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Anatomic Femoral and Tibial Tunnel Placement During Anterior Cruciate Ligament Reconstruction: Anteromedial Portal All-Inside and Outside-In Techniques

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Abstract: Tunnel malposition is one of the most common technical reasons for anterior cruciate ligament reconstruction failure. Small changes in tunnel placement can result in significant differences in outcome. More anatomic placement of the tunnels can lead to greater knee stability and a more accurate reproduction of native knee kinematics. This Technical Note describes 2 tibial tunnel—independent methods to obtain anatomic femoral tunnel placement. The all-inside anteromedial portal technique requires only minimal surgical incisions but allows precise femoral tunnel placement. However, hyperflexion of the knee is required, adequate surgical assistance is necessary, and this technique may be susceptible to graft-tunnel mismatch. The outside-in technique may be more beneficial in obese patients, skeletally immature patients, or revision cases. On the downside, it does require an additional 2-cm surgical incision. This article also provides surgical pearls to fine-tune tibial tunnel placement.

Although anterior cruciate ligament (ACL) reconstructions can fail for a variety of reasons, the most common technical error is incorrect tunnel placement, with the femoral tunnel more commonly misplaced than the tibial tunnel.[1-3] In fact, even small changes in tunnel placement have been shown to significantly affect knee kinematics after ACL reconstruction.[4] Epidemiologic data from the Multicenter ACL Revision Study (MARS) showed that 80% of failed ACL reconstructions were at least partially due to femoral tunnel malposition and 37% due to incorrect tibial tunnel placement.[3]

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Recently, many surgeons have transitioned away from the more traditional transtibial method of femoral tunnel reaming in favor of tibial tunnel—independent reaming (usually through an anteromedial portal).[5] This may allow for more anatomic femoral tunnel placement at the native ACL footprint.[6-8] Furthermore, tibial tunnel—independent femoral reaming allows positioning of the tibial tunnel based solely on anatomic considerations, free from femoral tunnel trajectory concerns. Biomechanical, anatomic, and cadaveric studies have shown potentially improved femoral and tibial tunnel position when reaming is performed independent of the tibial tunnel.[1,7-10]

In addition to surgical technique, knowledge of the native ACL anatomy is crucial to proper graft positioning.[11,12] The ACL footprint at both the femoral and tibial insertions has been well described. The center of the ACL femoral footprint is located at an average of 43% to 51% of the proximal-to-distal distance of the lateral femoral notch, usually centered over the lateral bifurcate ridge.[13,14] By use of the quadrant method, the average center of the ACL footprint on the femur is located at approximately 28% of the long axis of the quadrant and 35% of the short axis.[15] No fibers are located anterior to the lateral intercondylar ridge (resident's ridge),[16] and the distance between the posterior edge of the footprint and the posterior articular

Table 1. Comparison of Femoral Tunnel All-Inside and Outside-In Techniques

	All-Inside Technique	Outside-In Technique
Benefits	Tibial tunnel independent Minimal skin incisions Ability to fine-tune tunnel starting point	Tibial tunnel independent Ability to fine-tune tunnel starting point and trajectory (e.g., to avoid physis or previous tunnels)
Disadvantages	Requires knee hyperflexion Susceptible to graft-tunnel mismatch Needs sufficient assistance in the operating room to hold leg in hyperflexed position Risk of medial femoral condyle damage when inserting and removing reamers	Additional 1.5- to 2-cm lateral skin incision
Ideal patient	Thin Primary surgery	Obese Skeletally immature Revision surgery

cartilage is approximately 2.5 mm.[17] The center of the tibial footprint has been described as even with the posterior edge of the anterior horn of the lateral meniscus in the anterior-posterior direction,[18] 15 mm anterior to the posterior cruciate ligament, and 40% of the medial-to-lateral interspinous distance.[19]

Although the current literature has shown equivocal outcomes between transtibial and tibial tunnel—independent reaming methods, anatomic and biomechanical studies have clearly shown improved femoral tunnel placement with tibial tunnel—independent techniques.[4,8,10] Furthermore, nonanatomic tunnel placement is associated with decreased knee stability[20] and an increased failure rate.[3] Thus the purpose of this article is to describe surgical tips and techniques that can lead to more consistent and anatomic tibial and femoral tunnel positions during ACL reconstruction. In addition to describing ideal tibial tunnel characteristics, we describe 2 alternate methods to obtain anatomic femoral tunnel placement (Table 1).

Surgical Technique

Patient Positioning

Positioning for both femoral tunnel techniques is the same. The patient should be placed in the supine position, with the knee flexed and the foot hanging over the edge of the bed. A tourniquet should be placed as proximally as possible around the thigh, with an arthroscopic leg holder placed directly over this. The arthroscopic leg holder should be adjusted such that the femur is parallel with the ground. Alternatively, the thigh can be positioned with more hip flexion to allow for greater knee hyperflexion. Likewise, adequate space must be available behind the foot such that the knee can be hyperflexed when necessary for femoral tunnel drilling (Fig 1). The leg is then prepared and draped in the standard sterile manner.

Portals

We begin by making a "high and tight" anterolateral portal with an oblique stab incision adjacent to the lateral border of the patella, just superior to the inferior pole of the patella. The standard anteromedial (or middle anteromedial) portal is made under arthroscopic visualization with a spinal needle, just medial to the patellar tendon and directly superior to the anterior horn of the medial meniscus. This portal is the viewing portal for femoral tunnel placement and reaming. A far-medial accessory portal is made by use of a spinal needle under arthroscopic visualization. This portal incision is made horizontal to allow side-to-side movement when reaming the femoral tunnel with an all-inside technique. It is imperative to make this accessory medial portal low and medial to avoid exiting out the back of the femur in hyperflexion, as well as to avoid drilling a short femoral tunnel, potentially causing graft-tunnel mismatch. In addition, it is crucial to place the portal such that the arthroscopic instrumentation can reach the center of the femoral footprint without damaging the medial condyle. This portal will be used for reaming of the femoral canal with the all-inside technique.

Initial Arthroscopy and Exposure

After portal placement, the surgeon performs arthroscopic examination of the knee, paying special attention to the native femoral and tibial ACL footprints. Graft harvest is performed by the surgeon's preferred method. While the remnant ACL is preserved as much as possible, a notchplasty is performed to aid in visualization of the femoral footprint and to adequately visualize the posterior articular cartilage of the lateral femoral condyle. In some cases, a Dyonics radiofrequency ablation probe (Smith & Nephew, Andover, MA) can be used to remove soft tissue without altering the underlying bony architecture.

Femoral Tunnel

After graft preparation and sizing, the femoral tunnel is reamed. We discuss 2 equally useful methods to

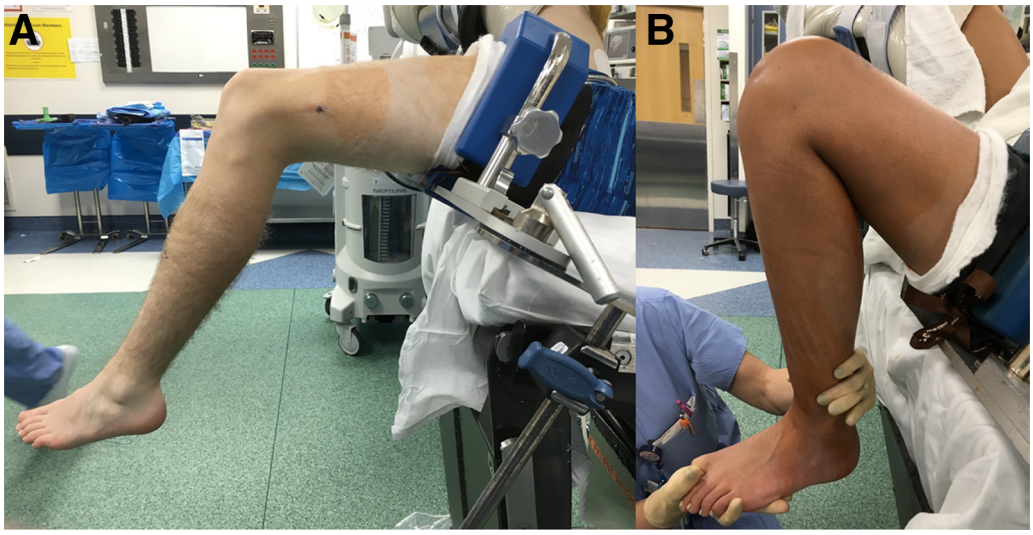

Fig 1. Setup for anterior cruciate ligament reconstruction. (A) A tourniquet is applied to the proximal thigh of the operative extremity, and the leg is then placed in the arthroscopic leg holder. The leg holder is angled such that the thigh is held in a perfectly horizontal position, parallel to the floor. The nonoperative leg is placed in a well-leg holder and abducted out of the way. (B) It is important to slide the patient far enough down the bed so that knee hyperflexion can be achieved when the foot of the bed is dropped. Of note, the hyperflexion maneuver includes both flexion of the knee and concomitant hip flexion, as visible in the photograph. When the outside-in technique is being used, less flexion is needed (approximately 95°).

obtain an anatomic femoral tunnel: reaming through an accessory anteromedial portal and reaming in an outside-in manner using an Acufex Pinpoint single-bundle femoral guide (Smith & Nephew).

All-Inside Femoral Tunnel. For all-inside reaming using the accessory anteromedial portal, we begin by using a 45° microfracture awl inserted through the accessory anteromedial portal to mark the preferred centrum of the femoral insertion (Video 1). The preferred tunnel center is at approximately 40% of the proximal-to-distal distance of the lateral notch and is centered between the lateral intercondylar ridge and the posterior articular margin. This point should coincide with a distance of approximately 2.5 mm plus the planned tunnel radius from the posterior articular cartilage and should be centered over the lateral bifurcate ridge. Care should be taken to ensure there is a 2-mm bony bridge between the tunnel wall and the proximal and posterior articular margins. An Acufex Pinpoint single-bundle femoral guide can be used to visualize the diameter of the planned femoral tunnel at the native footprint (Fig 2, Video 1).

A Beath pin is then inserted through the accessory anteromedial portal and into the bone at the previously marked femoral tunnel center. The knee is carefully hyperflexed, and the Beath pin is advanced through the lateral femoral condyle and out the far-lateral cortex. While the knee is held in hyperflexion, a 4.5-mm cannulated drill is used to drill over the Beath pin and through the far-lateral cortex. The drill and Beath pin are then removed, and the femoral tunnel is measured with an EndoButton tunnel depth guide (Smith & Nephew). The pin is reinserted through the tunnel, and a single fluted acorn drill bit is used to drill the femoral tunnel to the appropriate diameter (Fig 3). It is important to drill approximately 10 mm farther than the planned graft depth to allow room to flip the suspensory fixation device.

Outside-In Femoral Tunnel. For outside-in drilling, the Acufex Pinpoint femoral guide with aiming attachment is inserted through the anterolateral portal, and the aiming ring is placed over the femoral insertion site, by use of the same anatomic landmarks described earlier. The aiming hand is adjusted so that it is angled anteriorly approximately 40° to 50° (Fig 4). This will ensure that the femoral tunnel is away from the femoral insertion of the lateral collateral ligament. The bullet is then advanced until it is flush with the lateral cortex of the femur. A 1.5-cm incision is made through the skin and iliotibial band to facilitate adequate contact between the bullet and the bone, and a Gelpi self-retaining retractor is used to retract the soft tissues. A guide pin is then advanced in a lateral-to-medial direction through the aiming arm and bullet until it protrudes into the notch (Fig 5, Video 1). Once satisfactory pin placement is confirmed through arthroscopic visualization, the aiming guide and bullet are removed. The femoral tunnel is then drilled, starting with a 6.5- or 7-mm standard reamer and advancing in 2- to 2.5-mm increments up to the final tunnel size. After each

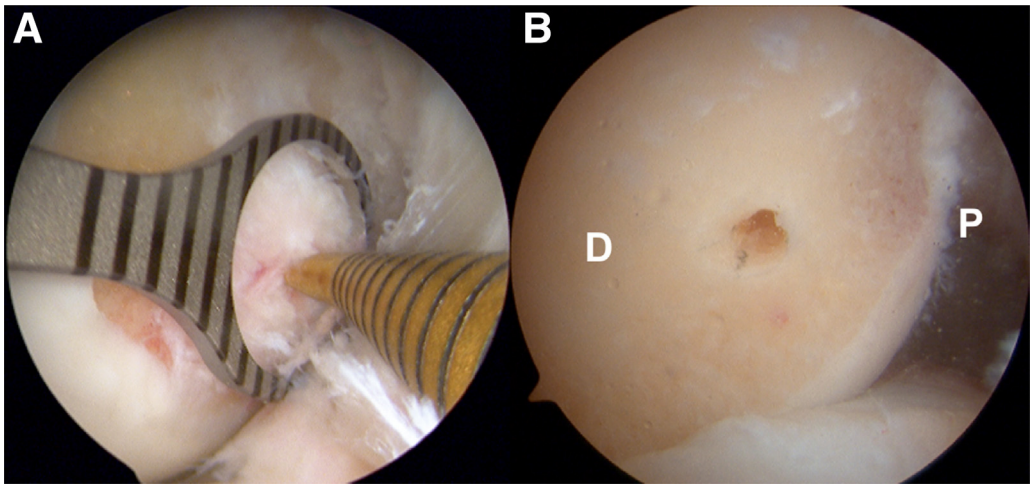

Fig 2. Native anterior cruciate ligament (ACL) femoral footprint and planned femoral tunnel using all-inside technique. (A) View of a right knee from the medial portal showing the native ACL footprint on the lateral wall of the intercondylar notch. An Acufex Pinpoint guide is used to outline the native footprint of the ACL on the femur. Guides of various diameters can be used, depending on the planned tunnel diameter, to visualize the planned tunnel. (B) View through the accessory medial portal to assess the planned femoral tunnel site, as marked with the microfracture awl. The center of the tunnel for single-bundle reconstruction should be located at approximately 40% to 50% of the proximal (P)—to—distal (D) distance of the lateral notch.

sequential drilling, tunnel position can be fine-tuned by holding the Beath pin eccentrically with a pituitary rongeur during subsequent drilling.

Tibial Tunnel

Proper visualization of the tibial footprint is aided by placing the anterolateral portal high and tight, allowing a bird's-eye view of the tibia and relevant landmarks. The tibial footprint is inspected, and the center of the planned tunnel is marked with a Dyonics radiofrequency ablation probe. The center of the tibial tunnel should be located at 40% of the medial-to-lateral width of the interspinous distance, in line with the posterior edge of the lateral meniscus anterior horn, approximately 15 mm anterior to the posterior cruciate ligament. An Acufex tibial guide (Smith & Nephew) is set to 55° and positioned with the aiming tip intra-articularly at the centrum of the ACL footprint. Extra-articularly, the guide should be set so that the center of the tunnel is 1.5 cm medial to the medial aspect of the tibial tubercle and 1 cm above the insertion of the hamstring at the pes anserinus. A 2.4-mm tibial guide pin is then advanced through the

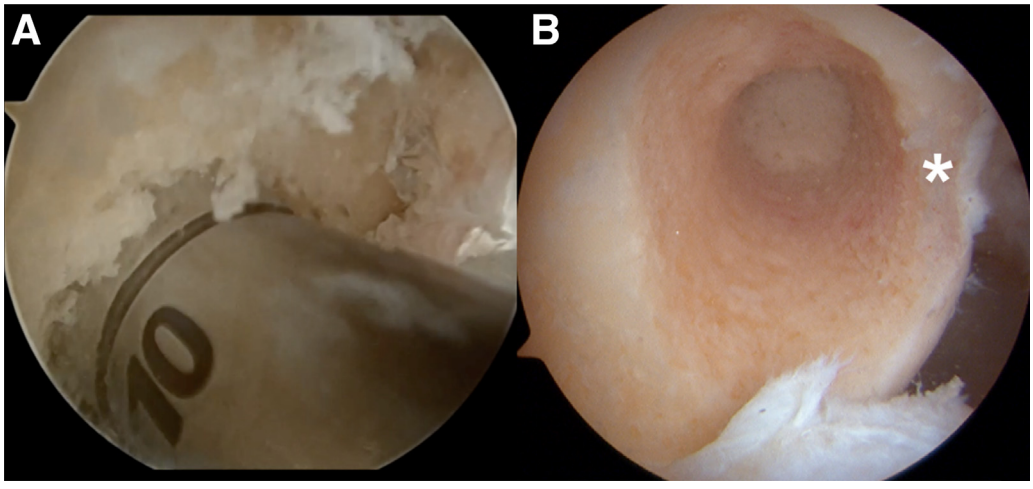

Fig 3. Reaming of femoral tunnel by all-inside technique. (A) View of the lateral notch in a right knee, from the medial portal, showing the reamer being advanced gradually. The reamer is using the accessory medial portal, and the knee is held in hyperflexion during this process. (B) View of resultant femoral tunnel from accessory medial portal. One should note that there is approximately 2 mm of a back wall (asterisk) behind the tunnel.

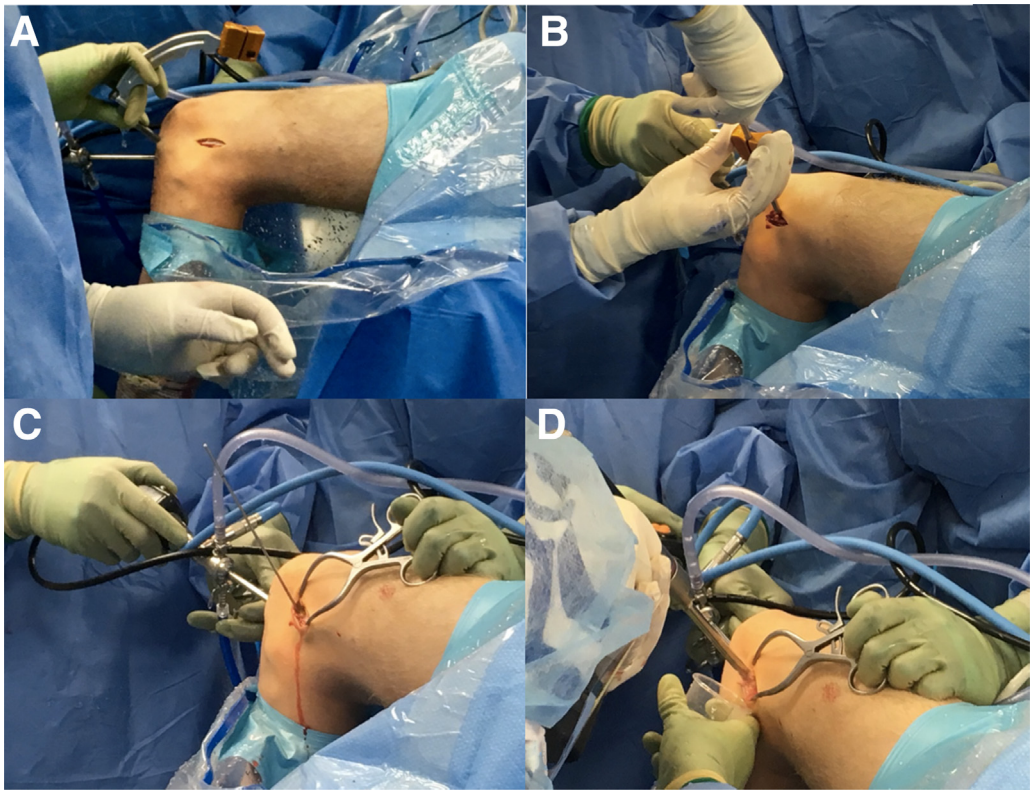

Fig 4. Outside-in technique for anterior cruciate ligament reconstruction. The extra-articular portion of the Acufex Pinpoint guide is visible (left knee). (A) The guide handle is positioned as desired to avoid previous tunnels, hardware, skeletally immature physes, and key anatomic structures, such as the femoral insertion of the lateral collateral ligament. In general, the guide handle should be 40° to 50° from horizontal. A 1.5- to 2-cm incision is made through the skin and iliotibial tract to allow the aiming "bullet" to have direct bony contact. (B) The bullet is advanced directly onto the near cortex and locked into place. (C) The guide pin is advanced until visible intra-articularly at the native footprint. (D) A cannulated reamer is used to ream the tunnel from the outside in, and any bone graft is collected in a specimen cup.

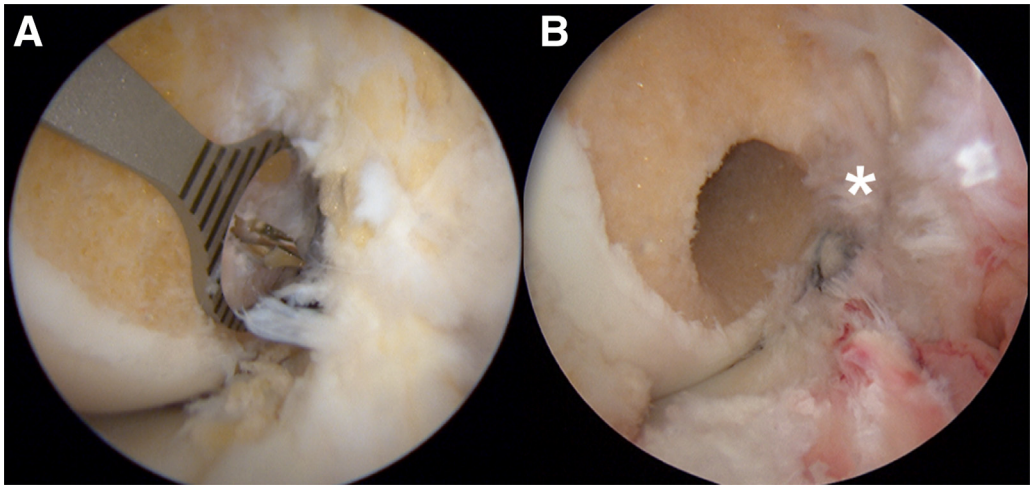

Fig 5. Arthroscopic view of outside-in reaming of femoral tunnel. (A) View of the lateral notch in a right knee from the medial portal. The Acufex Pinpoint femoral guide with aiming attachment is inserted through the anterolateral portal, and the aiming ring is placed over the femoral insertion site. The guide pin is advanced from outside in and is visible protruding through the native insertion site. (B) View of resultant femoral tunnel. One should note that there is approximately 2.5 mm of a back wall (asterisk) behind the tunnel.

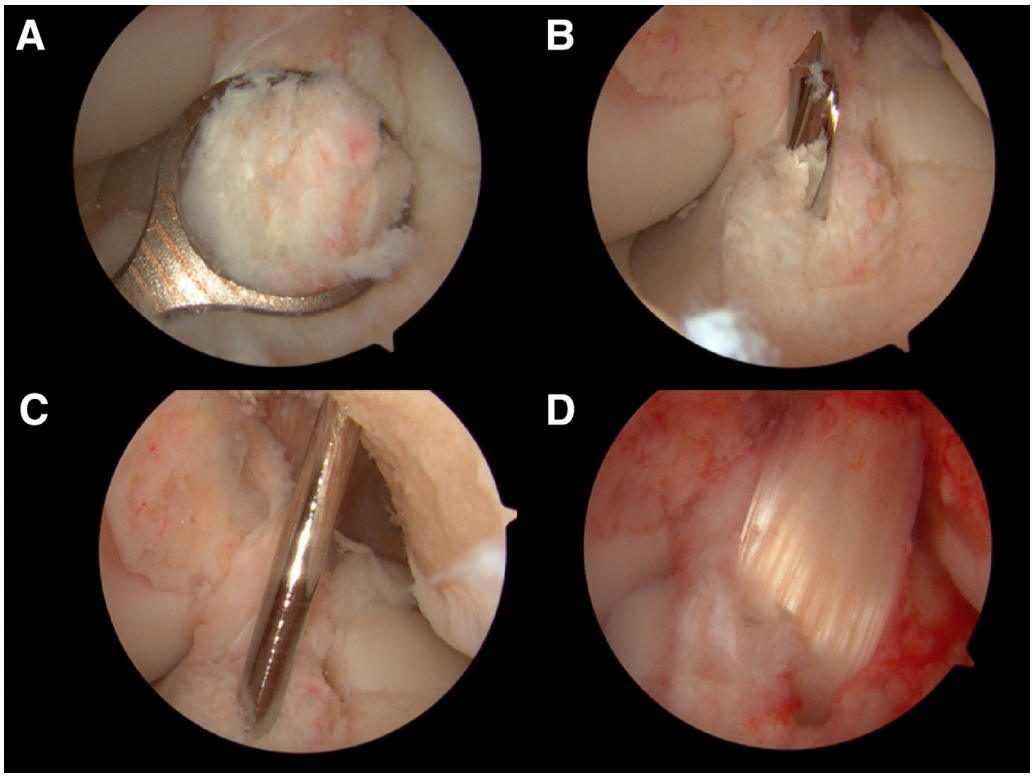

Fig 6. Arthroscopic bird's-eye view of tibial anterior cruciate ligament (ACL) footprint. This view of a left knee from the high and tight anterolateral portal shows the ACL remnant at the native site of the tibial footprint, just across from the anterior horn of the lateral meniscus. (A) An Acufex Pinpoint guide is used to outline the proposed tibial tunnel. (B) The tibial guide pin has been advanced through the ACL remnant. (C) After the guide pin position is confirmed, the guide pin is advanced into the roof of the femoral notch to prevent it from moving during reaming of the tunnel. (D) After final graft passage. One should note that the graft has been passed through the center of the footprint while preserving as much of the native ACL as possible.

guide until the tip is visible protruding through the tibial footprint (Video 1). Similar to the femoral tunnel, the pin can be translated eccentrically with a pituitary rongeur during sequential drilling to fine-tune the position of the tunnel. Once proper positioning is confirmed, the guide pin is set in place by advancing it forward until it docks in the roof of the femoral notch (Video 1). The tibial tunnel is then drilled sequentially, starting with a 6.5- or 7-mm tibial drill and increasing in size by 2- to 2.5-mm increments (Fig 6, Video 1).

Graft Passage and Fixation

A looped nonabsorbable pull suture is used to pull the graft into place, first through the tibial tunnel and then into the femoral tunnel. A blunt trocar, straight snap, or right-angle instrument can be inserted through the anterolateral portal and used to lift up on the graft, creating a lever and facilitating graft passage. An EndoButton CL Ultra (Smith & Nephew) is used for suspensory fixation on the femoral side, and a BioRCI bioabsorbable interference screw (Smith & Nephew) is

Table 2. Surgical Pearls

All-Inside Technique	Outside-In Technique
1. The surgeon should ensure that the positioning of the patient allows adequate hyperflexion that will be needed during femoral reaming.	1. After placement of the guide pin, the position of the femoral and tibial tunnels can continue to be fine-tuned by using a pituitary rongeur to hold the tip of the guide pin in the desired direction during sequential reaming.
2. The surgeon should make the accessory (far) medial portal with a spinal needle to ensure that instrumentation will be able to safely reach the femoral footprint without damaging the medial femoral condyle.	2. When the desired tibial guide pin placement is achieved, the guide pin can be advanced into the roof of the femoral notch. This holds the guide pin in place while the surgeon is drilling the tunnel.
3. The degree of knee flexion and position of the leg must not change during reaming or the guide pin may become bent or even break completely.	3. The trajectory and position of the femoral tunnel can be adjusted to account for previous femoral tunnels (in a revision case) or to avoid the femoral physis in a skeletally immature patient.

used on the tibial side. A bicortical 4.5-mm screw and spiked washer can be used for backup tibial fixation with soft-tissue grafts. Technique tips and tricks are summarized in Table 2.

Discussion

Anatomic placement of the femoral and tibial tunnels is crucial to the success of ACL reconstruction. Graft placement over the years has evolved from a relatively anatomically correct 2-incision technique to the less anatomically correct all-endoscopic, transtibial method and, more recently, to endoscopic tibial tunnel—independent methods. Because small changes in tunnel position can affect knee stability and outcomes,[2-4] consistent and accurate tunnel placement is paramount.

Although ACL anatomy has been well described by use of radiographic and cadaveric measures,[1,7,9,18] it is important to understand the anatomy relative to easily visible arthroscopic landmarks.[15,17-19] In this article, we have discussed reproducible and reliable landmarks for accurate tunnel placement for both the femoral and tibial footprints. Furthermore, we have described 2 equally effective methods of obtaining proper femoral tunnel position. Although the all-inside technique may be more preferable for primary ACL reconstruction in young, thin patients, it may not be ideal for all patients. In fact, large patients, skeletally immature patients, or revision ACL patients may be better served with the outside-in technique. In this subset of patients, the downside of an additional 1.5- to 2-cm lateral skin incision is outweighed by the ability to precisely adjust the trajectory and position of the femoral tunnel without the need for knee hyperflexion.

In summary, consistent and anatomically correct femoral and tibial tunnel placement during ACL reconstruction is possible. Just as displacement of a few millimeters can have significant implications for intra-articular fractures, small changes in tunnel position can substantially affect the results of ACL reconstruction. If football is a game of inches,[21] ACL reconstruction is a game of millimeters.

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