Comparison of "Inside-Out" and "Outside-In" Interference Screw Fixation for Anterior Cruciate Ligament Surgery in a Bovine Knee


Summary: Despite numerous advances in graft fixation with anterior cruciate ligament (ACL) reconstruction, few studies have compared the fixation strength of interference screws placed "outside-in" and from "inside-out" techniques. To compare techniques, a bovine model was designed to fail at the femoral tunnel bone-screw interface. Twenty-four fresh bovine knees were stripped of all soft tissues except the ACL. The native ACL was loaded to failure at a strain rate of 50 cm/min with the knee flexed 45°. One standardized femoral tunnel was created on all specimens. A 3-inch guide pin was drilled into the center of the ACL femoral origin and overreamed with an 11-mm reamer from inside-out until the lateral cortex was reamed. Consistently sized patellar bone blocks were created (8 x 5 x 25 mm) with an 8-mm tendon width. The bone blocks were randomized to an "inside-out" (group 1) and "outside-in" (group 2) technique. Bone blocks were secured with a 7 x 25 interference screw. Specimens were mounted with the femoral tunnel and bone block aligned parallel to the tensile force and strained to failure at 50 cm/min. Failure of the native bovine ACL occurred at a mean of 2,304 N (SD = 472 N; n = 24). The mode of failure for group 1 was 9 of 13 at the bone-screw interface and 4 of 13 interligamentous failures. The mode of failure for group 2 was 7 of 11 at the bone-screw interface, 3 of 11 interligamentous, and 1 bone block failure. The mean load to failure for group 1 was 1,151 N (SD = 320 N, n = 13) including the four ligamentous failures and 1,143 N (SD = 306 N, n = 9) excluding the ligamentous failures. The mean load to failure for group 2 was 1,017 N (SD = 262 N, n = 11), including all specimens and 843 N (SD = 262 N, n = 7) excluding the interligamentous and bone block failure specimens. The "inside-out" technique averaged 100 N greater fixation strength than the "outside-in" technique. Statistical analysis using two-sample Student's t-test showed no statistically significant differences between group 1 and group 2. Both techniques demonstrate comparable maximum load to failure in a bovine model tested at 50 cm/min. Key Words: Anterior cruciate ligament—Interference screw—Endoscopic.
A transition from double-incision to single-incision arthroscopy assisted ACL reconstruction using patellar tendon autograft has been occurring to decrease morbidity, decrease time of hospitalization, and accelerate rehabilitation. Concern remains over the strength and reliability of the femoral side fixation. The purpose of this study is to create a bovine knee model that directly compares the fixation strength of endoscopically placed interference screws with traditionally placed interference screws.

**MATERIALS AND METHODS**

Twenty-four fresh bovine knees were procured and maintained at 8°C until testing. The knees were stripped of all soft tissue except the ACL and its attachments to the femur and tibia. The patella, patellar tendon, and tibial tuberosity were detached en bloc. The femur and tibia were potted into steel cylinders with isocryl polymer and transfixed with 8-mm screws to prevent rotation. The femur-ACL-fibia unit was mounted into a tensile testing apparatus (Instron Model 1321; Instron Manufacturing, Canton, MA) with a 5-kN load cell. The mounting frame placed the femur 22.5° to the load cells and the tibia oriented at 22.5° for a total of 45° knee flexion (Fig 1). This orientation placed the ACL fibers parallel to the tensile load. All specimens were tested with a strain rate of 50 cm/min (8.3 mm/sec). The ultimate load to failure was recorded directly by the testing unit and verified graphically as the peak load sustained by the femur-ACL-tibia unit. The mode of failure was recorded after visual inspection.

After testing the native ACL strength, patellar bone-tendon-bone grafts were harvested. The bone grafts were milled on a Bridgeport milling machine to assure standardization of the bone grafts size to rectangular profiled grafts 8 × 5 × 25 mm dimensions. Thus, an 8-mm bone-tendon-bone graft was tested.

The 24 specimens were used to simulate an endoscopic or femoral tunnel that extended out through the lateral femoral cortex. A guide pin was placed through the origin of the native ACL and overdrilled with an 11-mm cannulated reamer out through the lateral femoral cortex. The tunnel was oriented at a 45° angle in the sagittal plane and 60° in the frontal plane (Fig 2). This method produced a tunnel that allowed graft fixation with an interference screw using the endoscopic “inside-out” technique or “outside-in” two-incision technique. Femurs and bone-tendon-bone grafts were randomized for use into either the endoscopic technique (“inside-out”) or the “outside-in” technique. The relative mismatch between the tunnel diameter (11 mm) and bone graft width (8 mm) was created to maximize the likelihood of a bone-screw interface failure rather than an interligamentous failure.

Thirteen specimens were randomized to the endoscopic technique (group 1) and 11 to the “outside-in” technique (group 2). In both techniques, the bone plugs were placed flush with either the intraarticular cortex or the lateral femoral cortex (Fig 3). All bone plugs were secured with 7 × 25 mm cannulated interference screws (Concept Inc., Largo, FL) over a guidewire to insure parallel screw placement “without screw divergence.” Anteroposterior and lateral radiographs verified parallel screw orientation in all knees.

The specimens were mounted with the bone tunnel oriented vertically in the tensile testing apparatus and tested at a strain rate of 50 cm/min. Mode of failure was observed, and ultimate load to failure was recorded. Statistical analysis was performed using a Microsoft
TABLE 1. Load to Failure

<table>
<thead>
<tr>
<th>Specimens</th>
<th>N</th>
<th>Load to Failure (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Femur-ACL-Tibia</td>
<td>24</td>
<td>2,304 (472)</td>
</tr>
<tr>
<td>Group I</td>
<td>11</td>
<td>1,151 (320)</td>
</tr>
<tr>
<td>Group I (Bone-screw interface failure only)</td>
<td>9</td>
<td>1,143 (306)</td>
</tr>
<tr>
<td>Group II</td>
<td>13</td>
<td>1,017 (409)</td>
</tr>
<tr>
<td>Group II (Bone-screw interface failure only)</td>
<td>7</td>
<td>843 (262)</td>
</tr>
</tbody>
</table>

Excel (Redmond, WA) statistical software package using Student's t-test with significance established at \( P < .05 \).

RESULTS

The ultimate load to failure of the femur-ACL-tibia in the 24 native bovine knees averaged 2,304 N (range, 1,430 to 3,344; SD, 472 N). All specimens failed at the ACL ligament–tibial junction.

Despite undersizing the bone plugs (8 mm) relative to 11 mm femoral tunnels, bone-screw interface failure did not occur in all cases. The modes of failure for the endoscopic or "inside-out" technique (group I) were nine bone-screw interface and four interligamentous failures (Table 1). The mean load to failure for all endoscopic specimens was 1,151 N (range, 638 to 1,601 N; SD ± 320 N, \( n = 13 \)). The mean load to failure for the bone-screw interface specimens was 1,143 N (range, 713 to 1,572 N; SD ± 306 N, \( n = 9 \)).

The modes of failure for the outside-in technique (group 2) were seven bone-screw interface, three interligamentous failures, and one bone plug fracture. The mean load to failure for all outside-in specimens was 1,017 N (range, 638 to 1,601 N; SD ± 409 N, \( n = 11 \)) and averaged 843 N (range, 713 to 1,572 N; SD ± 262 N, \( n = 7 \)) for the bone-screw interface failure specimens. Statistical analysis using two-sample Student’s \( t \)-test showed no statistically significant differences between group 1 and group 2.

DISCUSSION

Kurosaka et al \(^4\) compared a variety of fixation techniques in seven cadaver knees. Ten-millimeter grafts (25 mm length) were placed in 10-mm diameter tunnels, and the authors observed superior fixation strength with a 9-mm diameter interference screw compared with a 6.5-mm diameter (20-mm length) AO cancellous screw. Ultimate load to failure for the interference screw averaged 436 N ± 90, whereas the AO screw averaged 161 N ± 28 N. The length of the interference screw was not mentioned, gap spaces were not measured, and radiographic confirmation of parallel placement was not performed in the three specimens studied. In a larger subgroup (\( n = 7 \)), secured with staples, sutures over buttons, or a 6.5-mm AO screw, the load failure was inferior, ranging from 113, 186, and 162 N, respectively. The authors also reported that, despite the improved fixation with the interference screw, its fixation did not approach the ultimate load to failure of the native ACL (1,023 N ± 276).
Matthews and Soffer\(^6\) have reported on the potential pitfalls of interference screw fixation. Graft translocation, screw convergence and divergence, suture laceration, and tendon injury were independently reported by these two authors. With the introduction of the single-incision endoscopic technique, other problems were encountered. Tendon laceration, posterior cortical violation, and screw divergence were concerns voiced by experienced surgeons making the transition from double- to single-incision techniques.

Matthews et al.\(^7\) studied a variety of techniques for graft fixation techniques for the patellar tendon using a 9 × 25-mm Kurosaka screw, and 10-mm tunnels in 51 cadaver specimens, tested at 51 cm/min (8.5 mm/sec). Four variables were evaluated: (1) parallel screw placement, (2) effects of placement, removal, and replacement of a parallel screw, (3) fixation of the graft with number 2 nonabsorbable sutures, and (4) fixation of the graft with number 5 nonabsorbable sutures. They noted no significant differences in the load to failure in these four subgroups: 435, 458, 454, and 415 N respectively.

Lemos et al.\(^8\) reported on the increased incidence of femoral screw divergence in the endoscopic technique and observed a divergence incidence of 36% in their patients. Jewell and Bach\(^9\) observed an incidence of 17% divergence in the anteroposterior (AP) plane and 30% divergence in the lateral plane in our first 58 knees reconstructed endoscopically. Six knees had >30° of divergence in the lateral plane, whereas no patients had greater than 30° of divergence in the AP plane. When divergence occurred, it most commonly was observed in the lateral plane. No early failures could be ascribed to screw divergence either clinically or arthroscopically.

Hulstyn et al.\(^10\) studied the biomechanical aspects of interference screw fixation in 36 bovine knees. Testing variables included screw length (20 mm, 25 mm, and 30 mm) and screw width (5.5 mm, 7 mm, and 9 mm). An outside-in technique was studied, parallel screw placement was confirmed radiographically, 10-mm femoral tunnels were drilled, and triangular 10-mm grafts were tested at a rate of 0.85 mm/sec. The authors reported higher loads to failure in their control bovine knees (3,731 N ± 761 N). Although the authors did not use 7 × 25-mm screws, their data for 7 × 20-mm and 7 × 30-mm screws provide a relative comparison to our data. Hulstyn et al.\(^10\) reported mean loads to failure of 786 N ± 163 and 904 N ± 139, respectively. They observed that screw length and diameter had no effect for 7- and 9-mm screws.

Jomha et al.\(^11\) evaluated the effects of parallel and divergent screw placement in 20 porcine knees. Four subgroups (0°, 10°, 20°, and 30°) were studied. Eleven-millimeter tunnels were created, radiographic confirmation of screw placement was performed, and a 7 × 20-mm Kurosaka screw was used. Tensile testing was performed at 20 mm/min. They reported mean loads to failure of 621 ± 82 N, 594 ± 48 N, 508 ± 66 N, and 485 ± 62 N, respectively. They observed a significant decrease in fixation strengths in grafts placed ≥20°.

Brown et al.\(^5\) evaluated 27 elderly paired cadaver knees and compared endoscopic and antegrade screw placement, varied screw length and diameter, and insertion torque. The mean age of these specimens was 79 ± 9 years (range, 61 to 96 years). A 10-mm cylindrical diameter, 25-mm length graft was fashioned, secured in an Instron testing device, and tested at a strain rate of 1 mm/second. Radiographic confirmation was not performed, although parallel placement was confirmed using a parallel wire technique. There was no difference in pullout force observed between the inside-out and outside-in techniques. The authors used 7-mm diameter screws for endoscopic fixation and 9-mm diameter screws for outside-in fixation; interestingly, the mean pullout forces were higher with the endoscopic technique (235 ± 124 N v 256 ± 130 N, respectively). There were no statistically significant differences when screw lengths were compared (20 mm v 25 mm). There were significant differences in pullout force when screw diameters (5.5 mm v 7 mm) were compared. The authors concluded that properly placed 7-mm diameter endoscopic interference screws had similar holding strength to a standard 9-mm outside-in interference screw.

Lemos et al.\(^12\) studied the effects of parallel and divergent interference screw placement in 12 pairs of fresh bovine knees. The authors used cylindrical 9 × 25-mm bone plugs placed in 11-mm diameter femoral tunnels with an average gap space of 2.1 mm. They observed no statistical difference in ultimate load, stiffness, or deformation in these two groups, although they observed a difference in the mode of failure when tested at a failure rate of 30 mm/sec. One of the 12 parallel graft constructs failed when tested at a failure rate of 30 mm/second. One of the 12 parallel graft constructs failed at the bone-screw interface, whereas 4 of 12 divergent grafts failed at the bone-screw interface. Their mean ultimate load to failure in the parallel constructs was 1,222 ± 204 N, which was similar to our results using a larger gap space, although Lemos et al. used a faster testing rate.

Pierz and Fulkerson\(^13\) compared mechanical proper-
ties in antegrade and retrograde placed screws placed parallel and at 15° and 30° of divergence in a porcine model. The authors studied 66 specimens and used 9 × 20-mm cylindrical bone plugs placed into an 11-mm tibial tunnel. A 7 × 20-mm Kurosaka interference (DePuy, Inc., Warsaw, IN) was used for fixation. The authors reported a significant difference in the holding power, with retrograde fixation (endoscopic/inside-out) having superior results. There were significant decreases when the antegrade screw subgroup was placed in 15° divergence, whereas the 15° retrograde divergence showed no difference with parallel placed retrograde screws. They and Lemos et al.12 observed slight increases in pullout strength, although they were not significant in screws placed at <15° of divergence. The authors also noted that retrograde placed screws placed at 30° of divergence had significantly less fixation than screws placed parallel or at 15° divergence. Nevertheless, a screw placed in 30° divergence retrograde was superior to an antegrade placed screw in 15° divergence.

Kohn and Rose14 evaluated the effects of screw diameter, insertion torque, the effects of removal and replacement of a screw, and compared fixation strength in the femur versus the tibia in 10 paired cadaver knees. Nine-millimeter triangular grafts were placed in 10-mm diameter tunnels and tested at a rate of 200 mm/sec. Seven- and 9-mm screws of 20-mm length were tested. The authors concluded that fixation was greater on the femoral side, that a 9-mm diameter screw could be removed and replaced with minimal effects, that 7-mm screws should not be used on the tibial side, and if failure occurred with a 7-mm screw, replacement with a 9-mm screw provided predictable stability. Nine-millimeter screw fixation provided superior fixation to a 7-mm screw on both the femur and tibia. In a similar study, Butler et al.15 found 9-mm screw fixation superior to 7-mm screw fixation if a 3- or 4-mm gap opened.

Steiner et al.16 compared hamstring and patellar tendon fixation with a variety of fixation constructs in 18 pairs of cadaver knees. They used 10-mm wide patellar tendon grafts placed in 10-mm diameter tunnels. Outside-in and endoscopic techniques were evaluated in their patellar tendon subgroups. Nine-millimeter Acufex (Acufex Microsurgical, Inc., Mansfield, MA) screws (25 mm length) and 7-mm screws (25 mm length) were compared, respectively. Gap spaces and radiographic confirmation were not reported. Instron strain testing was performed at 50 mm/sec. Steiner et al.16 observed superior maximum load to failure and stiffness with endoscopically placed screws despite using a smaller-diameter screw.

The bovine knee model was selected because of its availability and expense. The quality of the bone has been reported to be denser than human bone and certainly more consistent than human cadaver specimens, which vary in age and degrees of osteopenia.17

All specimens were obtained from adult bovine specimens with similar femoral dimensions. Although not suspected, variations in femoral and bone block densities may be related to variations in pullout strength. Measurement of femoral condyle and bone block density may prove valuable in future experiments.

In this study, there was no statistical difference in the study groups when entire subgroups were compared. However, when only the bone-screw interface subgroups were compared, there was nearly an average 300 N decrease in the outside-in technique. This may be secondary to pulling the graft toward the screw rather than away from it; hence, there may be a wedge effect in the endoscopic technique.

When compared with the native bovine ACL, the results of interference fixation compared inferiorly. This observation has been observed by other authors.17 In our pilot study, we attempted to create a model that would optimize bone-screw interference failure rather than interligamentous failure. This most likely is attributed to the gap space purposely created.

A variety of factors can affect fixation strength. The quality of the bone, size and length of the bone plug ("fit and fill") relative to the tunnel diameter, an intact tunnel, the diameter and length of the interference screw, parallel versus divergent screw placement, and whether the screw is placed on the cortical or cancellous portion of the bone plug are all factors that may affect fixation.18 In this study, we used an 11-mm tunnel diameter, a standardized 25-mm bone plug that was milled to a consistent rectangular shape, only 7 × 25-mm interference screws from one manufacturer, and confirmed parallel placement in all specimens, and secured our graft on its cortical edge.

CONCLUSIONS

In a bovine knee model, overall fixation comparing an outside-in with an inside-out technique showed no significant difference in ultimate load to failure when screws were placed in a parallel fashion. However, when bone-screw interface failures occurred, there was a mean decrease to ultimate load failure in the outside-in technique.
REFERENCES