Influence of prolonged immersion on the resistance of arthroscopy knots in biological media

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- Knots;
- Healing time;
- Biomechanical test;
- Rotator cuff;
- Arthroscopy;
- Arthroscopic sutures

Summary

Introduction: Biomechanical studies of arthroscopic knots have been performed on sutures that were tied manually and tested immediately after tying. We performed this study to evaluate the knot and the suture during the healing phase, which was not evaluated in these previous studies. Our hypothesis was that the biomechanics features of arthroscopic knots may change in relation to the duration of incubation in biological media simulating synovial fluid. Thus our goal was to study the influence of incubation for 30 days in biological media simulating body fluid using a device to standardize knot tying and allow comparison of arthroscopic sutures.

Materials and methods: Three Ultra-High Molecular Weight PolyEthylene (UHMPE) sutures (Fiberwire, Orthocord and Maxbraid) were tested with a self-locking slip knot (SMC knot). Sixty identical knots were tied using a standardized device, and divided into two groups: the control group « D0 » and the group « D30 » where the knots were soaked in biological media simulating body fluid for 30 days. Cyclic loading tests were then performed on the knots in each group using a machine to define four variables: clinical failure, ultimate failure, knot slippage and the characteristics of failure.

Results: There was no significant difference between the two groups for knot resistance at clinical failure or ultimate failure, without regard to the suture, (P<0.05). After cyclic loading, the most slippage occurred in the Orthocord (≈5.6 mm) then the Maxbraid (≈3.55 mm) and the Fiberwire (≈2.51 mm). The only suture whose slippage was influenced by the duration of incubation was Orthocord. At clinical failure, the loop that slipped the most was the Orthocord suture (≈5.45 mm) then the Fiberwire (≈4.8 mm) and the Maxbraid (≈4.1 mm). In the Orthocord and Maxbraid sutures, knot slippage after clinical failure significantly increased with the duration of suture incubation (P<0.05). The reason for failure was breakage from tearing of suture fibers in all cases.

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Introduction

The increased use of arthroscopic shoulder surgery is due, in part, to improvements in material, suture anchors and sutures. Several arthroscopic knots have been described for fixation of repaired tissue. Repair may be unsuccessful if the suture fails and the tendon is not in contact with the bone during healing.

Numerous articles have studied the quality of different suture materials, and performed mechanical comparisons of arthroscopic knots by analyzing different variables such as response to cyclic loading, maximal loads, and knot slippage [1—10].

Tests are usually performed immediately after the suture is tied, on manually tied knots, with results that do not take into account the response of the knot and the suture to immersion in the biological media of human body fluids.

Our hypothesis was that the biomechanics of arthroscopic knots changes during incubation in the biological media simulating synovial fluid.

The goal of this study was therefore to evaluate the influence of 30 days incubation in a liquid simulating human body fluid (SBF). To reach this goal and study reproducible knots with a low standard deviation, a device to tie standardized knots was designed for this study.

Materials and methods

We selected a self-locking slip knot in the literature, the SMC knot, [11], for its high quality resistance and against slippage [4,6,7,9,11].

We tested this knot in three Ultra-High Molecular Weight PolyEthylene (UHMWPE) sutures, which are the most frequently used sutures for arthroscopy in France: Fiberwire (Arthrex®), Orthocord (Depuy Mitek®) which is partly composed of absorbable polydioxonone (PDS), and Maxbraid (Blomet®).

A device to tie knots that were as identical as possible was built on precise specifications.

This original device included a base with an electronic dynamometer mounted on one side and a winding reel on the other, so that reproducible knots could be tied on the same plane.

Each SMC knot was tied in the same way by the same surgeon (BR), with the help of the tightening mechanism, and wearing sterile gloves [7].

The sutures were first soaked in saline solution for 5 min. The knots were tied in the following manner, around a 9.5 mm diameter post to obtain loops with a 30 mm circumference, corresponding to the estimated circumference of in vivo loops during arthroscopic surgery [9]. A preload of 10 N was applied to the knot on the wrapping limb of the suture by pulling on the free suture limb to pre-tighten the knot and reduce its size (this was performed under real conditions, so that the knot could be passed through the arthroscopic cannula). The wrapping limb was then attached to the winding reel and the other limb to the dynamometer, with the steel bar placed at the same height between the two. By using the winding reel, tension could be applied to the wrapping limb of the suture until it reached 25 N [10]. During tightening, the knot descended until it touched the bar (Fig. 1). The knot was then locked by three reversing half hitches [12], which were also tightened to 25 N, by reversing loading of the wrapping limb of the suture on the device during each half-hitch. Both suture limbs were cut 3 cm from the knot to obtain the test loop.

We produced 60 loops divided into two groups of 30. Ten knots in each group were tied with Fiberwire, 10 knots with Orthocord and 10 knots with Maxbraid. The first group was called « group D0 », and was a control group. Once they were tied, the 30 loops were dipped in saline solution for 20 min [7], then immediately tested under loading.

In the second « D30 » group the loops were soaked in a biological media for 30 days then tested by cyclic loading. Loops were soaked in vials filled with saline solution, and incubated in a vat at 37 °C with 5% CO2 thus simulating the « in vivo » conditions of the human body (Fig. 2).

The biomechanical protocols [4,5,9] described in the studies by Burkhart et al. [13] were used for the loading tests. Cyclic loading of the loops was performed using an "INSTRON", model 5565 tensile-compression testing machine. Two 3 mm cylindrical posts, whose separation was controlled by machine, were used to attach the test loop and apply tension (Fig. 3).

There were different phases to the trials.

A preload of 10 N was applied at a speed of 0.1 mm/s for 1 min to stabilize the load response. The reference position was then defined. Then cyclic loading between 10 N and 45 N was applied for 1000 cycles, at a frequency of 1 Hz, simulating the stress on the shoulder during the first postoperative month [14]. Then the preload of 10 N was applied again to compare it to the initial values and identify any slippage from cyclic loading. Tension was then applied at a speed of 0.5 mm/s until there was a separation of 3 mm between the two posts. This threshold is often used [15—17] and corresponds to so-called “clinical” failure, because the loop is no longer tight enough to ensure bone—tendon contact. Then a load was applied at a speed of 0.5 mm/s until 25 mm of displacement was achieved, which always resulted in a so-called “ultimate” failure of the test loop; when the knot slips and comes undone or the suture breaks.

Any knot slippage was recorded with a camera that was placed in front of the loop to measure any displacement of two marks placed on the suture, as close as possible to the knot to prevent the influence of any suture deformity on measurements. The position of the marks was recorded before testing (after 10 N preload), after cyclic loading

Conclusion: Prolonged incubation of arthroscopic suture knots influences slippage, which could result in unsuccessful primary attachment of the tendon during the healing phase.

Level of evidence: Level IV. Biomechanical study.

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Figure 1  Knot performed under reproducible conditions: one left: the soaked string is tightened around the 9 mm steel bar and fastened with three inverted half hitches; one right: each loop is tightened with a digital dynamometer.

Figure 2  Dipping in biological media: each group of loops is soaked in saline solution (a) and incubated in biological media (b); they were kept for 30 days in a vat: 4.5%, CO₂, 37 °C, 95% humidity (c).

(again with 10 N preload) and at the end of the test until clinical failure, so that we could determine slippage after cyclic loading and at clinical failure.

The following variables were analyzed:

- load to clinical failure: maximum load necessary to produce 3 mm of displacement;
- load to ultimate failure: maximum load necessary to produce loop failure;
- knot slippage;
- causes of failure.

For the statistical analysis the Student t test was used to compare the data at D0 and D30 for the same suture
Resistance of arthroscopy knots in a biological media

Results

Validation of the standardized knot

The comparison of our results with those in the literature using slip knots are shown in Table 1. The coefficients of variance in our series were lower than those in the literature and less than 10% showing that there was little variation in the results in this series thanks to the standardized method.

For Fiberwire: there was a significant difference between the standard deviations in our series and those in the study by Barber (F = 0.0317, \( P = 1.9 \times 10^{-5} \)). There were no significant differences in standard deviations for Fiberwire sutures between the Swan series and ours (F = 0.29, \( P = 0.069 \)).

For Maxbraid: there was a significant difference between the standard deviations for Maxbraid sutures in the study by Barber and our series (F = 0.126, \( P = 0.0049 \)).

The standard deviations for Orthocord in the Barber series were significantly higher than those obtained in our series (F = 0.13, \( P = 0.0061 \)).

Test Results

The test results are presented in Table 2.

Clinical failure

There was no significant difference in knot resistance at clinical failure in any of the sutures between D0 and D30.

Results were significantly different for the three sutures whatever the duration of incubation. Fiberwire (97.1 N mean of D0 and D30) was the most resistant suture, then Maxbraid (74 N) and finally Orthocord (46.7 N).

Ultimate failure

At ultimate failure there was no significant difference in mean knot resistance between the two groups D0 and D30 with the three tested sutures.

Fiberwire and Maxbraid were significantly more resistant than Orthocord in both groups. There was no significant difference between Fiberwire and Maxbraid sutures. The mean value of D0 and D30 was: 324 N for Fiberwire, 318 N for Maxbraid and 188 N for Orthocord.

Slippage

After cyclic loading only Orthocord showed a difference between D0 and D30: slippage increased significantly after the suture was incubated (\( P < 0.05 \)). There was no change between D0 and D30 for Fiberwire or Maxbraid (\( P < 0.05 \)). The greatest amount of slippage occurred with Orthocord (a mean 5.6 mm between D0 and D30) then Maxbraid (3.6 mm) and Fiberwire (2.5 mm).

In Orthocord and Maxbraid, knot slippage increased as the duration of suture incubation increased (\( P < 0.05 \)) following clinical failure, but not in Fiberwire sutures. The Orthocord suture slipped the most (a mean 5.5 mm between D0 and D30), then Fiberwire (4.8 mm) and finally Maxbraid (4.1 mm).

Mechanism of failure

The only reason for failure was breakage by gradual tearing of the suture fibers.

Discussion

Our study shows that under these test conditions, the amount of time the knot was incubated in a biological media influenced the Orthocord suture knot after cyclic loading and clinical failure, while it only influenced clinical failure in the Maxbraid suture. After 30 days of incubation there was significant slippage in the Orthocord knots. The only suture knot that was not affected by incubation was the Fiberwire. Orthocord had the greatest amount of slippage of all three tested sutures. This UHMPE suture, unlike the others has an absorbable component that may partially explain these results at D30.

On the other hand our results show that duration of incubation does not influence knot resistance to cyclic loading.

The 2004 symposium of the French Arthroscopy Society (SFA) [18] confirmed that functional results in healed rotator cuffs were good, encouraging repair of these tears. The low rate of complications and the efficacy of arthroscopic procedures support the choice of this surgical solution at present. The quality of the functional results depends on tendon healing [19]. Indeed, this guarantees a watertight cuff, which is
### Table 1  Comparison of results of mechanical tests obtained with slip knots.

<table>
<thead>
<tr>
<th>Study</th>
<th>Suture</th>
<th>Knot</th>
<th>Clinical failure</th>
<th>ET “EE” (N)</th>
<th>%</th>
<th>Ultimate failure (N)</th>
<th>ET “EU” (N)</th>
<th>%</th>
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<td>–</td>
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<td>Our study</td>
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<td>3.12</td>
<td>6.6</td>
<td>Orthocord D0: 188.39</td>
<td>Orthocord D0: 188.39</td>
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<td>0.0</td>
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<td>MaxBraid D30: 315.09</td>
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</table>
the source of a significant improvement in the postoperative Constant score [18] mainly because of recovery of range of motion and strength [18,20].

However, the rate of secondary tears is high [20,21], perhaps associated with incomplete healing.

Good healing depends in part on patient characteristics but also on factors associated with the surgical procedure, in particular good surface contact between the tendon and the bone.

There are numerous articles in the literature testing the different available suture materials and knots in vitro [3–7], for cuff repairs or [8,9] Bankart repairs [10].

The preload protocol followed by cyclic loading [4,5,9,13] provides more reliable results by removing any initial distension in the knot [13], and simulating the loading that a suture undergoes during the healing phase [14]. However, all of these previous studies tested the sutures immediately after they were tied, and did not study the influence of the biological media over time on the knots.

The standard deviations in previously published studies were significant. Our study, based on knots that were standardized and as identical as possible, in very low standard deviations. In our study, the standard deviation was systematically less than 10% of the total load at failure, which was never the case in the previously published studies, confirming the interest and efficacy of this device designed to obtain identical knots. Barber et al. [1] and Lo et al. [15] had variations of more than 30% under the same knot tying conditions. The advantage of this fairly complicated protocol is that only one element is different (simulated body fluid) during the tests.

The aim of this study was to determine if there was a change in the sutures associated with incubation in biological media during the phase when they are the primary source of tendon attachment, which is a determining factor for correct healing [22]. Our results did not show any decrease in loop resistance during this period (they do not break more easily after incubation), but did show that slippage increased at D30 with the Orthocord suture and to a lesser extent with the others (Maxbraid).

Nevertheless, our study is limited because it only evaluated one knot with three types of sutures. We chose this knot because it has been shown to be the knot with the least slippage in the literature [4].

This study shows that Fiberwire is more resistant, with better results during cyclic loading [23], and no statistically significant slipping at D30 unlike the conclusions by Abbi et al., which showed a higher rate of slippage with this suture [9]; however this study compared different types of sutures.

Conclusion

Our experimental study shows that incubation for 30 days in biological media simulating body fluid influences slippage of loops with SMC knots in Orthocord and Maxbraid sutures. This is an important variable because knot slippage can compromise primary fixation of the tendon during the healing phase, and result in unsuccessful repair. Tests were performed with a standardized knot, thanks to a device that was specially designed for this study. We suggest that this device be used for future biomechanical studies on knots or sutures.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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References