

# Controversies in Soft-tissue Anterior Cruciate Ligament Reconstruction: Grafts, Bundles, Tunnels, Fixation, and Harvest

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## Abstract

Increased stability has been reported with both autografts and allografts for anterior cruciate ligament (ACL) reconstruction. However, meta-analysis has shown significantly lower overall knee stability rates and more than double the abnormal stability rate with allografts. Some issues surrounding allograft sterilization (ie, risk of disease transmission) are unresolved, and cost is also a concern. Single-bundle ACL reconstruction can produce high stability rates when tunnels are properly placed, but there is evidence that double-bundle repair may offer greater rotatory stability. Cortical fixation has been associated with increased stability owing to the high stiffness of cortical bone. Anterior and posterior approaches are both recommended. The controversy related to single-bundle versus double-bundle ACL reconstruction remains unresolved.

## Allograft Versus Autograft

An ideal graft for anterior cruciate ligament (ACL) reconstruction would reproduce the histologic and biomechanical characteristics of the native ligament, would incorporate fully and quickly within bone tunnels, would have no risk of immune-rejection or of disease transmission, would minimize donor-site morbidity, would be of sufficient length and diameter, and would be inexpensive and readily available. Unfortunately, the ideal graft does not yet exist. The two primary options, autograft and allograft, each have advantages and shortcomings (Table 1).

Several types of autograft are commonly used for ACL reconstruction, including four-strand hamstring

(4HS),<sup>6,7</sup> bone–patellar tendon–bone (BPTB),<sup>6,8</sup> and quadriceps tendon.<sup>9</sup> Common types of allografts used include BPTB,<sup>10</sup> Achilles tendon,<sup>11</sup> and tibialis anterior or posterior tendon.<sup>12</sup> There are advantages and disadvantages for each type of autograft and allograft, and these must be considered during graft selection.

## Donor Site Morbidity

Donor site morbidity is not a factor with allograft, and it has been minimal with autograft hamstring. The only reported morbidities with the latter are mild knee flexion weakness and mild internal rotation weakness, both of which are seen only at relatively high knee flexion angles.<sup>13-18</sup> No clinical performance deficit associated with these findings has been reported. The now well-

established observation that the semitendinosus reliably grows back may help provide an explanation.<sup>19,20</sup> It has been suggested that allograft may be preferable in the obese patient, in whom hamstring autograft harvest may be difficult.

### Stability

Stability is objectively compared with instrumented Lachman testing, usually with the KT1000 (MEDmetrics, San Diego, CA). The International Knee Documentation Committee categorizes side-to-side differences (SSD) of 0 to 2 mm as normal and >5 mm as abnormal. Grafts with >5 mm laxity are classified as failures. The magnitude of force applied should be "maximum manual," or at least a 30-lb force. The application of a 20-lb force, which was standard in the past, will overstate stability, especially with a heavy leg. Grafts so tested are not useful for analysis.

Clinical series showing both high and low stability results have been reported for both autografts and allografts. Meta-analytic data pooling recently showed allografts to have a significantly lower normal stability rate than do soft-tissue tendon autografts ( $P < 0.001$ ).<sup>1</sup> Allografts also had a failure rate roughly three times greater than autografts.<sup>1</sup> BPTB autografts were found to have similar but slightly lower stability rates compared with 4HS autografts. BPTB allografts were found to have failure rates two to three times greater than BPTB autografts. In a recent study, 23% of patients required revision ACL reconstruction.<sup>21</sup> These patients were treated with tibialis autografts.

### Disease Transmission and Infection Rate

Disease transmission does not occur with autografts. Disease inci-

dence with allografts obtained by modern harvesting and processing techniques is very low.<sup>22,23</sup> Nonetheless, bacterial infection and one death have occurred in recent years. Deviation from proper processing procedures occurred in both instances, a detail that points to the inherent problem of using a graft whose preparation is out of the direct control of the surgeon. Concerns also have been raised regarding lack of screening for prion infections, in light of a reported death from Jakob-Kreutzfeldt disease attributed to infection from an allograft dural graft transplant;<sup>24</sup> the disease may take more than a decade to manifest. Concern may also be warranted regarding currently unknown and thus untested-for viral strains; a relevant example from the recent past is hepatitis C. Before its discovery, testing was done only for hepatitis antigens A and B.

Infection rates are low for all ACL grafts. A recent Centers for Disease Control study of infection rates from a single surgical center discovered a 0% infection rate for both autograft and irradiated allograft but a 4% infection rate for nonirradiated allografts.<sup>2</sup> This finding warrants concern as most allografts are currently not irradiated because bactericidal levels of radiation have been shown to weaken them. The search is ongoing for an allograft sterilization method that will prevent infection but will neither weaken the graft nor inhibit its recellularization.

### Cost

Although autografts do not incur direct graft costs, allograft costs may be substantial. Typical allografts cost from \$1,800 to \$3,000 per procedure. The cost for double-bundle procedures ranges from \$3,600 to \$6,000.<sup>4</sup> In the United States, the

**Table 1**

### Advantages of Autograft and Allograft

Autograft
Higher normal stability rate and lower graft failure rate <sup>1</sup>
Lower infection rate <sup>2</sup>
No risk of disease transmission
No risk of immune reaction <sup>3</sup>
Lower cost <sup>4</sup>
Faster graft incorporation/faster return to full activities <sup>5</sup>
Allograft
Faster immediate postoperative recovery
Less postoperative pain
Graft harvest not part of surgery
No donor site morbidity
Larger grafts available for double-bundle reconstruction
Improved cosmesis

third-party payer total global payments for all operating room and equipment costs, including grafts, are typically  $\leq$ \$2,000; thus, routine allograft use may subject surgical centers or hospitals to a substantial financial loss on each surgery.

### Recovery Time

When discussing recovery time, it must be specified whether one is speaking of early perioperative or late ultimate recovery time. Allograft proponents often describe shorter recovery time as an advantage over autograft in the immediate postoperative period. This is based on the assumption that the patient will have less perioperative pain, resulting in faster recovery. However, there is more likely to be significantly less pain in the comparison of allograft with BPTB than in the comparison of allograft to hamstring autograft.<sup>25</sup>

Dr. Howell or a member of his immediate family serves as a consultant to or is an employee of Biomet Sports Medicine and has stock or stock options held in OtisMed. Dr. Johnson or a member of his immediate family has received royalties from and has served as a consultant to ConMed Linvatec. None of the following authors or a member of their immediate families has received anything of value from or owns stock in a commercial company or institution related directly or indirectly to the subject of this article: Dr. Prodomos, Dr. Fu, and Dr. Lawhorn.

**Figure 1**

Intraoperative photograph of posterior mini-incision hamstring harvest technique. The accessory semitendinosus muscle sits on the neck of the tendon stripper outside the posterior incision, where it can be easily sectioned under clear visualization.

Autograft proponents often describe a shorter recovery time with regard to late final recovery and release to full activities. This is because allografts recellularize more slowly and less completely<sup>5</sup> than do autografts. For this reason, many surgeons delay aggressive rehabilitation and return to full activities for patients receiving allograft.

### Posterior Versus Anterior Hamstring Harvest Technique

Traditionally, hamstring tendons have been harvested via an anterior approach. Typically, the incision is roughly 5 cm in length. The harvest has been described as the most difficult part of the hamstring ACL reconstruction procedure.<sup>26</sup> If they are not sectioned before the tendon stripper is used, the intertendinous hamstring cross-connections, especially the accessory semitendinosus muscle, may divert the tendon stripper so that it cuts the hamstring tendon to a length too short for use.

When this occurs, the surgeon must use either an allograft or another autograft, such as BPTB.

The hamstring harvest may be far more problematic for the many surgeons who were initially trained in the BPTB technique. Concerns about BPTB donor site morbidity, as well as recent reports of excellent stability with hamstring tendons, have resulted in increased use of hamstring autografts rather than BPTB graft. The posterior mini-incision harvest technique, which was devised in 1991,<sup>27</sup> places the incision close to the tendinous cross-connections. When done in connection with a sharp anterior incision, this technique allows the surgeon to visualize all cross-connections, especially the accessory semitendinosus muscle (Figure 1), which facilitates sectioning them before harvest. Posterior mini-incision also allows more rapid differentiation of one tendon from another; the tendons exist as separate structures posteriorly but are conjoined anteriorly. Cosmesis has also been excellent.

### Double- Versus Single-bundle ACL Reconstruction

#### Double-bundle Advantages

Despite advancements in single-bundle ACL reconstruction, a review of the literature demonstrates that between 10% and 30% of patients report persistent instability following single-bundle surgery.<sup>28</sup> Among single-bundle restorations, only 70% of KT1000 test results are reported to demonstrate a <2 mm side-to-side difference, with a failure rate of 5% to 10%.<sup>29</sup> The return-to-sport rate for single-bundle restorations is only 60% to 70%. Anatomic studies reveal that the functional anatomy of the ACL has two bundles: the anteromedial (AM) and the posterolateral (PL) (Figure 2). These structures are initially seen during fetal development and remain distinct throughout life. The femoral

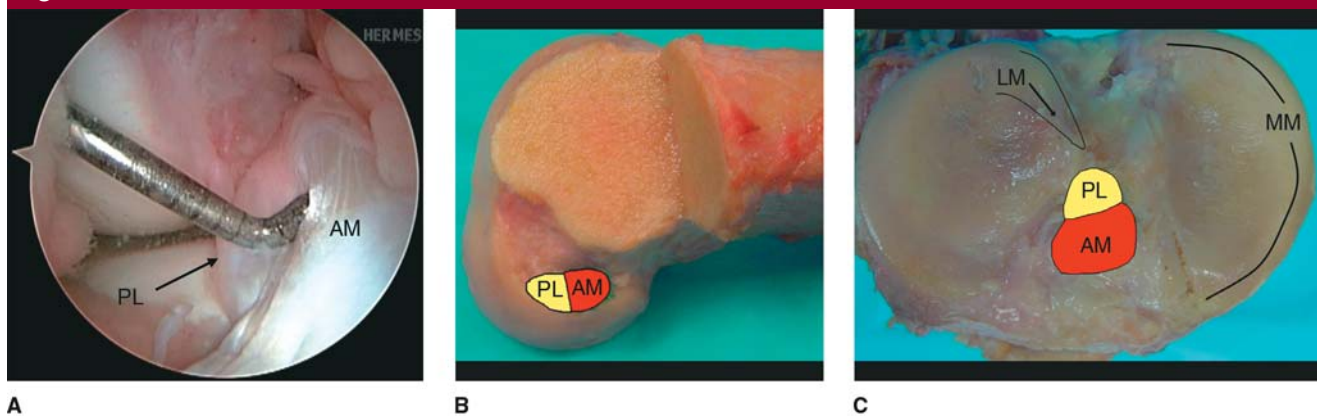
insertion sites of the AM and PL bundles are oriented vertically with the knee in extension but become horizontal in 90° of flexion, as the PL insertion site lies anterior to the AM site. In extension, the two bundles are parallel, and in flexion, they become crossed. Each bundle makes a unique contribution to knee kinematics at different flexion angles. The AM bundle in flexion tightens as the PL bundle (Figure 2, A) becomes lax, whereas in extension, the PL bundle tightens and the AM bundle relaxes.<sup>30</sup>

Anatomic double-bundle reconstruction has some logical rationales in its favor and is supported by biomechanical studies. These studies suggest that conventional single-bundle ACL reconstruction may successfully restore anteroposterior knee stability, but the reconstructed knee may be unable to resist combined rotatory loads.<sup>31</sup> Cadaveric studies of double-bundle knee reconstructions reveal a closer restoration of normal knee kinematics.<sup>32</sup> A closer restoration of normal knee kinematics may be associated with improved functional outcomes following ACL reconstruction.

An important goal for current and future clinical studies evaluating the anatomic double-bundle approach is improved evaluation of knee kinematics, specifically rotation. Better restoration of normal kinematics is one of the potential advantages of the double-bundle approach over single-bundle reconstruction and may play a key role in determining outcomes.

#### Single-bundle Advantages

Surgeon experience may be an important factor in surgical outcomes. ACL reconstruction is the sixth most common orthopaedic procedure, and most surgeons who do such surgery perform fewer than 10 procedures per year, providing them limited opportunity to perfect a highly complex procedure. Experienced surgeons have a 5% to 10% failure rate, and it would be expect-

**Figure 2**

Intraoperative photograph (**A**) of the two functional bundles of the anterior cruciate ligament: the anteromedial (AM) and the posterolateral (PL). The PL bundle lies posterolateral to the AM bundle and can be better exposed by pushing the AM bundle medially. **B** and **C**, Photographs demonstrating the anatomic ACL footprints. LM = lateral meniscus, MM = medial malleolus. (Panels B and C adapted with permission from Starman JS, Ferretti FH, Fu FH: *Anatomy and biomechanics of the ACL*, in Prodromos CC [ed]: *The Anterior Cruciate Ligament: Reconstruction and Basic Science*. Philadelphia, PA: Elsevier, 2007, p 6.)

ed that this rate would be higher for surgeons who do fewer procedures. The most common cause of failure is improper positioning of the bone tunnels. The double-bundle procedure, which is more complex than the single-bundle approach, would be expected to be associated with more misplaced tunnels. Poor outcomes may be related to increased difficulty in surgical technique. For instance, tunnel placements can interfere with each other when they are not meticulously created. In particular, a PL tunnel may push the AM tunnel too far anteriorly, resulting in roof impingement and potential graft rupture.

The double-bundle procedure has other disadvantages. The greater complexity of double-bundle repair results in longer surgical time. Femoral fixation options also are limited; currently, the EndoButton (Smith & Nephew Endoscopy, Andover, MA) is the most common fixation device. Cross-pin graft fixation is generally not possible. The larger footprint on the tibial side offers greater potential for notch impingement. Revisions are also more difficult with double-bundle ACL reconstruction than with single-

bundle ACL reconstruction. There is no consensus on the amount of tensioning or the optimum knee flexion angle, although some surgeons prefer to tension the AM bundle in moderate flexion and the PL bundle near full extension.<sup>33</sup>

Few clinical data indicate that double-bundle repair is superior to single-bundle repair. At least one study indicates disappointing results for double-bundle reconstruction, with lax outcomes in 11% of procedures and partial tearing of the graft in 54%.<sup>34</sup> In that study, the average degree of laxity was greater at 2-year follow-up than at 1-year follow-up. Evidence is needed in the form of a randomized clinical trial of double-versus single-bundle procedures. Overall, the reported results following single-bundle procedures show a relatively high rate of stable knees and return to sports (Table 2). It remains to be proved that double-bundle ACL reconstruction can significantly improve on the results reported in these long-term studies.

### Tunnel Placement

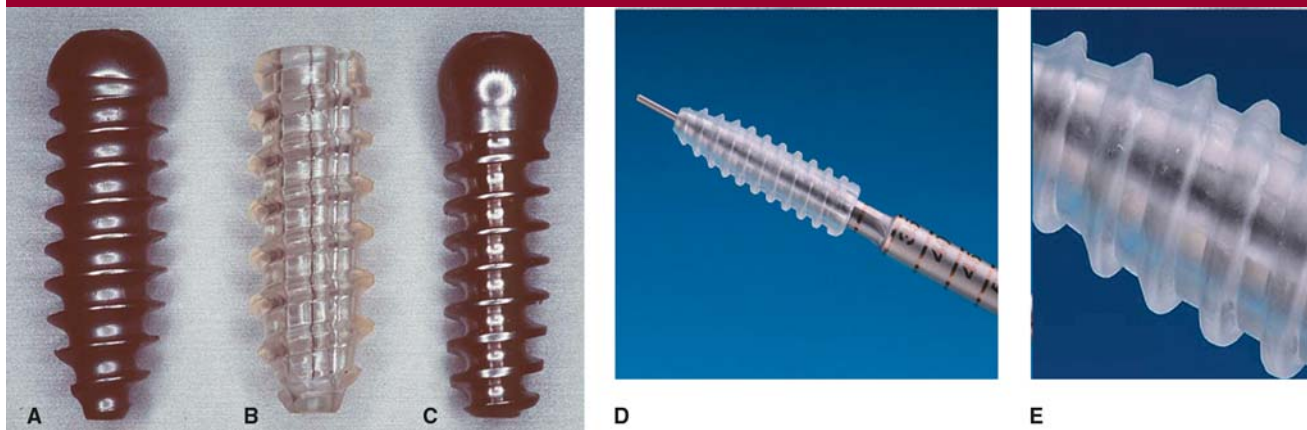
ACL reconstruction should not cause posterior cruciate ligament

**Table 2**

#### Advantages of Single- Versus Double-bundle Reconstruction

Single-bundle reconstruction
Proven success <sup>31</sup>
Greater technical ease
Less tunnel widening
Fewer complications
Easier revision
Lower graft cost for surgeons using allograft (\$1,800 to \$3,000 less)
Lower implant cost
Shorter surgical time
Double-bundle reconstruction
Greater rotatory stability
More normal knee kinematics <sup>34</sup>

(PCL) impingement. The diagnosis of PCL impingement is made radiographically. PCL impingement exists when the tibial tunnel is placed in a vertical orientation at an angle  $>70^\circ$  from the medial joint line of the tibia and the femoral tunnel is then drilled through that tibial tunnel. Placement of the ACL graft vertically at the apex of the notch causes the graft to wrap around the PCL, which causes high tension in the graft

**Figure 3**

Interference screws used in anterior cruciate ligament reconstruction. **A**, Early metallic interference screw, sharp-threaded. **B**, Sysorb biodegradable interference screw, round-threaded. **C**, RCI interference screw, metallic, round-threaded. **D**, MegaFix biodegradable interference screw, sharp-threaded at the tip and round threaded at the body. **E**, Close-up view of the MegaFix biodegradable interference screw. (Panel B courtesy of Zimmer, Warsaw, IN. Panel C courtesy of Smith & Nephew Endoscopy, Andover, MA. Panel D courtesy of KarlStorz, Tuttlingen, Germany.)

when the knee is flexed. High graft tension in flexion causes the graft to stretch out and prevents the patient from regaining full knee flexion.<sup>35,36</sup>

The prevention of PCL impingement requires several steps. The first is to widen the notch so that the space between the PCL and the lateral femoral condyle exceeds the diameter of the graft by 1 mm. A wall-plasty (ie, notchplasty of the wall without a roofplasty) is required because the round ACL graft is always larger in cross section than is the narrow, spindle-shaped, intact ACL.<sup>37</sup> The second step is to construct the tibial tunnel at an angle of 60° to 65° with respect to the medial joint line of the tibia. This technique moves the femoral tunnel farther down the side-wall and decreases the risk of PCL impingement.<sup>36</sup> Finally, the lateral edge of the tibial tunnel is placed through the tip of the lateral tibial spine.

Reciprocal tensile behavior has long been a quest of the surgeon who performs ACL reconstructions and has been a rationale for pursuing the double-bundle technique. The concept is that the AM bundle should carry more tension in flexion and the PL bundle should carry more

tension in extension. However, two tunnels are not needed because a 4HS graft in a single femoral tunnel restores reciprocal tensile behavior as long as the tunnel has been placed without PCL and roof impingement.<sup>38</sup>

The two most important surgical factors in achieving a stable, fully functional, pain-free knee after ACL reconstruction are correct placement of the femoral and tibial tunnels without PCL and roof impingement and the use of slippage-resistant, stiff, strong fixation. After surgery, the patient's ability to undergo brace-free, aggressive rehabilitation that is self-administered at home seems to be related to positive outcome. The less important outcome factors are the type of graft tissue used, the use of a brace or immobilizer, and the use of formal physical therapy.

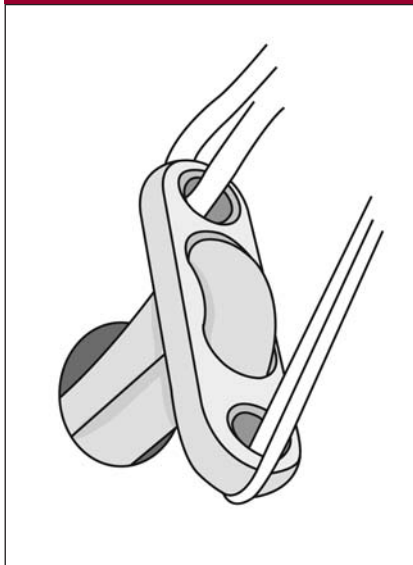
### Controversies in Fixation

Most surgeons who prefer BPTB autografts use interference screw fixation. However, among surgeons who prepare soft-tissue graft, a large and increasing variety of fixation devices

are used, with no consensus as to what is best. Fixation can be broadly divided into interference screw-based, cortical, and cross pin. Interference screw fixation can be used in the femur and tibia and functions by generating frictional holding power between the graft and the bone tunnel wall (Figure 3). This method of fixation is used comfortably by the many surgeons who were trained in BPTB but who have switched recently to soft-tissue reconstruction.

Cortical fixation also may be used for both the tibia and femur and is achieved with EndoButton femoral fixation devices (Figure 4) and with interference screws used as cortical posts to achieve tibial fixation (Figure 5). Cortical fixation was first recommended and advocated by Rosenberg, who was the most influential early advocate for 4HS graft use.<sup>39</sup> It may be direct, as with the Washer-Loc (Biomet, Warsaw, IN) tibial device (Figure 6), which compresses the graft against the cortex, or indirect, in which an interface is used to connect the graft to the anchoring cortex. In the femur, this interface is typically a fabric loop (eg, EndoButton CL) or a metal loop (eg, EZLoc

**Figure 4**



EndoButton femoral fixation device. (Courtesy of Smith & Nephew Endoscopy, Andover, MA.)

**Figure 5**



Screws used as cortical posts. *Left*, Smith & Nephew (Andover, MA) MDA 4.5 mm; no washer used. *Center*, ConMed Linvatec (Utica, NY) 6 mm; washer mandatory. *Right*, Arthrex (Naples, FL) 4.5 mm; washer optional.

**Figure 6**



WasherLoc tibial fixation device. *Left*, Long spike. *Right*, Standard spike. (Courtesy of Biomet, Warsaw, IN.)

**Figure 7**



EZLoc femoral fixation device. (Courtesy of Biomet, Warsaw, IN.)

[Biomet]) (Figure 7) through which the folded graft is passed. On the tibia, the interface is either a suture whipstitch or a woven fabric material such as Fastlok (Neoligaments Ltd, Leeds, UK).<sup>40</sup>

Cross-pin fixation is a relatively new technique that has been gaining in popularity, in part because of the perception that it provides secure fixation that is closer to the tunnel aperture than does that provided by cortical fixation (Figure 8). Although there is no evidence that aperture fixation provides greater stability than does cortical fixation, many surgeons prefer it because of the so-called bungee effect, which purports that fixation closer to the joint provides higher stability. This may be an incorrect perception. In fact, a recent meta-analysis<sup>29</sup> showed cortical rather than aperture fixation to be associated with the highest rates of ACL reconstruction stability for soft-tissue grafts.

On the tibia, distal cortical fixation of a soft-tissue ACL graft is stronger, stiffer, and more slippage-resistant than is joint-line fixation

done with an interference screw.<sup>41</sup> The use of an interference screw causes tunnel widening and prevents circumferential tendon-tunnel healing, resulting in inferior strength and stiffness at 4 weeks compared with cortical fixation.<sup>42</sup> The insertion of a bone dowel alongside a tendon graft in the tunnel in conjunction with distal cortical fixation prevents tunnel widening, increases stiffness, promotes circumferential healing, and simplifies revision surgery.<sup>42-46</sup>

Aggressive, brace-free rehabilitation with early weight bearing is safe following high-stiffness, slippage-resistant, distal cortical fixation.<sup>45</sup> The high stiffness provided by distal cortical fixation reduces the tension needed in the graft to restore stability and lowers graft tension during open-chain exercise.<sup>46</sup> Reducing the graft tension without increasing anterior laxity requires high-stiffness distal cortical fixation, which also resists slippage and tension loss during aggressive rehabilitation.<sup>46,47</sup>

Whipstitch-post tibial (cortical) fixation was the first method used successfully for 4HS grafts.<sup>48</sup> ACL

reconstruction patient cohorts<sup>7,29</sup> have shown unsurpassed stability in clinical use. Simple interference screw fixation has also had mixed results, while interference screw fixation combined with cortical fixation has shown very good results.<sup>29</sup> Similarly, interference screw-based methods such as the Intrafix (Mitek, Raynham, MA) (Figure 9, A), TriTis (Covidien, North Haven, CT) (Figure 9, B), and the Smith & Nephew graft

**Figure 8**



**A**

**B**

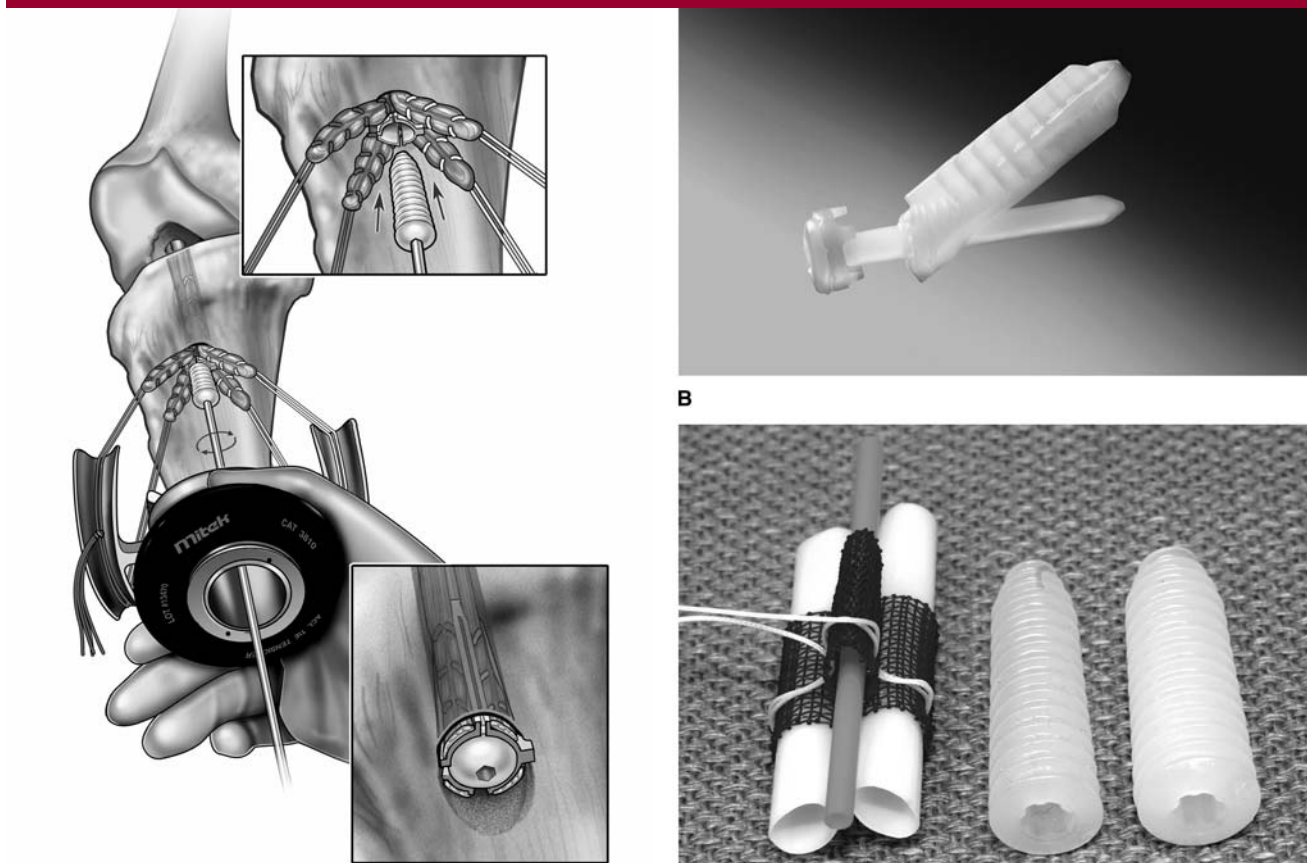
**A**, Transfix femoral fixation device. **B**, Stratis femoral fixation device. (Panel A courtesy of Arthrex, Naples, FL. Panel B courtesy of Covidien, North Haven, CT.)

sleeve (Figure 9, C) appear to be quite promising.<sup>49</sup> Although cross-pin fixation is popular among surgeons, there is a paucity of clinical data pertaining to it, and the clinical series that have been published to date have shown mixed results.<sup>29</sup>

### Summary

Controversy exists regarding the best method and choice of graft (autograft versus allograft) in ACL reconstruction. Graft choice is multifactorial. Concerns related to donor-site mor-

**Figure 9**



**A**

**B**

**C**

**A**, Intrafix tibial fixation device (Mitek, Raynham, MA). The top inset shows the device in prefixation stage; the bottom inset shows a fixed graft. **B**, TriTis tibial fixation device. **C**, Graft sleeve tibial fixation device set. (Panel A reproduced with permission from Sklar J, Brown CH: Hamstring ACLR with Intrafix Tibial Fastener, in Prodromos CC [ed]: *The Anterior Cruciate Ligament: Reconstruction and Basic Science*. Philadelphia, PA: Elsevier, 2007, p 346. Panel B courtesy of Covidien, North Haven, CT. Panel C reproduced with permission from Brown CH, Darwich N: Intratunnel tibial fixation of soft tissue ACL grafts: Graft sleeve and tapered screw, in Prodromos CC [ed]: *The Anterior Cruciate Ligament: Reconstruction and Basic Science*. Philadelphia, PA: Elsevier, 2007, p 331.)

bility favor allograft or 4HS graft over the BPTB graft. Comparative stability results, infection/disease transmission concerns, and cost considerations favor autografts relative to allografts. Early recovery time favors allografts; final recovery time favors autografts. Double-bundle fixation provides improved bench-tested rotatory stability, and it more accurately reproduces the anatomic footprint of the ACL relative to the single-bundle procedure; however, no clinical benefit has yet been described for it. The posterior mini-incision hamstring harvest approach allows easier identification of the hamstring tendons and greatly reduces the risk of cutting the hamstring tendons too short for use.

Fixation devices include the cortical, interference screw-based, and cross-pin methods. Cortical fixation offers high stiffness and has been associated with excellent clinical results. No benefit has been shown for aperture fixation compared with cortical fixation, and a bungee effect does not appear to exist. Interference screw-based or hybrid interference screw/cortical methods appear to have advantages over simple interference screw fixation for soft-tissue grafts. Cross pins are in wide clinical use, but clinical data showing high levels of efficacy comparable to more established methods have not yet been produced.

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*Evidence-based Medicine*: Level I and level II randomized controlled studies include references 6 and 8. level III/IV case-control and cohort studies include references 1, 4, 7, 9-21, 25, 26, 28, 29, 35, 37, 38, 40, 44, 45, and 48.

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