The Krackow Stitch: A Biomechanical Evaluation of Changing the Number of Loops Versus the Number of Sutures

Brian P. McKeon, M.D., James F. Heming, D.O., John Fulkerson, M.D., and Rolf Langeland, M.D.

**Purpose:** The purpose of this study was to biomechanically evaluate several configurations of the Krackow stitch and determine which configuration provided the best fixation with regard to load to failure and elongation. **Type of Study:** Biomechanical study. **Methods:** Thirty fresh-frozen porcine Achilles tendons were randomly assigned into 6 groups. For 3 of the groups, 1 suture was used (No. 5 Ethibond; Ethicon, Somerville, NJ) with 2, 4, or 6 Krackow locking loops. For the other 3 groups, 2 sutures (interlocking and at 90°) with 2, 4, or 6 Krackow locking loops were used. Data were evaluated using analysis of variance. **Results:** There were no statistical differences in peak load to failure and elongation among any of the 1-suture techniques regardless of the number of locking loops (2, 290 N; 4, 302 N; and 6, 298 N; standard deviation, 25.2, 9.0, and 28.6, respectively). Similarly, there were no statistical differences among any of the 2-suture techniques regardless of the number of locking loops (2, 534 N; 4, 492 N; and 6, 505 N; standard deviation, 42.0, 65.4, and 76.3, respectively). There was, however, a significant difference \( P < .05 \) in peak load to failure between the 1-suture and the 2-suture groups. The mechanism of failure was suture rupture in all cases. **Conclusions:** Load to failure did increase with the addition of a second interlocking suture placed at 90° to the first. **Clinical Relevance:** Tendon fixation with gap formation or suture rupture is at risk of failure. This study identifies that increasing the number of sutures is more important than increasing the number of locking loops. **Key Words:** Krackow suture—Suture fixation—Biomechanical testing—Soft tissue fixation.

Repair and reconstruction of ligaments and tendons present a challenge to the orthopedic surgeon when considering fixation. Secure fixation is crucial and allows for early rehabilitation and a successful outcome. Biomechanical characteristics may be affected by a number of variables, such as strength and size of the suture, quality of the tissue, the suturing technique, and strength of the suture-to-bone fixation. There are a variety of techniques that allow soft-tissue fixation to bone.1-4 The use of tunnels, anchors, interference screws, and screws with washers used as a post have been thoroughly described and tested. Fixation of soft tissue is mostly accomplished with suture. A biomechanical study using flexor tendons revealed that increasing suture caliber increased repair strength when using smaller No. 5-0 to 2-0 sutures. It was also reported that the suturing technique became more important with the larger No. 2-0 and 3-0 caliber sutures.5

There are a variety of suture techniques described for grasping and holding soft tissues. In 1986, Krackow et al.2 published the description of a new locking suture for fixating ligaments, tendons, or capsular components to bone. The classic Krackow stitch involves 3 or more locking loops placed along each side of the ligament or tendon. The Kessler and Bunnell Stitches are also well known for their holding power and are often used when repairing tendons.6,7

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*From Pro Sports Orthopedics Inc (B.P.M.), Waltham, Massachusetts; Genesys Region Medical Center (J.F.H.), Michigan State University, Grand Blanc, Michigan; Orthopedic Associates of Hartford (J.F.), Hartford, Connecticut; and the Orthopedic Specialty Group (R.L.), Fairfield, Connecticut, U.S.A.*

Address correspondence and reprint requests to James F. Heming, D.O., 6014 Long Point, Davison, MI 48350, U.S.A. E-mail: JD1330@aol.com

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Biomechanical testing on human Achilles tendons has shown the Krackow to be substantially stronger. In regard to ligament reconstruction, soft-tissue grafts are becoming more common. Studies have shown the fixation strengths of the Krackow locking loop stitch tied over a screw to be equivalent to interference screw with bone plug fixation. An earlier study evaluating constructs using suture techniques for reconstruction of the ACL reported high failure loads due to graft elongation and low stiffness. More recently, in rabbit Achilles tendons, it has been shown that increasing suture pitch with the Krackow technique, 1 cm versus 0.5 cm, is related to increasing stiffness. It is clear that secure fixation without elongation and lengthening through deformation, stitch pullout, or suture rupture is very important. Without this, gap formation may develop at the repair and it may fail. The principal objectives of this study were to biomechanically evaluate several different configurations of the Krackow stitch and determine which configuration provides the best fixation with regard to elongation and load to failure. Our hypothesis was that adding a second Krackow suture interlocked with the first at 90° will increase load to failure.

**METHODS**

Thirty fresh-frozen porcine Achilles tendons were harvested and the working length was standardized to 10 cm after thawing for 24 hours. Moisture of the tendon was maintained with saline sprays during preparation and testing. The thirty tendons were randomly assigned into 6 groups (5 per group) and had different configurations of the Krackow stitch, as described by Krackow, in his original article, starting 1 cm from the tendon end. The suture material used throughout the study was No. 5 Ethibond (braided, nonabsorbable polyester fiber; Ethicon, Summerville, NJ). For 3 of the groups, 1 suture with 2, 4, or 6 paired Krackow locking loops was used. For the other 3 groups, 2 sutures, the second placed at 90° and interlocking with the first suture, were used. They also had 2, 4, or 6 paired Krackow locking loops (Fig 1). Care was taken to measure and space the loops 5 mm apart and tension each individual locking stitch to remove excess suture material present within the locking loops. The tendons were preloaded to 5 N for 2 minutes. The construct was mounted securely in the jaws of a materials testing system (Model 858; MTS, Minneapolis, MN) around a knot leaving 8 cm of suture from the jaws to the first locking loop. Standard load to failure input parameters for the MTS were used: rate, 2 mm/sec; load limit, 4,999 to −4,999 N; displacement limit, 99 to −99 mm; and time limit, 60 seconds. All specimens were then loaded to failure in tensile mode. Failure loads and elongation at failure were measured directly by the MTS machine and digitally transferred to a computer. Load deformation curves were plotted, and data were analyzed using analysis of variance.

**RESULTS**

There was no statistical difference in peak load to failure among the 1-suture techniques, regardless of the amount of locking loops (2, 290 N; 4, 302 N; and 6, 298 N; standard deviation, 25.2, 9.0, and 28.6, respectively). Similarly, there was no statistical difference among the 2-suture techniques, regardless of the number of locking loops (2, 534 N; 4, 492 N; and 6, 505 N; standard deviation, 42.0, 65.4, and 76.3, respectively). There was, however, a significant difference (P < .05) in peak load to failure between the 1-suture and 2-suture groups. Elongation at failure between the 1-suture and 2-suture configurations, did not reliably vary by treatment condition (P = .63).

Table 1 summarizes the peak load to failure and elongation at failure data of the 6 Krackow stitch configurations tested. The mechanism of failure was suture rupture in all cases. Eighteen of the sutures ruptured at midsuture and the other 12 at the first locking loop-tendon interface.
The purpose of this study was to biomechanically evaluate several configurations of the Krackow stitch and determine which configuration provided the best fixation with regard to elongation and load to failure. We found that load to failure was greatly increased by adding a second interlocking Krackow stitch placed 90° to the first. We also found that adding more than 2 locking loops did not increase load to failure or consistently change elongation. Three well-known tissue grasping stitches used for tendon and ligament repair are the Kessler, Bunnell, and Krackow. When using these stitches for tendon and ligament repair, the resistance of gap formation is of great importance. If there is a gap at the repair, increased granulation tissue, adhesions, and delayed collagen maturation will result. As the gap becomes larger, healing is delayed and the result is a weaker, more attenuated repair. In a biomechanical Achilles tendon study by Watson et al., these 3 were tested on an Instron machine to determine load to failure. No. 1 nonabsorbable Ethibond suture was used for the repair. Mean load to failures were: Kessler, 85.24 N; Bunnell, 93.18 N; and Krackow 147.18 N. This study showed the Krackow stitch to be superior. A weakness, though, was that the Krackow stitch used 4 suture strands that did not interlock and the Bunnell and Kessler used only 2 suture strands. Therefore, a direct comparison among suture techniques is hard to establish. All failed by suture rupture and, therefore, they concluded that more suture strands crossing the repair is beneficial.

The benefit of doubling the number of suture strands in the repair of distal biceps tendons has also been reported. Morrey et al. described a modification of the modified Boyd Anderson 2-incision technique to repair distal biceps tendon ruptures. They showed the addition of 2 (4 total) suture strands to be biomechanically beneficial.

During cruciate ligament reconstructions, many surgeons prefer soft-tissue grafts. Fixation of soft tissue to bone in ligament reconstruction is often achieved using a variety of techniques. A common stitching technique used to “hold” the ligament or tendon during an anterior cruciate ligament (ACL) reconstruction is the one described by Krackow et al. In this setting, soft-tissue fixation to bone is extremely important for a successful ligament reconstruc-

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Mean Peak Load (standard deviation)</th>
<th>Mean Elongation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1S2L</td>
<td>290 (25.2) N</td>
<td>21.2 mm</td>
</tr>
<tr>
<td>2S2L</td>
<td>534.2 (42.0) N</td>
<td>19.5 mm</td>
</tr>
<tr>
<td>1S4L</td>
<td>301.7 (9.0) N</td>
<td>17.5 mm</td>
</tr>
<tr>
<td>2S4L</td>
<td>491.4 (65.4) N</td>
<td>12.9 mm</td>
</tr>
<tr>
<td>1S6L</td>
<td>298.3 (28.6) N</td>
<td>17.9 mm</td>
</tr>
<tr>
<td>2S6L</td>
<td>504.9 (76.3) N</td>
<td>18.0 mm</td>
</tr>
</tbody>
</table>

NOTE. 1S2L, 1 suture with 2 locking loops; 2S2L, 2 suture with 2 locking loops; 1S4L, 1 suture with 4 locking loops; 2S4L, 2 suture with 4 locking loops; 1S6L, 1 suture with 6 locking loops; 2S6L, 2 suture with 6 locking loops.
tion.18-21 Few studies have evaluated the biomechanics of the Krackow locking stitch for ACL reconstructions. In a porcine ACL reconstruction model, Leyget and Fulkerson10 found equivalent pullout strengths for the Krackow whipstitch tied over a screw and the Kurosaka interference screw fixation.

This study presents a detailed biomechanical analysis of various configurations of the Krackow locking stitch with regard to elongation and load to failure. We found that the number of paired locking loops (2, 4, or 6) does not affect the peak load to failure or the amount of elongation. Similarly, the number of sutures (1 or 2) did not effect elongation, but adding a second interlocking suture at 90° to the first nearly doubles the peak load to failure (Figs 2 and 3). We believe that the Krackow stitch configuration with the 2 sutures and 2 locking loops was superior to the other configurations. The mean load to failure of this configuration was 534.2 N. This was not statistically different to the 2-suture 4-loop (491.4 N) or 2-suture 6-loop (504.9 N) configurations. Using only 2 locking loops not only saves valuable operative time but avoids potential necrosis and injury of soft tissue constricted by the loops of the suture. One must also consider the possibility that additional unnecessary suture loops will add more “links” in the chain, more nonlinear sutures, and perhaps increased risk of eventually lengthening through slippage.12

The typical load displacement curve is shown in Fig 4. These results compare favorably with those of Kurosaka et al.22 (mean pullout of 436.5 N with bone–patellar tendon–bone interference screw fixation) and Legeyt and Fulkerson10 (interference screw fixation mean pullout of 533.8 N in the porcine ACL reconstructed bone–patellar tendon–bone). In a cadaveric study, ACL reconstructed knees with various graft and graft fixation techniques were tested to failure by translating the tibia anteriorly.20 These researchers found the average maximum load to failure using interference screw fixation to be 423 N.

The limitations of this study include a nonphysiologic load. This study assessed tensile properties using a pullout test. Investigators have argued that motions used in these tests are not physiologic and the forces may not be clinically relevant.17,23,24 Evaluating the Krackow stitch in cadaveric knees with anterior tibial translation may be a more effective way to simulate the primary stress that an ACL or a reconstructed ACL experiences in vivo.3,20,23,25 Also, these data are based on porcine Achilles tissue.

The purpose of this study was not to advocate the use of the Krackow locking loop for a specific type of reconstruction or repair, but rather to demonstrate the optimal Krackow suture configuration when fixating soft tissue to itself or to bone. This study used large porcine Achilles tendons that were standardized to 10 mm in diameter and No. 5 Ethibond suture. The materials used best compare with large tendon repairs or ligament reconstructions around the knee. Based on this study, we recommend the Krackow stitch with 2 interlocking sutures at 90° that have 2 locking loops each (Fig 1). This configuration will insure the greatest peak load to failure and least elongation of the ligament-tendon graft when secured to bone.

REFERENCES

9. Krackow KA, Thomas SC, Jones LC. Ligament-tendon fixa-


