Mechanical Strength of Arthroscopic Rotator Cuff Repair Techniques

An In Vitro Study

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Background: Retears after rotator cuff repairs occur relatively frequently and may compromise the functional result. The goal of this study was to analyze the mechanical properties following arthroscopic techniques for rotator cuff repair and to evaluate possible alternative techniques.

Methods: In the first part, five different bone anchors (the Revo screw; Mitek Rotator Cuff anchor, 5.0-mm Statak, PANALOK RC absorbable anchor, and 5.0-mm Bio-Statak) were tested in vitro under cyclic loading on five pairs of cadaveric shoulders. Then five types of arthroscopic tendon suturing instruments were tested on rotator cuff tendons. Finally, the arthroscopically performed mattress and modified Mason-Allen stitches, fixed with either the Revo screw or the Bio-Statak, were evaluated on ten pairs of human cadaveric shoulders.

Results: The holding strengths of the various anchors were similar, ranging from 130 to 180 N, and approximated the holding strength of knotted number-2 suture materials. The fixation of the tested anchors yielded comparable values of stiffness except for one anchor, which showed significantly greater subsidence under cyclic load (p = 0.003). All tested, commercially available arthroscopic suturing devices were unsuitable for performing a modified Mason-Allen stitch on normal supraspinatus tendons. Modification of a commercially available suture punch with a longer needle allowed us to consistently perform a modified Mason-Allen stitch. The modified Mason-Allen stitch, which has shown favorable mechanical properties in open repairs of the rotator cuff, was not found to be stronger than the mattress stitch when performed arthroscopically and used with bone anchors. When the modified Mason-Allen stitch was fixed to one anchor, it was even weaker than a mattress stitch repaired with another anchor (168 versus 228 N). Unequal loading of the two suture branches due to the more rigid modified Mason-Allen stitch may be the reason for this difference.

Conclusions: Arthroscopic techniques for rotator cuff repair with use of the mattress stitch and bone anchors allow for a relatively solid fixation. The holding strength is not improved with use of the modified Mason-Allen stitch. Although a direct comparison with previous in vitro studies is not possible, the holding strength of open fixation techniques seems to be stronger. If rotator cuffs are subjected to high postoperative loading, open repair might be preferred to reduce the risk of a retear, until stronger arthroscopic fixation techniques are developed.

Retears after rotator cuff repairs occur with a relatively high frequency, and it seems that intact repairs yield substantially better functional results than retears do. In previous in vitro and in vivo studies, we assessed different open tendon-suturing and bone-anchoring techniques on sheep infraspinatus tendons. A modified Mason-Allen tendon stitch was found to be biologically compatible, and, combined with a bone augmentation membrane, it yielded the most favorable mechanical repair properties with high failure loads of about 350 N for two stitches, with use of number-3 Ethibond sutures (Ethicon, Somerville, New Jersey), and superior stiffness characteristics (Fig. 1). Because of the improvement in arthroscopic tools, and considering the advantages of arthroscopic surgery, interest in arthroscopic repairs of the rotator cuff is growing rapidly. Most current arthroscopic techniques for rotator cuff repair use simple or mattress stitches fixed with bone anchors with use of number-1 or 2 suture materials. Simple or mattress stitches have, however, shown failure loads of only 184 and 269 N, respectively, with two stitches of number-3 suture material. With thinner suture materials, which are currently used in arthroscopic surgery, even lower holding strengths would be expected. Furthermore, in the previous in vitro study, bone anchors yielded less stability than transosseous suture fixation with cortical bone.
The goals of this in vitro investigation were to determine the holding strength and stiffness of current arthroscopic techniques and to evaluate possible improvements in the fixation strength with use of the modified Mason-Allen tendon stitch and different bone anchors.

Materials and Methods

Mechanical Testing of Different Bone Anchors

Five bone anchors were tested (Fig. 2). Three of them were metallic: the Revo screw (Linvatec, Largo, Florida), the Mitek Rotator Cuff anchor (Mitek Products, Ethicon, Westwood, Massachusetts), and the 5.0-mm Statak anchor (Zimmer, Warsaw, Indiana). Two anchors were absorbable: the PANALOK RC absorbable anchor (Mitek Products, Ethicon) and the 5.0-mm Bio-Statak anchor (Zimmer). The Revo screw, the Mitek Rotator Cuff anchor, and the PANALOK RC absorbable anchor were selected for this experiment because they have been successfully used for arthroscopic repairs of the rotator cuff by others. The 5.0-mm Statak and the 5.0-mm Bio-Statak anchors were tested as potential metallic and absorbable alternatives, respectively, because Barber et al., in previous in vitro studies, found that these two devices had the greatest pullout strengths from a cancellous trough compared with those of other metallic or absorbable devices, although the significance of the differences was not specified. All anchors were delivered and tested with number-2 braided polyester suture materials.

The anchors were tested on five pairs of fresh-frozen human shoulders from three male and two female cadavers. The mean age at the time of death was sixty-eight years (range, fifty-seven to seventy-eight years). Slight osteoarthritic changes were present in three humeral heads, and the other seven showed no apparent degenerative changes. To eliminate the influence of different degrees of bone quality among the ca-
davera, each type of anchor was tested on one of the two humeral heads of the same cadaver. Three types were tested on one humeral head and the remaining two types, on the contralateral humeral head. For the testing, all soft tissues were removed from the humeri. The heads were then fixed to a special device that later served for fixation to the testing machine (Fig. 3). To simulate the arthroscopic environment, all steps of insertion of the bone anchors were performed through a 7-cm-long cannula with an internal diameter of 8.25 mm (Twist-In Cannula; Arthrex, Naples, Florida). The three-dimensional orientation of the cannulae corresponded to the anterior, lateral, and posterior portals for shoulder arthroscopy. The experiments were performed at room temperature in an air environment, not in arthroscopic fluids. The specimens were kept moist with saline solution. The cortical bone was first partially removed at the superior part of the greater tuberosity on an area adjacent to the cartilage at a length of 30 mm and a width of 5 mm. With a 5.5-mm arthroscopic burr (Spherical Burr; Linvatec, Largo, Florida), removal of the cortical bone was minimal and continued only until the most superficial layer of cancellous bone was exposed. A formal trough was not created. Then the different bone anchors were inserted according to the instructions of the manufacturers. The threads of the Mitek Rotator Cuff and the PANALOK RC absorbable anchors were both manually loaded with 40 N each after insertion to lock and further set them within the bone. The load applied to the anchors was controlled by a spring balance. The angle of insertion was similar to that previously suggested (Fig. 4). To consistently reproduce the angle of introduction, a specially built insertion guide with a 60° angle was used. The distance between the sites of insertion of the different anchors was 1 cm. There were five different insertion sites on the humeral heads (Fig. 5). Three anchors were tested on one head, and two were tested on the contralateral head. The order of introduction of the five anchors into the various positions was regularly altered in order to avoid the influence of a difference in bone quality at the various positions.

The humeral heads were then fixed to the universal testing machine (model 4202; Instron Limited, High Wycombe, England) with the adjustable fixation device. This device allowed adjustment of the direction of pull of the sutures at 135° to the axis of the humeral shaft (see Fig. 4). This direction was selected to replicate the physiological pull of the supraspinatus tendon. One anchor of each type was tested individually. The threads of the bone anchors were wrapped twice around a metal bar, which was fixed to the crosshead of the testing machine, and were knotted with six simple square knots. The knots were positioned on the top of the metal bar so that the pull of the two branches of the threads was partially absorbed by the two turns of thread around the bar, and the knots themselves were therefore loaded to a lesser extent. A preload of 20 N was set at the crosshead of the testing machine.

Cyclic loading was performed, as it was considered the
best way to simulate the postoperative conditions in a manner similar to those used in prior studies. Fifty cycles with tensile loads of 75 N were then applied with a crosshead extension rate of 20 mm per minute. The tensile load was then increased by 25 N, to 100 N, for the next fifty cycles. Additional increases of the tensile loads by 25 N per fifty cycles were applied until failure of the anchor fixation system. The ultimate tensile strength, the failure modes, and the displacement of the fixation device of the threads (crosshead displacement) under load were recorded.

Development and Comparison of Arthroscopic Tendon-Suturing Devices

The mattress stitch, which is a currently used technique, was compared with the modified Mason-Allen stitch. Whereas the mattress stitch can be performed with conventional arthroscopic needles, suture retrievers, or suture punches, the modified Mason-Allen stitch requires specific arthroscopic suturing tools to apply the stitch within a reasonable period of operative time. Evaluation of the tendon sutures, therefore, consisted of the development and testing of arthroscopic suturing devices followed by a comparison of the mattress and modified Mason-Allen stitches.

Five suturing devices that were potentially suitable for arthroscopic use were tested (Fig. 6). Four of them were commercially available: the Caspari 4-mm slotted-jaw Suture Punch (Linvatec), the Mini-Straight Caspari Suture Punch System (Arthrotek, Warsaw, Indiana), the ArthroSew (Surgical Dynamics, Norwalk, Connecticut), and the Acufex Suture Punch (Smith and Nephew, Andover, Massachusetts). The fifth device was a personal modification of the slotted-jaw Caspari Suture Punch with a longer needle.

These suturing devices were tested on five fresh-frozen sheep rotator cuff tendons, as they have been previously shown to resemble human rotator cuff tendons in size, shape, and microstructure. Only macroscopically normal tendons were utilized. The testing consisted of the creation of the modified Mason-Allen stitch on the tendons, with special attention to the consistency of passing the needles and the sutures through the tendons. These tests were performed in part by an experienced orthopaedic surgeon and in part by two orthopaedic residents. Arthroscopic suturing is considered to be technically difficult, and the quality of the arthroscopically performed tests and tendon stitches can be influenced by surgical experience. The experimental setup, however, facilitated arthroscopic suturing since the environment was dry as no arthroscopic fluids were used, the space for creating the stitches was open and not restricted by surrounding soft tissues, the visibility was optimal, and there was no time limitation as with anesthetized patients. Only correctly performed tests and optimally positioned stitches were accepted for the experiment, and, therefore, the possible differences of quality of the arthroscopic suturing by the different surgeons was thought to be minimized.
Mechanical Properties of the Mattress and Modified Mason-Allen Stitches

The mechanical properties of the mattress stitches and the modified Mason-Allen stitches were then compared on ten pairs of fresh-frozen human cadaveric shoulders. The mean age of the three men and seven women at the time of death was seventy years (range, fifty-three to eighty-eight years). Only shoulders with macroscopically intact rotator cuffs were considered. Twelve shoulders had no signs of osteoarthritic changes, and four specimens had minimal degenerative joint changes. Two cadavera (four shoulders) had moderate osteoarthritic changes. The humeral heads were freed of all soft tissues except for the supraspinatus tendons, which were left intact. As was done in the testing of the bone anchors, the humeral heads were fixed with methylmethacrylate to the special fixation device. The supraspinatus tendons were then detached at their insertion. The thickness and width of the tendons were a mean (and standard deviation) of 3.8 ± 0.6 mm (range, 3 to 5.2 mm) and 26 ± 4.6 mm (range, 19 to 32 mm), respectively. The tendons were grasped by a special clamp that helped to hold them during arthroscopic repair and was later used to mount them to the crosshead of the Instron testing machine (Fig. 7).

The arthroscopic environment was again simulated in the same manner as that used in the previous tests. Only arthroscopic instruments were used. For the new modification of the slotted-jaw Caspari Suture Punch, a Small Oval Cannula System (Arthrotek) was used because of the larger diameter of the suturing device.

The supraspinatus tendons were repaired either with two mattress or with two modified Mason-Allen stitches. For each pair of humeral heads, the mattress stitch was used on one head and the modified Mason-Allen stitch was used on the contralateral head. Braided number-2 polyester suture materials were used for all tests. The sutures were fixed to the humeri with bone anchors: the Revo screw was used on five pairs and the Bio-Statak was used on the other five pairs.

A minimal amount of cortical bone at the superior part
of the greater tuberosity at the site of insertion of the supraspinatus tendon was removed, as was done for the bone-anchor testing. Two bone anchors per humeral head were then introduced in the same manner as that used for the bone-anchor testing.

For the mattress stitches, the threads were passed through the cuffs with use of 130-mm arthroscopic needles (Suture Hooks; Linvatec) and the Shuttle-Relay Suture Passer (Linvatec) as previously described. The width of the tendon tissues grasped by the mattress stitches was 8 mm. The stitches were inserted at a distance of 5 mm from the tendon end. The giant knot, which is a self-locking slip knot made with a single-hole standard knot pusher (Knot Pusher; Linvatec), was used for the mattress stitches.

The modified Mason-Allen stitches were made with the Caspari Suture Punch that had been modified with a longer needle because only this device allowed for a consistent passage of the suture material through the supraspinatus tendons (see Results). One of the threads of a bone anchor was passed three times through the supraspinatus tendon, as required for the modified Mason-Allen stitch, with use of the Shuttle-Relay Suture Passers. The width of the tendon tissue grasped by the modified Mason-Allen stitches was 5 mm. The stitches were placed at a distance of 5 mm from the tendon end. Six simple square knots were used to fix the modified Mason-Allen stitches. These knots were performed with use of a cannulated double-diameter knot pusher (6th Finger Knot Pusher; Arthrex). Slip knots were not suitable for the modified Mason-Allen stitches because the threads did not slip easily enough within the tendons.

The humeral heads were then fixed to the universal testing machine (Instron) with the special fixation device. The special clamp with the fixed supraspinatus tendon was attached to the crosshead of the testing machine. The direction of pull on the tendons was 135° to the axis of the humeral shaft to replicate the physiological pull of the supraspinatus tendon (see Fig. 4). A preload of 20 N was set at the crosshead of the testing machine. Cyclic loading was again performed. Fifty cycles with tensile loads of 150 N were then applied with a crosshead extension rate of 20 mm per minute. Afterward, the tensile load was increased by 50 N to a load of 200 N for the next fifty cycles. Additional increases of the tensile load by 50 N per fifty cycles were applied until failure of the tendon fixation occurred. The ultimate tensile strength, the failure modes, and the crosshead displacement under load were recorded.

**Statistical Methods**

Analysis of variance for repeated measures with the Bonferroni-Dunn post hoc test was used to test possible differences between the failure loads and the crosshead displacements of the different bone anchors. Paired and unpaired t tests were used to evaluate possible differences between the mattress and modified Mason-Allen stitches.

**Results**

**Mechanical Strength of Different Bone Anchors**

The failure loads and the displacement of the crosshead of the testing machine at 75 N are shown in Table I. The failure loads of the different anchors were similar and ranged from a mean of 130 N for the Mitek Rotator Cuff anchor to a mean of 180 N for the Bio-Statak anchor. The differences were not significant. The failures occurred in most instances by rupture of the suture material. For the metal anchors, the threads almost always ruptured at the eyelets of the anchors (five of five times for the Statak and four times for the Revo screw and the Mitek Rotator Cuff anchor each). The Revo

### Table I: Data on the Mechanical Strength of the Bone Anchors

<table>
<thead>
<tr>
<th>Bone Anchor</th>
<th>Failure Load* (N)</th>
<th>Crosshead Displacement at First Cycle at 75 N† (mm)</th>
<th>Mode of Failure† (No. of Anchors)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revo</td>
<td>140 ± 14 (125-150)</td>
<td>4.9 ± 1.6</td>
<td>Rupture at eyelet (4), anchor pullout (1)</td>
</tr>
<tr>
<td>Mitek Rotator Cuff</td>
<td>130 ± 21 (125-150)</td>
<td>4.4 ± 0.8</td>
<td>Rupture at eyelet (4), anchor pullout (1)</td>
</tr>
<tr>
<td>5.0-mm Statak</td>
<td>160 ± 29 (125-200)</td>
<td>4.5 ± 1.0</td>
<td>Rupture at eyelet (5)</td>
</tr>
<tr>
<td>PANALOK RC</td>
<td>145 ± 45 (75-175)</td>
<td>7.7 ± 2.0§</td>
<td>Rupture at eyelet (2), rupture at knot (1), anchor pullout (2)</td>
</tr>
<tr>
<td>5.0-mm Bio-Statak</td>
<td>180 ± 41 (125-225)</td>
<td>3.3 ± 0.7</td>
<td>Rupture at eyelet (2), rupture at knot (1), anchor pullout (2)</td>
</tr>
</tbody>
</table>

*Cyclic loading, with fifty cycles per load, was used. Failure of fixation occurred after a various number of cycles, ranging from the first to the last cycle of a total of fifty cycles performed per load. The values are given as the mean and the standard deviation, with the range in parentheses. No significant differences were found between any of the bone anchors. †The displacement was measured after the first cycle. The values are given as the mean and the standard deviation. §The PANALOK RC anchor had significantly greater crosshead displacement compared with all other tested anchors (p = 0.003).
screw and the Mitek Rotator Cuff anchor each failed by pullout only once. For both absorbable anchors, the threads ruptured only twice at the eyelets and once at the knot. In two cases, both absorbable anchors failed by pullout.

**Characteristics of Various Arthroscopic Tendon-Suturing Devices**

All tested, commercially available suturing devices were found to be unsuitable for a modified Mason-Allen stitch on normal supraspinatus tendons. The needle of the Caspari 4-mm slotted-jaw Suture Punch was found to be too short. Frequently, it did not fully penetrate the tendon, especially with oblique passages. The needles of the ArthroSew and the Acufex Suture Punch were found to be too short or the devices were too weak. As a result, the needles either deviated so that they could not be retrieved at the opposite side of the tendon (ArthroSew) or they could be grasped at the opposite side of the tendons but the instruments were not strong enough to pull the needles though the tendon tissue (Acufex Suture Punch). The Mini-Straight Caspari Suture Punch System consistently perforated the tendons and retrieved the sutures but always damaged the suture material (Fig. 8).

To obtain consistent penetration, the needle of the Caspari Suture Punch was lengthened from 4.5 to 8 mm, which allowed us to perform a modified Mason-Allen stitch consistently. This stitch was identical to the modified Mason-Allen stitch performed with an open technique as shown in a previous study on open techniques of rotator cuff repair.

**Mechanical Strength of the Mattress and Modified Mason-Allen Stitches**

The mean failure loads of the mattress and modified Mason-Allen stitches were similar when repaired with the Revo screw (228 and 210 N, respectively) (Table II). When repaired with the Bio-Statak, the failure loads of the mattress and modified Mason-Allen stitches averaged 230 and 168 N, respectively. No significant differences of the crosshead displacement between the types of stitches were found.

<table>
<thead>
<tr>
<th>Tendon Stitch</th>
<th>Failure Load† (N)</th>
<th>Crosshead Displacement at First Cycle at 75 N‡ (mm)</th>
<th>Mode of Failure of First Repair/Second Repair§ (no. of cases)</th>
</tr>
</thead>
<tbody>
<tr>
<td>With Revo screw fixation Mattress</td>
<td>228 ± 26 (200-250)#</td>
<td>3.1 ± 1.4 (1.5-5)</td>
<td>Rupture at eyelet/stitch slip-out (1)</td>
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<td></td>
<td></td>
<td></td>
<td>Rupture at eyelet/anchor pullout (1)</td>
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<td></td>
<td></td>
<td></td>
<td>Anchor pullout/stitch slip-out (1)</td>
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<td></td>
<td></td>
<td></td>
<td>Anchor pullout/anchor pullout (1)</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Stitch slip-out/stitch slip-out (1)</td>
</tr>
<tr>
<td>With Bio-Statak fixation Mattress</td>
<td>230 ± 57 (150-300)</td>
<td>3.6 ± 0.5 (2.8-4)</td>
<td>Anchor pullout/anchor pullout (2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Anchor pullout/stitch slip-out (1)</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Anchor pullout/rupture at eyelet (1)</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Rupture (not at eyelet)/rupture (not at eyelet) (1)</td>
</tr>
<tr>
<td>Modified Mason-Allen</td>
<td>210 ± 22 (200-250)</td>
<td>3.7 ± 1.0 (2.8-4.5)</td>
<td>Rupture at eyelet/rupture at eyelet (3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Rupture at eyelet/anchor pullout (1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Anchor pullout/rupture at eyelet (1)</td>
</tr>
<tr>
<td>Modified Mason-Allen</td>
<td>168 ± 46 (140-250)#</td>
<td>4.1 ± 0.9 (3.3-5.2)</td>
<td>Anchor pullout/anchor pullout (1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Anchor pullout/stitch slip-out (3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Rupture at eyelet/anchor pullout (1)</td>
</tr>
</tbody>
</table>

*Two anchors with two stitches of the same technique were used for each supraspinatus tendon. †Cyclic loading, with fifty cycles per load, was used. Fixation failed after a various number of cycles, ranging from the first to the forty-fourth cycles of a total of fifty cycles performed per load. The values are given as the mean and the standard deviation, with the range in parentheses. ‡The values are given as the mean and the standard deviation, with the range in parentheses. There were no significant differences of the crosshead displacement between the types of stitches. §Rupture at eyelet = suture material ruptured at the eyelet of the anchor. #The difference of the failure load between the modified Mason-Allen stitches fixed with Bio-Statak and the mattress stitches fixed with the Revo screw was significant (p = 0.03).
differences between these failure loads were found, with the number of tests available (p = 0.2). However, the modified Mason-Allen stitches with use of the Bio-Statak were significantly weaker than the mattress stitches with use of the Revo screw (168 versus 228 N, respectively) (p = 0.03). No significant differences in the stiffness of the various repairs were found, with the number of tests available.

The failure modes varied. The mattress stitches (fixed with either the Revo screw or the Bio-Statak) slipped out of the tendons five of twenty times compared with three failures with the modified Mason-Allen stitch. Rupture of the suture material occurred in ten of the twenty Revo screw fixations and in four Bio-Statak repairs. Pullout of the anchor was observed six times for the Revo screw and ten times for the Bio-Statak.

Discussion

Obtaining healing of rotator cuff repairs is crucial if restoration of postoperative function is a major goal.\textsuperscript{1,3} Current clinical\textsuperscript{3,5} as well as experimental evidence suggests that the technique of repair plays an important role in the prevention of failure of the repair\textsuperscript{2,5}. In a previous in vitro study in sheep, we found that the modified Mason-Allen stitch provided the strongest rotator cuff repair when heavy sutures such as number-3 Ethibond were used and the knots were tied over a plate-like bone-augmentation device over the greater tuberosity.\textsuperscript{4} For such repairs, the number-3 Ethibond (braided polyester) was the weakest link in the chain and failed at loads of >300 N.

Arthroscopic tendon-to-bone repairs are technically more difficult than open repairs because all surgical steps have to be performed through cannulae. This limits the selection of the instruments and the implants and may increase operative time. Except for the technique of Shea and Jennings\textsuperscript{5}, most of the currently applied arthroscopic techniques of rotator cuff repair use a simple or a mattress stitch and suture fixation with bone anchors\textsuperscript{6,7}. The bone anchors typically use number-2 braided polyester sutures, which are weaker. For example, the holding strength of two knotted loops of number-3 Ethibond is 424 N, but it is only 328 N for number-2 Ethibond sutures.\textsuperscript{5}

In the current study, the holding strengths of the various anchors were similar and approximated the holding strength of knotted loops of number-2 braided polyester suture. The failure loads of the metallic anchors were slightly inferior to those of the absorbable devices. Rupture of the suture material occurred more often at the eyelets of the metallic implants than at the eyelets of the absorbable anchors. Careful inspection revealed that the eyelets of the metallic anchors had some sharp edges and the eyelets of the absorbable anchors had smooth edges. Design changes with smoother eyelet edges for the metallic implants might reduce the likelihood of suture breakage. However, on the basis of these biomechanical tests, we found no significant or important differences among the anchors tested except for the PANALOK RC absorbable anchor, which showed less fixation stiffness. Factors other than the mechanical performance might be considered for the selection of one particular anchor. For example, the outside diameter of the tested anchors varied from 5 mm for the 5.0-mm Statak and Bio-Statak to 3.2 mm for the PANALOK RC absorbable anchor. Absorbable anchors have certain advantages. They can easily be overdrilled in case of rupture of the suture material, and they do not interfere during later revision surgery or for imaging studies such as magnetic resonance imaging.

We were surprised that the modified Mason-Allen stitch, when performed arthroscopically and used with bone anchors, was not stronger than the mattress stitch. There may be various reasons for this finding. The mattress stitches allowed a certain amount of slippage of the threads within the tendons. After the first few cycles, the loads seemed to be equally distributed between both mattress stitches. Conversely, the sutures of the modified Mason-Allen stitches showed no slippage within the tendons. Although use of the new modification of the Caspari punch allowed the creation of an acceptable modified Mason-Allen stitch, the two stitches often were not equally tightened, resulting in unequal distribution of the loads between them.

This study had some drawbacks. Only five anchors were tested despite the large number of devices currently available. The nonabsorbable 5.0-mm Statak anchor and the absorbable Bio-Statak anchor were tested because, in previous in vitro studies, they showed the greatest pullout strengths from a cancellous trough in comparison with numerous nonabsorbable and absorbable devices.\textsuperscript{15,16} Nonetheless, there might be other anchors with a higher fixation strength than the anchors tested in this study.

The anchors were tested one at a time with two or three sequential pullout tests per humeral head. The distance between the anchors was 1 cm. It seemed that the pullout tests of the anchors did not interfere with each other because only limited bone destruction was observed at the site of anchor failure. However, this variable was not specifically investigated in the present study.

Only five measurements per anchor or tendon stitch were performed. The anchors or stitches were always compared on the shoulders from the same individual, and the potential influence of interindividual differences of the bone quality was therefore minimized. A larger number of tests would have increased the power of the statistical tests. However, because the modified Mason-Allen stitch yielded a lower mean holding strength than the mattress stitch, it was therefore not expected that more measurements would have changed the conclusions of this study by showing an improvement of the fixation strength with the modified Mason-Allen technique.

The evaluation of the tendon stitches was performed on intact tendons and not on degenerated tendons from long-standing rotator cuff tears. It is possible that the tested stitches would behave differently on severely degenerated tendons. Therefore, the findings of this study should be applied to tears of tendons of good tissue quality rather than to chronic, massive tears.
The tendon suturing devices were tested on intact sheep rotator cuff tendons. It has been shown that they resemble human rotator cuff tendons in size, shape, and microstructure. Intact tendons are usually harder and thicker than tendons that are degenerated and thinned from chronic tears, which might explain why the suturing devices did not consistently penetrate the tendons used in the current study. Our intraoperative experience confirms, however, that arthroscopic performance of tendon stitches during rotator cuff repair is not consistently possible with use of some of the tested suturing devices.

The holding strength of bioabsorbable anchors decreases with time. Both absorbable anchors tested in this study consisted of poly(L-lactic) acid. According to the manufacturer of the PANALOK anchor, >90% of its strength is retained for three months after implantation in vivo. Although it has been suggested that there is little difference between absorbable and nonabsorbable anchors, failure by loosening of absorbable anchors has been reported. It should be emphasized that these are tests of the initial fixation strength only and do not address the issue of a bioabsorbable response in vivo over time.

In conclusion, the holding strength of currently used arthroscopic techniques of rotator cuff repair with use of anchors and a mattress stitch cannot be improved significantly with use of various bone anchors or the modified Mason-Allen stitch. Although a direct comparison with previous in vitro studies is not possible, the holding strength of the arthroscopic fixations in this study reached only about 230 N compared with values of >300 N for open tendon-to-bone repairs. The reason for the lower holding strength with arthroscopic techniques is the use of number-2 suture materials and bone anchors; in comparison, open techniques use stronger number-3 sutures and augmented transosseous suture-to-bone fixation, which has been shown to be stronger than bone anchors for fixation. For rotator cuff repairs that are subjected to postoperative loading, open repair might be preferred to reduce the risk of a retear until stronger arthroscopic fixation techniques are developed.

References


