) supplemented by three alternating half-hitches.

Following completion of the repair, specimens were frozen at 20°C and were later thawed over a period of twenty-four hours prior to biomechanical testing. Except for the rotator cuff musculature, all overlying tissues and the clavicle were excised. The coracoacromial ligament was released and the acromion was resected at the scapular spine to allow direct visualization of the repaired supraspinatus tendon.

The rotator cuff muscles were elevated from the scapula and each tendon was released, leaving the glenohumeral joint capsule intact. Multiple Mason-Allen sutures were passed through the tendinous portion of each muscle, and the shoulder was mounted on a shoulder-testing rig (Fig. 4). The humerus was secured with an intramedullary stainless steel rod

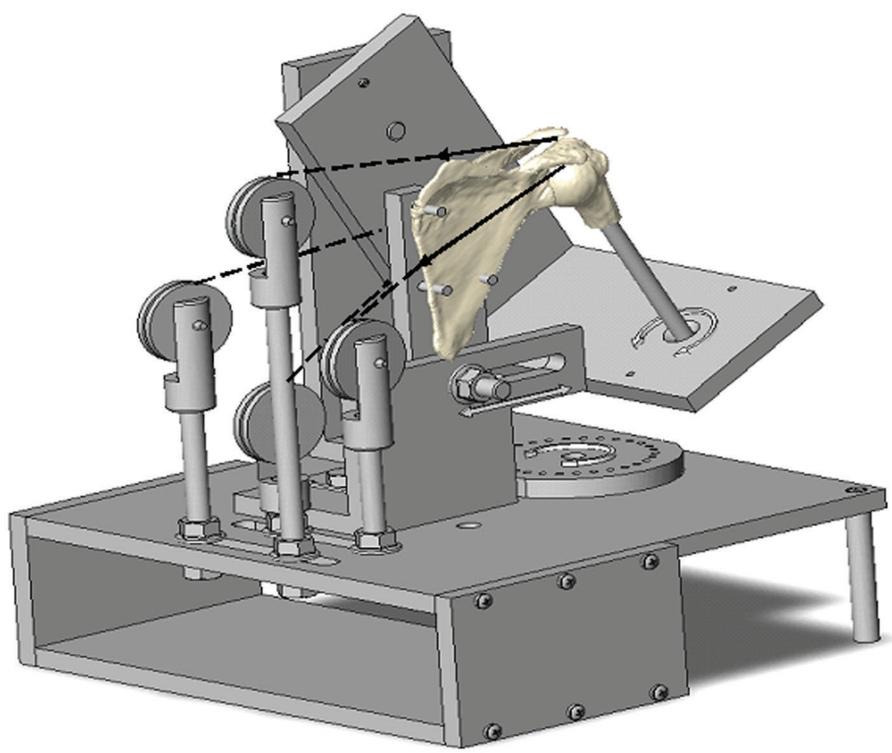

Fig. 4

Schematic illustration of the configuration of a scapula and rotator cuff in the shoulder-testing rig.

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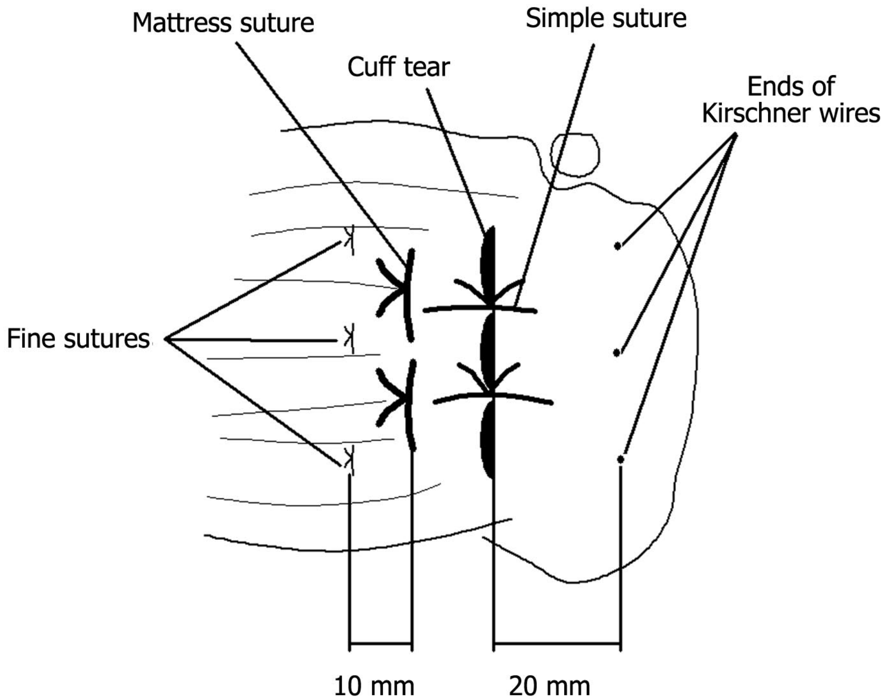

Fig. 5

Schematic illustration of the position of Kirschner wires and sutures used for the measurement of gap formation.

with use of polymethylmethacrylate bone cement. This allowed for accurate positioning of the shoulder at 30° of abduction to simulate the normal resting position in a wedged sling that is often used following a rotator cuff repair.

Once each shoulder was mounted on the rig, three fine-tipped 1.5-mm-diameter Kirschner wires measuring 40 mm in length were placed into the proximal part of the humerus, 20 mm distal and parallel to the tear. The three wires were placed adjacent to the anterior edge, the posterior edge, and the center of the tear. Opposite each Kirschner wire, fine suture knots were inserted 10 mm medial to the medial sutures (10 mm medial to the mattress sutures in the double-row repair or 10 mm medial to the simple sutures in the single-row repair). These sutures were tied tightly through the superficial bursal side of the supraspinatus tendon to act as markers but did not interfere with the biomechanics of the repair (Fig. 5). Gap formation was defined as the change in the distance between the tip of each wire and the fine knot of its corresponding suture. Three reference measurements between each wire and suture could then be made with use of Vernier calipers, and the mean was derived.

Loads were applied to the Mason-Allen sutures with use of a cord-and-pulley system. Calibrated weights were used to apply loads of 40 N for the supraspinatus, 10 N for the teres minor, 20 N for the infraspinatus, and 50 N for the subscapularis. The value of 40 N was established on the basis of the literature, reflecting the passive tension values found in in vitro long-standing rotator cuff tears after repair[10]. This value was believed to be appropriate to use because it would leave the specimens in a condition that would allow them to undergo cyclic testing. As no previous data were available for passive tension in all of the tendons of the cuff, representative loads for the remaining three tendons were estimated on the basis of published physiological cross-sectional areas of their associated muscles[11] and were calculated at a third of the value for the supraspinatus tendon. Therefore, the load was relatively higher on the supraspinatus, while the remaining cuff tendons were tensioned equally with respect to their cross-sectional areas. The pulleys were adjusted for each specimen on the rig, so that each tendon was loaded in the direction of its long axis and was aligned with the position of its muscle belly origin on the scapula. The loads were manually applied to the tendons simultaneously, and a measurement of the initial gap formation (mean increased wire-to-suture distance) was recorded immediately. The static load was maintained for an hour, with wire-to-suture distances being recorded every fifteen minutes. Throughout the dissection and subsequent testing, all of the specimens were regularly sprayed with 0.95% phosphate-buffered saline solution to prevent dehydration.

At the conclusion of the static testing, the specimens were unloaded and were removed from the rig. The intramedullary rod was then potted with polymethylmethacrylate bone cement into a prepared steel cylinder pot and was mounted onto a tensile testing machine (Instron 5565; Instron, High Wycombe, United Kingdom). The pots were attached to the testing machine with use of a specifically designed clamp, which allowed for accurate angulation of the humeral shaft relative to the horizontal[12]. The specimens were again mounted

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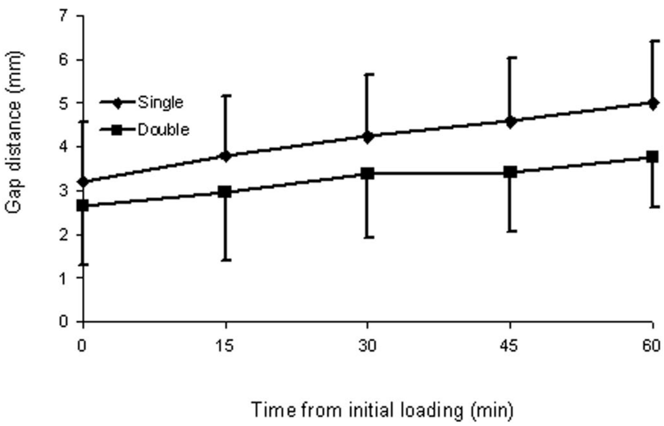

Fig. 6
Graph showing the relationship between gap distance due to static loading of the rotator cuff tendons and time for the two groups.

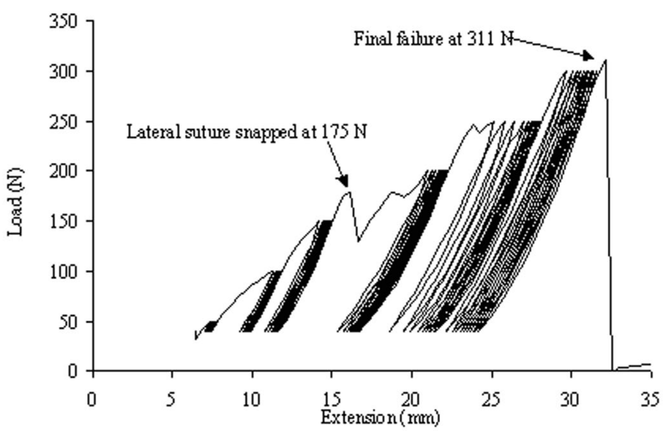

Fig. 7
Graph showing an example of the relationship between cyclic loading and extension until failure of a double-row repair.

at 30° of abduction and 0° of axial humeral rotation. A cryojaw[13] was used to fix the supraspinatus tendon to the crosshead of the testing machine. The temperature of the tissue within the clamp was regulated with a thermocouple and was kept at a mean (and standard deviation) of –20°C ± 2°C by opening and closing the valve supplying the CO_2. The remaining rotator cuff tendons were unloaded.

Each specimen was preloaded to 40 N and then was cycled from 40 to 50 N for ten cycles at a displacement speed of 50 mm/minute. After ten cycles, the maximum load was increased to 100 N and the specimen was again cycled ten times between 40 and 100 N. After each complete cycle set, the maximum load was increased by 50 N and the specimen was cycled ten times until failure was reached. Force, time, and crosshead displacement were recorded. Throughout cyclic loading, the suture, anchor, and tendon were examined and the mode of failure was documented. The ultimate cyclic failure load was recorded as the highest load that was sustained by the repair prior to failure. Therefore, if the sample had completed at least one cycle of a set, the failure load was the upper limit of that set. However, if the sample failed on ascent to the next level, the actual load at the time of failure was recorded.

Statistical Methods

The static data were tested for normality with use of the Lilliefors test for normality. The null hypothesis that the gap formation under static testing and the ultimate cyclic failure loads were the same in the two groups was tested with use of independent-samples t tests. The non-normally distributed cyclic data were tested with use of the Mann-Whitney U test. The alpha level was set at 0.05. All data are presented as the mean and the standard deviation.

Results

With static loading, there was an immediate mean gap formation of 3.2 ± 1.4 mm in the single-row group and of 2.7 ± 1.4 mm in the double-row group on initial loading ($p = 0.21$) (Fig. 6). The mean increase in gap formation from initial loading to the final reading was 1.8 ± 0.6 mm in the single-row group, compared with 1.1 ± 0.3 mm in the double-row group ($p = 0.004$). There was a trend toward larger gap formation over time when the single-row group was compared with the double-row group. However, this trend did not reach significance until the sixty-minute mark, at which point the ultimate gap formation was 5.0 ± 1.2 mm in the single-row group and 3.8 ± 1.4 mm in the double-row group ($p < 0.05$). One of the single-row repairs failed on static loading.

In the double-row group, the two suture anchors typically failed at different points during the cyclic testing regime (Fig. 7). The mean ultimate cyclic failure load was 320 ± 96.9 N for the double-row group and 224 ± 147.9 N for the single-row group. The difference between the single and double-row groups with regard to the ultimate cyclic failure load was not significant ($p = 0.058$). There was less overall variability in the failure loads in the double-row group (range, 250 to 350 N; lower 95% predictive value, 253 N) than in the single group (range, 40 to 450 N; lower 95% predictive value, 122 N).

Four of the double-row repairs failed through a midsubstance tear within the supraspinatus tendon (see Appendix). At the time of failure, one of these specimens had both sets of sutures intact and the other three specimens had failure of the lateral sutures only; thus, these results do not represent the repair strength. One of the single-row repairs also failed through a midsubstance tear with its sutures intact.

Discussion

The present study suggests that the addition of an extra anchor appears to provide a biomechanical advantage to a supraspinatus tendon repair by reducing the gap formation under a static load. However, the advantage of a second anchor during cyclic testing was not proven.

The most critical period for the success or failure of a rotator cuff repair is the early postoperative phase before healing has occurred, during which time the load transfer from tendon to bone is entirely carried through the means of

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fixation—in this case, the sutures and anchors. It is reasonable to suggest that excessive gap formation between tendon and bone at the repair site may contribute to the failure of healing and recurrence of the tear. Unfortunately, the "critical size" of the gap beyond which healing is inhibited has not yet been determined. It could be argued that failure due to gapping, and therefore inhibition of healing, would have taken place prior to mechanical failure of the sutures. However, as this distance is not known, it was decided to use absolute failure as the defined end point.

Although the double-row technique significantly reduced initial gap formation ($p < 0.05$), the finding that a static load of 40 N caused a mean gap of 3.8 mm to form after one hour of loading remains a concern. This load was used because the experiment was designed to simulate the normal resting position in a 30° abduction wedged sling as is commonly used following a rotator cuff repair. Although it can be expected that a repair will be subject to a static load due to recovery of resting muscle tone while in a sling[14], undoubtedly some voluntary and involuntary movement also will occur during normal daily activity. To simulate this scenario, the repair was loaded statically for one hour to evaluate the extent of gap formation of the tendon without complete failure, and then the specimens were evaluated further during cyclic loading.

To ensure that the mechanical testing environment was as "physiological" as possible, several design decisions were made. The scapula was left in situ to guide the loading of the tendons and, as anatomical dissections[15] have shown that all of the rotator cuff tendons fuse to form a common distal insertion, all of the tendons were loaded individually. The percentage contributions of the individual rotator cuff muscles and tendons are not known, so the situation at 30° of abduction was simulated by basing the load-sharing on the physiological cross-sections of the muscles. The main aim was to at least partially tension the whole of the rotator cuff to allow centralization of the humeral head within the glenoid while testing the supraspinatus. The cyclic loading regime has been used previously for biomechanical evaluation of rotator cuff anchors[16] with similar loads at failure; however, a modification of a preload of 40 N was included to allow for the prior loading during the static testing.

There are some limitations related to the interpretation of the results of these in vitro tests. The methodology required several freeze/thaw cycles, which has been shown to reduce the Young's modulus of tendons[17]. Therefore, the actual mechanical properties will have been affected by the storage procedures and the ultimate values cannot be translated to the in vivo setting. However, the purpose of the experiment was a comparison of two repair techniques, and this effect applied to both groups in equal measure. Another limitation was that the gap was measured in a plane tangential to the humeral surface, although repair obviously takes place between the tendon and the osseous insertion. However, measuring this vertical component of the gap would be very difficult in a dynamic testing situation. No technique of measuring gap formation is perfect, and there may be some degree of error due to elongation of muscle fibers, allowing additional movement of the superficial marking sutures. The degree of this error was not studied.

With respect to cyclic loading, several issues were raised. Some of the specimens had considerable gapping at the end of the static loading, and although the sutures remained intact in all specimens (except for one of those in the single-row group, which failed on static loading), this amount of gapping could be deemed as a failure prior to the cyclic testing. Also, the specimens had a 20-mm defect (rather than a complete cut) in the supraspinatus tendon, which allowed some interdigitated fibers to remain intact on either side of the repair. The presence of these fibers may have resulted in the assessment of the tension bridge created over the repair, in addition to the repair itself, during cyclic testing; however, this experimental scenario is a reflection of the actual in vivo scenario. The failure that occurred as the result of anchor pull-out may have been due to poor-quality bone. However, the bone density was not measured prior to testing.

The improvement of the repair due to the addition of the second row of sutures may be of clinical importance. In the double-row group, many of the lateral sutures failed first, which suggests they may provide a line of defense protecting the medial row. This additional "belt and braces" safety factor provided by the lateral sutures may translate into a greater rate of successfully healed tendons if a double-row technique is used. The low-strength outliers in the single-row technique support this idea and represent the difficulty of performing the procedure arthroscopically.

In a similar experiment[18], double-row fixation increased strength by 48% and increased stiffness by 46% as compared with single-row fixation. Another study demonstrated an increased load at failure in association with the double-row technique (287 ± 24 N) as compared with the single-row technique[19], yet a third study demonstrated no difference between double and single-row repairs[20]. Care must be taken when comparing the results of these studies as different testing protocols were used and none of the repairs were performed arthroscopically. In spite of this difference in surgical approach, the results of two of these studies[18,19] are consistent with our findings.

The large initial gap formation in both groups under static loading remains a concern and may be related to factors such as the stiffness of the suture material, the security of the knots, and the length of the suture loop. Improvements in fixation technique may help to alleviate this problem.

Recent reports have drawn attention to the high failure rate of arthroscopic rotator cuff repairs[21], particularly in patients with large or massive tears. Although techniques continue to evolve, and therefore may be difficult to compare directly, our findings suggest that for tears of ≤2 cm, arthroscopic double-row repair is feasible and provides acceptable mechanical results. This approach also may be applicable to larger tears as more than two suture anchors can be used. However, additional experiments would be required to confirm this hypothesis.

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Appendix

eA A table showing details on each specimen studied is available with the electronic versions of this article, on our web site at jbjs.org (go to the article citation and click on "Supplementary Material") and on our quarterly CD-ROM (call our subscription department, at 781-449-9780, to order the CD-ROM). ■

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