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Graft Fixation Alternatives

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Summary: Stable graft fixation is critical to successful ACL reconstruction. Graft migration must be prevented during the 6 to 12-week postoperative period that is required for graft-tunnel incorporation. Maximizing interference screw fixation, avoiding pitfalls of screw insertion, managing graft-tunnel mismatch, and alternative fixation techniques are discussed. **Key Words:** Anterior cruciate ligament—Graft—Fixation.

Contemporary rehabilitation protocols after anterior cruciate ligament (ACL) reconstruction stress early postoperative knee motion and weight bearing to reduce morbidity secondary to stiffness, delayed strength recovery, and anterior knee pain. In the first weeks after surgery the weakest link of the reconstructed ACL is not the graft itself but rather the fixation sites. Resultant graft forces during an accelerated rehabilitation protocol are estimated to range between 150 N and 450 N.[24,28,51,52,61,68] Therefore, the stability of initial graft fixation is critical and must be strong enough to withstand these forces and prevent graft migration during the six to twelve week period that is required for graft-tunnel incorporation.[16,44,50,67] Patellar tendon allograft incorporation may be delayed compared with autografts,[37] and when this graft is used fixation may need to provide additional primary stability beyond 12 weeks.

It has been estimated that ACL graft failure is responsible for 0.7% to 8% of cases of recurrent instability after reconstruction. Furthermore, errors in surgical technique are the primary cause of early graft failure.[29,32,34] In addition to inadequate primary fixation, technical factors which should be considered include nonanatomic tunnel placement, graft impingement from an inadequate notchplasty, improper graft tensioning, graft material problems and failure to address injured secondary stabilizers. In the absence of these problems early construct failures are almost universally related to loss of fixation.

The purpose of this manuscript is to discuss interference screw fixation with a focus on avoiding pitfalls of insertion, strategies for managing graft-tunnel mismatch, and graft fixation alternatives which may be required in primary or revision situations.

INTERFERENCE SCREW FIXATION

In 1983 Lambert[46] introduced interference fixation using 6.5 mm AO cancellous metal screws (Synthes, Paoli, PA). In the landmark human cadaveric study by Kurosaka et al.,[44] novel headless fully threaded 9-mm interference screws demonstrated superior fixation strength compared with 6.5 mm AO cancellous screws, sutures over buttons, and staples. The maximal load to failure was 436 $\pm$ 90 N. Other authors have subsequently shown that the single load to failure strength of metal interference screws with human in vitro models is up to 703 N.[14,41,54,75] Despite the fact that specimen donors in these studies were on average older with decreased bone density compared with the ACL reconstruction patient population, fixation strength was adequate for accelerated rehabilitation.

Multiple factors are related to the ultimate failure strength of interference screw constructs. These include bone quality, screw length, screw diameter, bone plug size, and its relation to the bone plug-tunnel gap space interval, and parallel versus divergent screw placement. Knowledge of the relationship of these factors to initial fixation strength is crucial when dealing with complications during primary or complex revision reconstruction.

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MAXIMIZING FIXATION

Screw Diameter and Length

The influence of screw diameter is controversial. A positive correlation between ultimate failure load and screw diameter related specifically to screw insertion torque has been demonstrated.[9,10,17,20,41,55,66] However, comparing 7 mm and 9 mm metal interference screws, Hulstyn et al.[35] found no statistically significant influence of screw diameter on maximal load to failure in a bovine model. Shapiro et al.[72] similarly showed no load to failure differences comparing these screw diameters placed in bovine femurs with 2 mm circumferential bone plug-tunnel gaps.

Other studies have demonstrated that proper selection of screw diameter should be related to plug-tunnel gap and bone quality to assure optimal fixation. Butler et al.[17] showed that if a 1 mm to 2 mm gap exists between the bone plug and tunnel, then a 7-mm interference screw was satisfactory. For 3 mm to 4 mm gaps, a 9 mm interference screw is required to provide adequate fixation. Similarly Daniel[20] has suggested that screw diameter minus gap size should equal 4 mm to 6 mm. Kohn and Rose[41] found that 9 mm interference screw fixation was stronger than fixation with a 7 mm screw in both the femur and tibia. A 7-mm screw did provide adequate femoral fixation. However, because of inherently decreased tibial bone density a 9-mm screw was recommended for tibial fixation. In our experience, we routinely use a 7-mm screw for femoral fixation and 9-mm screw for tibial fixation in uncomplicated primary ACL reconstruction.

Interference screw length should maximize bone plug contact whereas avoiding excessive length which risks graft laceration or joint penetration. Standard screw lengths of 20 mm and 25 mm are commonly selected. However, in a porcine model Black et al.[9] showed that 9 mm tibial interference screws and bone blocks as short as 12.5 mm can be used with no significant compromise of insertion torque and construct stiffness, displacement, or load to failure. This situation is important when considering shortening of the bone block in cases of graft-tunnel mismatch.

Divergence

Femoral screw-tunnel divergence has been identified as a potential problem with interference screw use.[5,21,22,39,47,48,54,56,58,65] Depending on the plane of divergence, consequences can include loss of fixation, posterior femoral tunnel blowout, or bone plug fracture. Endoscopic parallel screw placement can be more difficult to attain than with an outside-in two-incision technique. Lemos et al.[47] noted a 36% incidence of divergence of femoral screws placed with an endoscopic technique. However, divergence may be clinically less relevant with endoscopic reconstruction. When the femoral interference screw is placed in a retrograde fashion as in the endoscopic technique, the best area of fixation occurs distally at the apex of the divergent angle. For graft failure to occur, the graft load needs to overcome this area of maximum fixation. In the two-incision technique when the screw is placed antegrade, the more divergent region and relatively weaker fixation is based distally where failure may occur (Fig. 1).

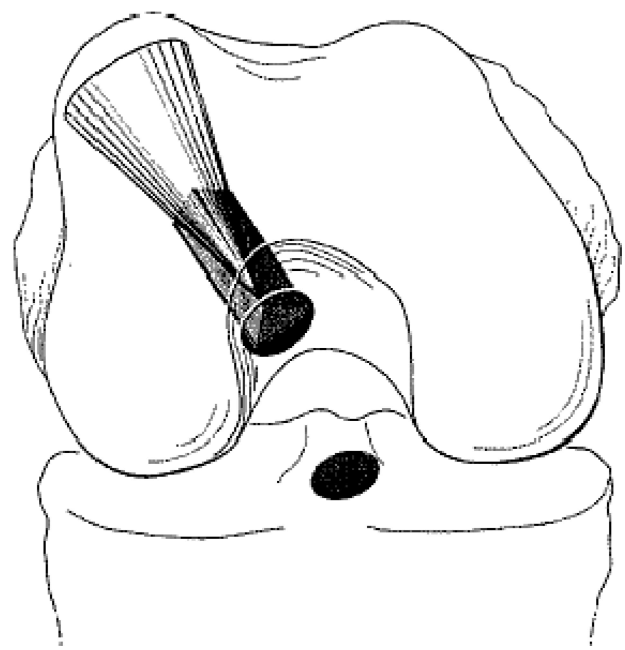

FIG. 1. The endoscopic screw, if placed divergently, may act as a wedge because the bone plug will be pulled *toward* the screw. Conversely, screw divergence in the two-incision technique may be more problematic because the bone plug is pulled *away* from the proximal area of best fixation. (Reprinted with permission from Dworsky BD, Jewell BF, Bach BR, Jr. Interference screw divergence in endoscopic anterior cruciate ligament reconstruction. *Arthroscopy* 1996; 12:45–49.)

Lemos et al.[48] showed no difference in pullout strength with up to 15 degrees of coronal plane divergence in endoscopically placed screws in a bovine model. Higher divergence angles were not examined. Jomha et al.[39] evaluated divergence in porcine knees and found significant decreases in fixation strength for endoscopic interference screws with divergence ≥20 degrees. Pierz and Fulkerson[65] tested both endoscopic and rear-entry interference screw fixation in porcine knees with divergence angles of 0, 15, and 30 degrees. Compared with parallel placement, there were significant decreases in load to failure in the 15-degree antegrade screw subgroup whereas the endoscopic 15-degree divergence group showed no significant change in load to failure. In the endoscopic 30-degree divergence group significant loss of fixation did occur. Across all divergence subgroups loss of fixation was significantly less with endoscopic screw placement; in fact, screws placed with 30 degrees of divergence endoscopically were superior to antegrade screws with 15 degrees of divergence.

Clinical significance of graft-screw divergence remains unclear. In a retrospective analysis of 73 consecutive endoscopic patellar tendon ACL reconstructions Dworsky et al.[22] showed a 15% incidence of sagittal divergence averaging 2 degrees with no cases having divergence greater than 23 degrees. Coronal divergence was more common and noted in 29% of patients averaging 5 degrees with 6% having greater than 30 degrees of divergence. There were no differences in outcome related to divergence arthrometrically or clinically. These authors commented that femoral graft fixation should be confirmed intraoperatively by applying enough load to the tibial bone plug sutures to "rock" the patient on the operating table.[22] This should confirm adequate fixation regardless of potential screw divergence.

Techniques for minimizing interference screw divergence include using an accessory inferomedial portal just above the meniscus for screw insertion. This allows the surgeon to better match the angle of the femoral tunnel. A 14-inch Nitenol (Linvatec, Largo, FL) guide wire is preliminarily positioned, the knee is further flexed to approximately 110 degrees, and the pin advanced in the femoral graft-tunnel interface to direct the cannulated interference screw into position.

This technique is also useful to minimize the risk of graft laceration that can occur with the use of a metal interference screw. The screw is naturally directed away from the tendinous portion of the graft. We routinely position our bone block with the cortical side positioned toward the back wall of the femur; the screw is then placed along the anterior, cancellous side of the bone plug (Fig. 2). Graft laceration can be further minimized with the use of a commercially available graft protector. This device is used to place a metal shield against the tendinous portion of the graft during screw insertion. If a graft protector is not available, we have also used a cut 8.25-mm arthroscopic cannula in a similar fashion.

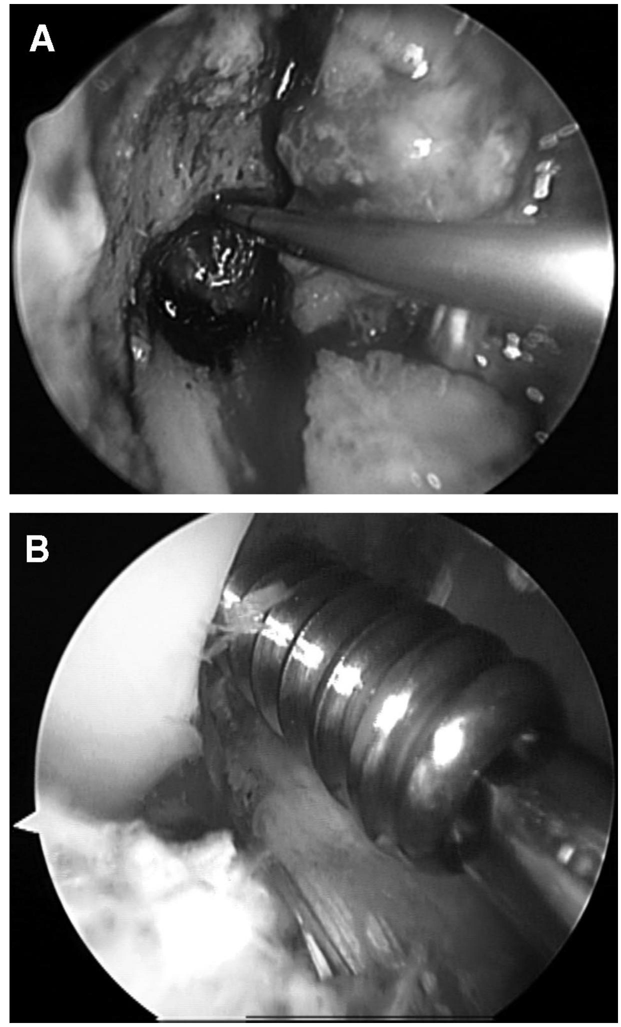

FIG. 2. Arthroscopic views of the guide wire (**A**) and femoral interference screw (**B**) placed along the anterior, cancellous side of the bone plug.

Bioabsorbable Interference Screws

Metallic interference screws are a proven method of solid fixation using material that has a long track record of being well tolerated by the body. Bioabsorbable interference screws have been developed to minimize the problems of long-term retained hardware. Bioabsorbable screws cause no artifact with subsequent magnetic resonance scans, their removal may not be necessary, and fixation at revision reconstruction may be more easily attained if the screws are resorbed and replaced by host bone. If the screw is still present at the time of revision, tunnel reaming may proceed without screw removal.

The primary debate regarding bioabsorbable interference screws involves fixation strength compared with standard metal interference screws. Pena et al.[64] concluded that the ultimate failure strength of bioabsorbable screws (418 N) was lower than titanium screws (640 N) in a human cadaveric model. However, there was specimen-related bias; the mean donor age was 51 in the bioabsorbable group and 42 in the titanium group. The mean bone mineral density was 0.50 g/cm^3 versus 0.70 g/cm^3, respectively. Multiple other cadaveric studies in human,[18,38] porcine,[1,42,70] and bovine[43] knees showed no significant difference in pullout strength[1,18,38,42,43,70] or migration with cyclic submaximal loading[42,70] when comparing various bioabsorbable interference screws with standard titanium screws. Screw breakage during insertion has been cited as a concern with an reported incidence of 0% to 12%.[7,25,40,53,57] Screw breakage has become less problematic with initial tapping and with development of screwdrivers that fully seat into the entire cannulated portion of the screw.[70]

Possible nonspecific granulomatous inflammatory reactions and osteolysis secondary to bioabsorbable implants is also a concern. Current implants typically contain either poly-L lactic acid (PLLA), the faster-resorbing polyglycolic acid (PGA), copolymers of these, or a combination with other materials such as trimethylene carbonate (TMC). There have been several reports of adverse inflammatory reactions with use of these materials for fracture fixation,[11,12,27,33,63,79] intra-articular osteochondral[8,26,76] or labral[23] fixation causing recurrent effusions, synovitis, and pain. It remains to be determined whether biodegradable screws placed in bony tunnels cause clinically relevant inflammatory reactions, and some authors recommend slower-resorbing materials to minimize potential reaction.[40] To date, bioabsorbable interference screws do not appear to cause increased inflammatory or osteolytic responses compared with titanium screws regardless of the polymer used.[7,25,40,53,57,78] It should be noted that screw resorption takes one year with PGA[25] and 3 to 5 years with PLLA.[45,53] Replacement of the screw void with bone takes at least 3 years with PGA[25] and longer with other polymers.[45,53]

Clinical studies have demonstrated equivalent results with both metal and bioabsorbable screws. In a multicentered prospective randomized study, Kaeding et al.[40] compared results of ACL reconstruction with titanium interference screws and Phantom (DePuy, Warsaw, IN) bioabsorbable interference screws. Subjective outcome measures included activity level assessment and International Knee Documentationmmittee (IKDC) scores. Objective measures included arthrometer testing, radiographic evaluation, range of motion, presence of effusions, and intraoperative or postoperative complications. There were no cases of intraoperative screw breakage. With at least 1-year follow up, subjective and objective results were comparable between the 2 groups. Furthermore, on radiographic evaluation there was no change in bone plug position or increased osteolysis in the bioabsorbable group. Multiple other studies have confirmed equivalent fixation of bioabsorbable screws and early clinical results comparable with titanium screws.[7,25,53,57,78]

Endoscopic Versus Rear-Entry Femoral Screw Insertion

The benefits of endoscopic femoral screw insertion include aperture fixation and a more parallel graft-tunnel orientation with decreased tunnel margin graft shear, accurate graft placement, and decreased surgical morbidity. However, there is an increased risk of tendon injury or laceration, posterior cortical violation, and screw divergence compared with rear-entry insertion. Whether there is a difference in the quality of fixation between these two techniques remains a matter of debate.

Brown et al.[14] reported no difference in the pullout strengths between one- and two-incision femoral constructs. In this study 9-mm screws were inserted with the rear-entry technique and 7-mm screws were inserted endoscopically. Bryan et al.[15] placed interference screws of the same diameter with these 2 techniques and found no significant difference in average ultimate failure load. However, some of the endoscopic constructs failed by tendon avulsion from the bone plug. When the bone plug-screw interface failures alone were compared, there was an average 300 N decrease in load to failure with the outside-in technique.

Stapleton et al.[74] compared these femoral constructs and found a significantly higher load to failure in the one-incision group (695 N) versus the two-incision group (593 N). Steiner et al.[75] also observed significant construct differences with superior stiffness and maximum load to failure of endoscopically placed 7 mm screws versus outside-in 9 mm screws.

Although the results of these studies are compelling, both one- and two-incision femoral screw insertion techniques have excellent clinical track records. In addition, each technique may have specific advantages in a given reconstruction situation when a new tunnel path is desirable. An understanding of the potential risks and benefits of each technique combined with an individual surgeon's expertise should dictate the technique selected.

Aperture Fixation and Tunnel Expansion

Graft isometry is maximized if both femoral and tibial bone plugs are fixed as close to the articular surface as possible.[59] Aperture fixation also prevents "windshield wipering"[30] and intra-tunnel strain or pistoning[49] of the tendinous portion of a graft that is recessed or the entire graft that is fixed with suspension methods. These effects will decrease construct stiffness and potentially diminish knee stability following ACL reconstruction. Micromotion at the graft-tunnel interface may also theoretically delay graft incorporation and, in combination with increased exposure of the graft-tunnel interface to synovial fluid, may promote tunnel expansion.[2,30,62]

Ishibashi et al.[36] examined the effects of variations in tibial fixation distance from the tibial plateau on knee stability in a porcine model. Anterior tibial displacement and internal tibial rotation steadily increased as the fixation site moved more distal. However, similar findings would theoretically occur if the femoral plug is translated proximally. With standard one- or two-incision reconstruction techniques, aperture fixation is only attained on one side of the graft.

To examine the clinical relevance of aperture fixation, Otsuka et al.[62] compared standard endoscopic interference screw placement with femoral and tibial aperture fixation. Tibial aperture fixation was achieved with either a bone plug placed at the articular margin or a tibial screw placed in an antegrade fashion. At an average of 2 years follow up there was no difference in knee stability between groups by arthrometer testing but the aperture fixation groups had less tunnel enlargement. Aglietti et al.[2] also showed no clinical benefit of bipolar aperture fixation but also noted decreased tibial tunnel expansion with this technique.

The etiology of radiographic tunnel enlargement following ACL reconstruction remains unknown. It is commonly noted in the tibia where standard endoscopic reconstruction techniques do not afford aperture fixation. Biologic factors related to local bone resorption or osteolysis may include tunnel wall necrosis from drilling and synovial fluid propagation within the tunnel.[2,30,62] In addition, it has been proposed that the use of allograft tissue may potentiate tunnel enlargement because of delayed incorporation or by an induced immunologic reaction. However, multiple animal studies have revealed no evidence of an immune reaction[3,31,73] and some clinical studies have failed to show increased tunnel enlargement with allografts versus autografts.[69,80] Mechanical factors related to tunnel expansion may include stress shielding of subchondral bone and graft micromotion because of the fixation method or aggressive rehabilitation.[13,30,31,36,49,59]

Clatworthy et al.[19] challenged the idea that graft-tunnel motion is a primary cause of widening. Comparing suspension femoral fixation for hamstring and patellar tendon grafts, they noted a mean increase in femoral tunnel widening of 100% in the hamstring group versus 25% in the patellar tendon group. Although graft "windshield wipering" may have been reduced in the patellar tendon group because of the bone plug, pistoning behavior was likely similar. It was concluded that inherent differences in the biology of graft tissues may play a more significant role in tunnel enlargement.

The presence of tunnel expansion has not been correlated with increased clinical laxity or graft failure. However, in the revision setting tunnel enlargement presents a difficult challenge with possible compromise of graft placement, fixation, and incorporation. Decreased tunnel enlargement combined with improved isometry suggest that obtaining aperture fixation whenever possible is ideal.

Graft-Tunnel Mismatch

Graft-tunnel mismatch is a potential challenge associated with single-incision endoscopic ACL reconstruction. Mismatch between the length of the graft and the tibial tunnel may leave the bone plug protruding, shortening the effective length of the plug and potentially compromising interference fixation. Despite accurate intra-articular measurement techniques for tunnel placement, Shaffer et al.[71] reported a graft-tunnel mismatch incidence of 26% in their series of 34 endoscopic ACL reconstructions.

One method of correcting the mismatch involves further recession of the femoral bone plug. This risks inaccurate buried femoral interference screw placement or graft laceration by the screw, alteration in the femoral isometric point, and possibly tendon abrasion by the tunnel edge. Shortening the tibial bone plug and using standard interference fixation may lead to inadequate fixation or tendon laceration by the relatively long screw. However, as previously discussed Black et al.[9] have demonstrated that adequate fixation can be achieved with a screw and bone plug as short as 12.5 mm.

Barber[6] reported flipping the tibial bone plug 180 degrees over its tendon insertion to shorten the effective graft length and allow standard interference fixation. Using this technique 86% of 50 patients had good to excellent results and 92% had stable knees by arthrometer testing.

Auge and Yifan[4] described graft rotation as a method of eliminating mismatch. External rotation of the graft 630 degrees results in up to 25% effective shortening of the tendinous portion of the graft. Clinical stability using this technique was retained at 1-year follow up. Verma et al.[77] subsequently documented in a porcine model that 540 degrees of graft rotation produces average shortening of 5.4 mm (11.0% of initial tendon length) with no significant effect on ultimate failure load. However, ultimate failure strain was increased and graft modulus was decreased when compared with rotations of 180 degrees or less. Internal or external graft rotation was not controlled and therefore the most effective direction of

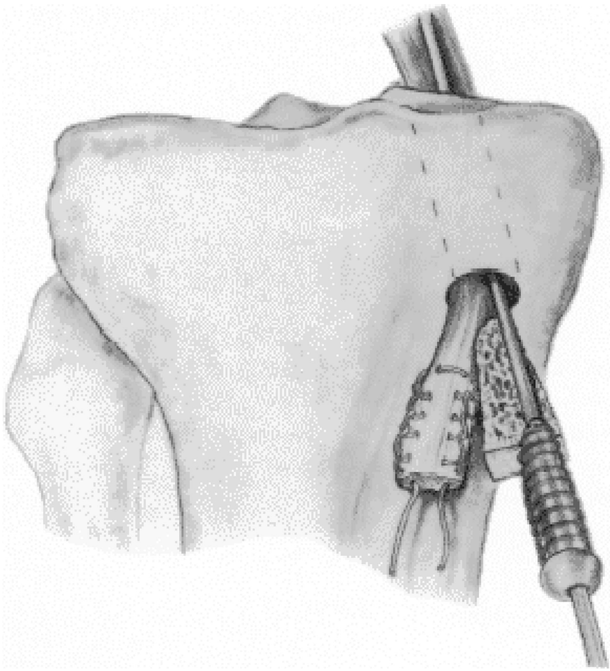

FIG. 3. Free bone block interference fixation. (Reprinted with permission from Novak PJ, Wexler GM, Williams JS, Jr., et al. Comparison of screw and postfixation and free bone block interference screw fixation for anterior cruciate ligament soft tissue grafts: biomechanical considerations. *Arthroscopy* 1996;12:470–473.)

rotation was not established. Whether graft rotation affects the biology of graft remodeling or revascularization and the graft's late biomechanical properties remains unknown.

To manage significant mismatch Novak et al.[60] described free bone block interference fixation. This technique involves removal of the proud tibial bone plug that is then press-fit into the tibial tunnel over the tendinous portion of the graft. The construct is secured with a standard interference screw (Fig. 3). This technique can also be used in situations where graft laceration has occurred. The graft is removed and the intact bone block is placed in the femoral tunnel. A bone block technique is then used to secure the free tendinous portion of the graft on the tibial side. In a bovine model[60] graft stiffness and ultimate load to failure was increased with the free bone block technique (699 N) versus screw-and-post fixation technique (374 N). The effects of cyclic loading on this construct have not been determined and graft healing using this method has not been validated.

Other techniques to resolve graft-tunnel mismatch involve bone block staple fixation and/or screw-post suspension fixation, both of which secure the graft on the anterior tibial cortex. Disadvantages of these techniques include difficulty in obtaining proper graft tension as well as loss of graft isometry.

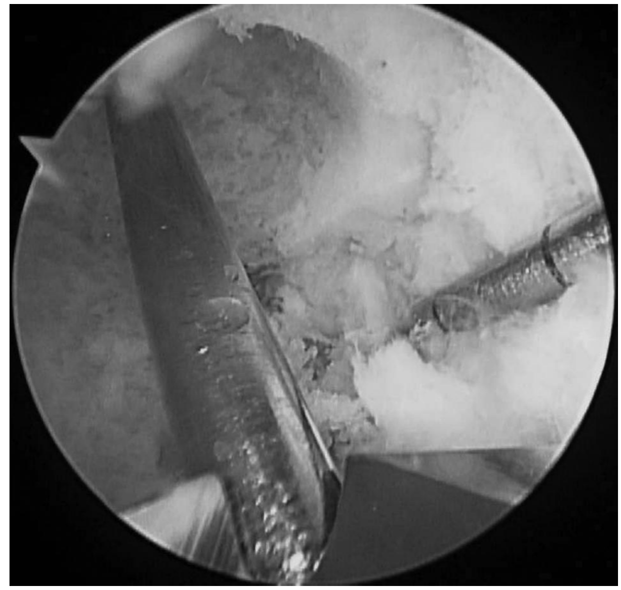

FIG. 4. Creation of a femoral tunnel "footprint" and confirmation of an intact posterior femoral cortex with 1.5 mm to 2.0 mm of remaining bone before completion of reaming.

Posterior Wall Blowout

Posterior cortical breach of the femoral tunnel can occur during endoscopic ACL reconstruction in cases where the guide wire is placed too close to the posterior cortex. The best defense against this problem is maintaining a high index of suspicion during femoral tunnel reaming to avoid it. The use of commercially available offset femoral aiming guides allow placement of the guide wire an appropriate distance away from the posterior femoral cortex. In general, we allow 1.5 mm to 2.0 mm of remaining posterior cortex when reaming our femoral tunnel. Therefore, if a 10-mm tunnel is desired a 7 mm over the top guide is used. If a 9-mm tunnel or smaller is desired, a 6 mm over the top guide can be used to maximize posterior tunnel placement.

The second technique used to avoid posterior cortical blowout is reaming a "footprint" of the femoral tunnel before reaming the entire tunnel depth. In this manner, a 5 mm to 7 mm footprint of the femoral tunnel is created with the cannulated reamer. The surgeon should be cognizant of increased resistance to reaming at this stage that may indicate posterior cortical penetration. Bone debris is cleared and an intact back wall is confirmed with visualization and palpation before drilling the remainder of the tunnel (Fig. 4). If posterior cortical breach

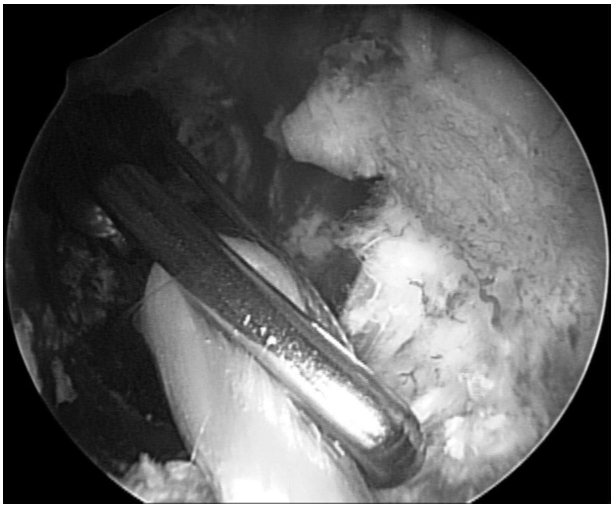

FIG. 5. Arthroscopic view of an Endobutton (Smith & Nephew, Hamburg, Germany) being used for hamstring graft fixation.

is noted as this time, the guide wire can be repositioned before drilling the remainder of the tunnel.

When posterior cortical violation does occur, the options for dealing with the situation are dependent on the degree of cortical breach. If only a small portion of the wall is involved (<2–3 mm), sufficient bone usually remains to support standard interference screw fixation. When more significant blowout is noted, alternate forms of fixation should be considered. These include suspension fixation options or using a two-incision technique for interference fixation via a divergent tunnel.

The use of suspension fixation relies on the anterior femoral cortex rather than an intact posterior cortical wall. One of the more common suspension devices used is the Endobutton (Smith & Nephew, Hamburg, Germany) (Fig. 5). In this case, the femoral tunnel is drilled to a depth equal to the length of the bone plug plus 10 mm. The additional tunnel length allows the Endobutton to be flipped after passage. The Endobutton drill is then used penetrate the anterior femoral cortex. The device is secured to the graft using the strongest suture material available; sutures are secured to both the bone plug and tendon to prevent failure because of suture cut out from the bone plug. The device is passed across the femoral cortex and flipped to achieve fixation.

The second suspension fixation alternative involves an over-the-top technique. A second incision is made on the lateral aspect of the femur just proximal to the epicondyle similar to that used for a two-incision reconstruction. The iliotibial band is incised, the vastus lateralis is elevated off the intermuscular septum, and access to the posterolateral femur and intercondylar notch is obtained

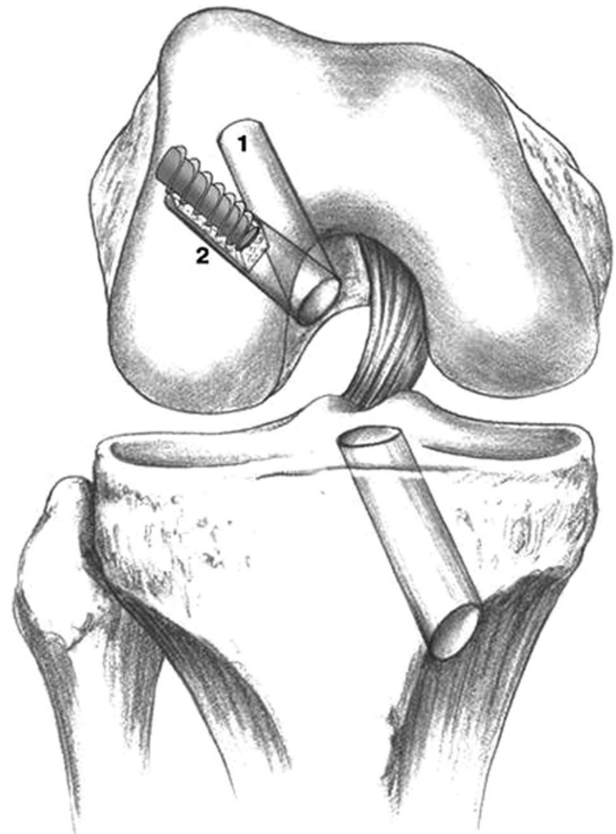

FIG. 6. The two-incision technique provides a divergent femoral tunnel path and more proximal fixation at the lateral femoral cortex.[2] (Reprinted with permission from Bach BR, Jr, Mazzocca AD, Fox JA. Revision anterior cruciate ligament reconstruction [AAOS OKO web site]. November 12, 2002. Available at: http://www5.aaos.org/oko/sports/rev_acl_recon/surgery/p1step1.cfm. Accessed May 1, 2005.)

by penetrating the intermuscular septum. The graft is then passed into this window and secured to the femoral cortex using staples or a screw-and-post technique.

The two-incision technique for ACL reconstruction may also be used in cases of posterior wall blowout or in the revision situation when a new tunnel path is required. Fixation is achieved in the divergent tunnel more proximally at the lateral femoral cortex (Fig. 6). A thorough knowledge of both one- and two-incision reconstruction techniques allows the surgeon to achieve femoral fixation in complicated reconstruction situations.

CONCLUSIONS

Stable graft fixation is critical to allow immediate postoperative rehabilitation without compromising graft incorporation and ultimate knee stability. Precise interference screw placement techniques and knowledge of fixation alternatives when faced with graft-tunnel mismatch or intraoperative complications will allow the surgeon to reliably achieve solid fixation.

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