Technical Note

Freehand Anatomic Transtibial Single-Bundle Anterior Cruciate Ligament Reconstruction

Naser M. Selim, M.D., Ehab R. Badawy, M.D., and Kamel Youssef, M.D.

Abstract: Creation of the femoral tunnel for single-bundle anterior cruciate ligament (ACL) reconstruction has a high rate of nonanatomic placement with the transtibial (TT) technique but yields better restoration with the anteromedial portal technique and close restoration of the anatomic femoral footprint with the outside-in technique. Modifications of the traditional (TT) technique have been described to restore the native femoral ACL footprint and to simulate double-bundle reconstruction. Modified TT techniques try to capture the anatomic femoral footprint through an anatomic tibial tunnel. In the technique described in this article, the anatomic femoral footprint is drilled first by the use of a 2.5-mm Kirschner wire through the parapatellar anteromedial portal, making an angle 30° to the sagittal plane and 20° to the horizontal plane. The wire is drilled while the knee is hyperflexed and then withdrawn from outside until its distal end reaches the intercondylar notch. The wire is then advanced in an antegrade manner while the knee is flexed 90° until it reaches the center of the marked tibial footprint. The angle of knee flexion may be slightly increased or decreased around 90° with or without slight internal rotation to capture the anatomic tibial footprint. The procedure is completed as a TT single-bundle ACL reconstruction.

Anatomic tunnel placement during anterior cruciate ligament (ACL) reconstruction restores the anatomic tibial and femoral ligament insertions, native ligament orientation, and knee kinematics more closely to those of the intact knee[1-3] and hence provides superior clinical results[4,5] and a lower ACL failure rate. Different techniques are used for the creation of anatomic tunnel placement for single-bundle ACL reconstruction. Anatomic tibial tunnel placement is easily obtained. Although creation of the femoral tunnel has a higher rate of nonanatomic placement with transtibial (TT) drilling,[6,7] it yields better restoration of the anatomic femoral footprint with anteromedial (AM) drilling[8-11] and close restoration of the anatomic femoral footprint with the outside-in (OI) technique.

In the TT technique, TT drilling through the anatomic tibial tunnel obliges the guidewire to pass to a nonanatomic shallow or deep and high or low position in the notch.[6,7,12] To obtain an anatomic femoral tunnel, the entry point of the tibial tunnel should be medial and proximal close to the joint line, which may break the anterior tibial cortex.[13]

Giron et al.[14] reported that it is technically impossible to restore both the anatomic tibial and femoral origins of the ACL using a TT technique despite any modifications. The merits and the complications of the AM portal technique and OI technique are major hindrances for their use.[15,16]

Lee and Kim[17] (2017) presented a modified TT technique for ACL reconstruction and anticipated that it would provide more anatomic placement of the femoral tunnel than the previous traditional TT techniques. However, possible pitfalls were posterolateral (PL) tibial tunnel widening, difficulty in approaching the center of the femoral footprint via the tibial tunnel, and bending of the guide pin at the tibial tunnel aperture after engaging it in the femoral anatomic center.

In the technique described in this article, the anatomic femoral footprint is drilled first by use of a 2.5-mm Kirschner wire (K-wire) through the parapatellar (AM) portal, making an angle 30° to the sagittal plane and 20° to the horizontal plane. The wire is

From the Knee Surgery—Arthroscopy and Sports Injuries Unit, Orthopedic Department, Mansoura University, Mansoura, Egypt.

The authors report no conflicts of interest in the authorship and publication of this article. Full ICMJE author disclosure forms are available for this article online, as supplementary material.

Received May 23, 2021; accepted October 19, 2021.

Address correspondence to Naser M. Selim, M.D., Knee Surgery—Arthroscopy and Sports Injuries Unit, Faculty of Medicine, Mansoura University Hospital, Gomhorrya Street, Mansoura city, Dakahellia Governorate, Egypt. E-mail: dr.nasserselim728@yahoo.com

2212-6287/21771

https://doi.org/10.1016/j.eats.2021.10.013

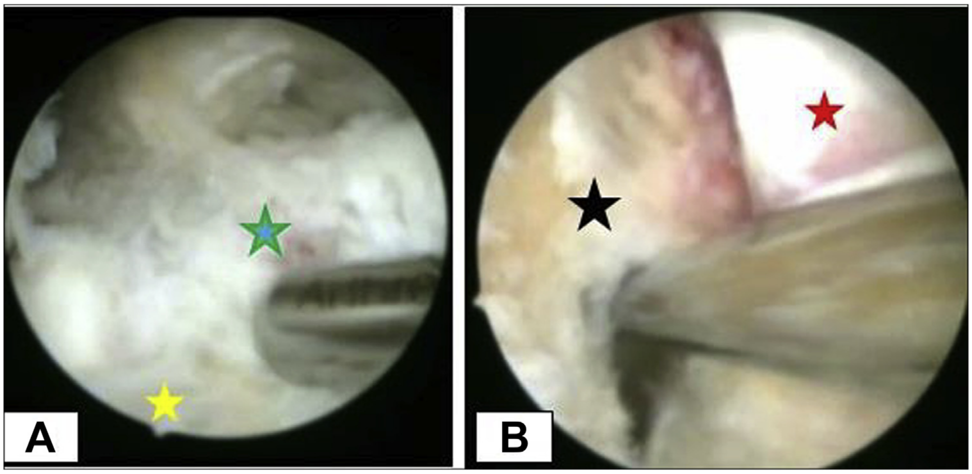


Fig 1. Arthroscopic views of the right knee through the lateral portal with 90° of knee flexion show the anterior cruciate ligament footprints. (A) Tibial footprint (green star) and anterior horn of lateral meniscus (yellow star). (B) Femoral footprint (black star) and posterior cruciate ligament (red star).

drilled while the knee is hyperflexed (120°) and then withdrawn from outside until its distal end reaches the intercondylar notch.

The wire is subsequently advanced in an antegrade manner while the knee is flexed 90° until it reaches the tibial footprint. The angle of knee flexion may be slightly increased or decreased around 90° with or without slight internal rotation to capture the anatomic tibial footprint. When the K-wire exits the distal tibial cortex, retrograde reaming using the appropriately sized reamer is started, and the procedure is completed as a TT single-bundle ACL reconstruction (Figs 1-6, Video 1).

Technique

Graft Preparation

A tourniquet is applied on the limb. After draping, an oblique skin incision at the upper tibia is used to harvest the graft. The incision is made midway between the tibial tubercle and the posteromedial border of the tibia. The incision extends from the anteroinferior to posterosuperior part of the upper tibia. The semitendinosus and gracilis tendons are harvested and prepared to be used as the ACL graft.

Portal Creation

Standard AM and AL portals are created. A medial parapatellar (paramedian) portal is made just medial to the patellar tendon and slightly inferior and lateral to the standard AM portal. The medial parapatellar portal is used during femoral tunnel drilling and helps bring the wire and hence the graft into a more lateral position on the medial aspect of the lateral femoral condyle. Moreover, this helps bring the distal end of the K-wire not to pass far medially during tibial tunnel drilling and so better capability of capturing the anatomic tibial footprint.

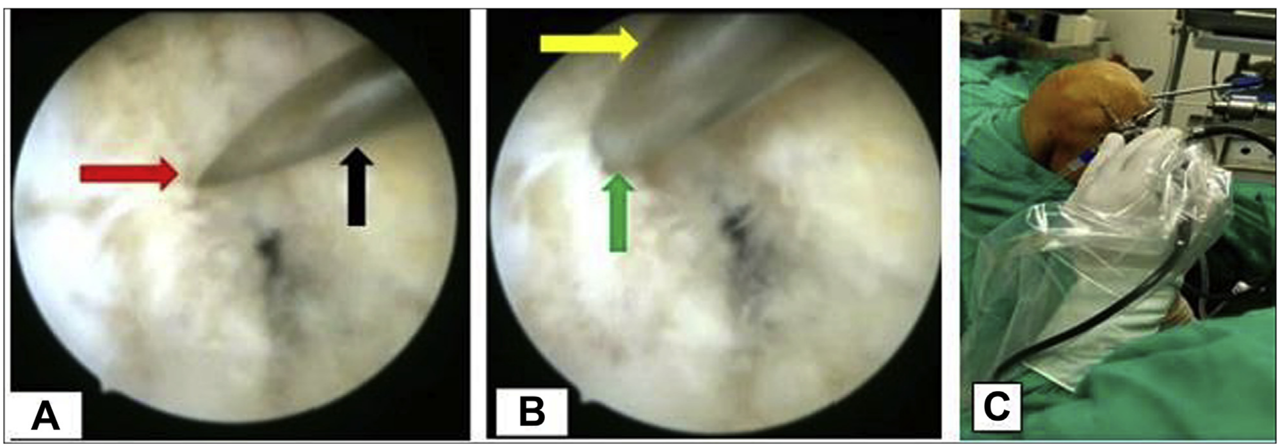


Fig 2. (A, B) Arthroscopic views of right knee through lateral portal with 90° of knee flexion. The 2.5-mm K-wire (black arrow) is drilled into the center of the femoral footprint (red arrow) through the anteromedial portal. The K-wire (yellow arrow) is drilled into the center of the femoral footprint (green arrow) through the paramedian portal. (C) An intraoperative photograph of the right knee with 120° of knee flexion shows drilling of the femoral footprint site using the K-wire shown in A and B.

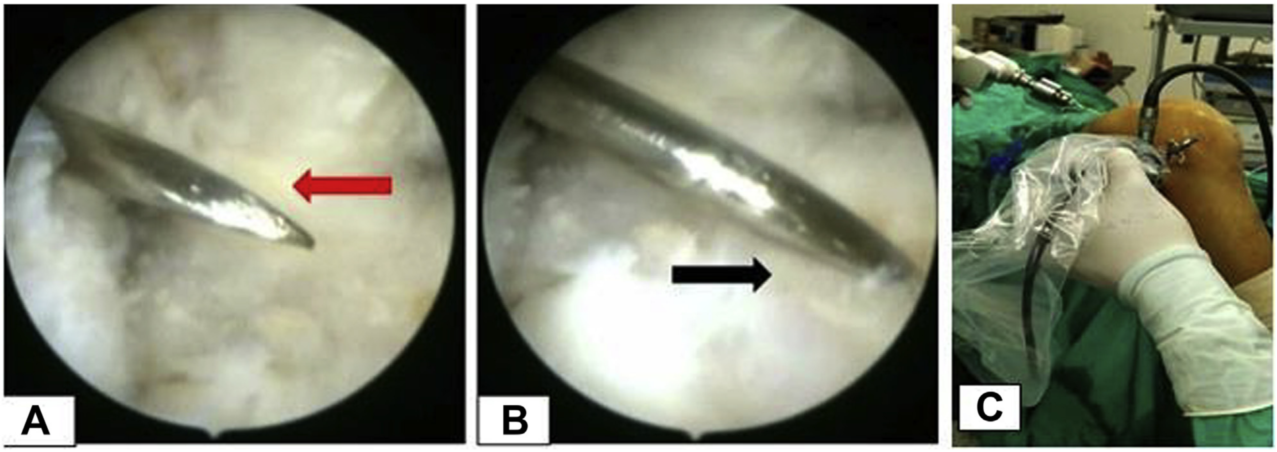


Fig 3. (A, B) Arthroscopic views of right knee through lateral portal. With the knee flexed 120°, the K-wire is withdrawn from the knee until its distal tip appears in the intercondylar notch (red arrow). With the knee flexed 90°, the wire is advanced in an antegrade manner to reach the center of the tibial footprint (black arrow). (C) An intraoperative photograph of the right knee with 90° of knee flexion shows antegrade drilling using the K-wire as seen in the intercondylar notch in A and then at the tibial aperture site in B.

Tunnel Drilling

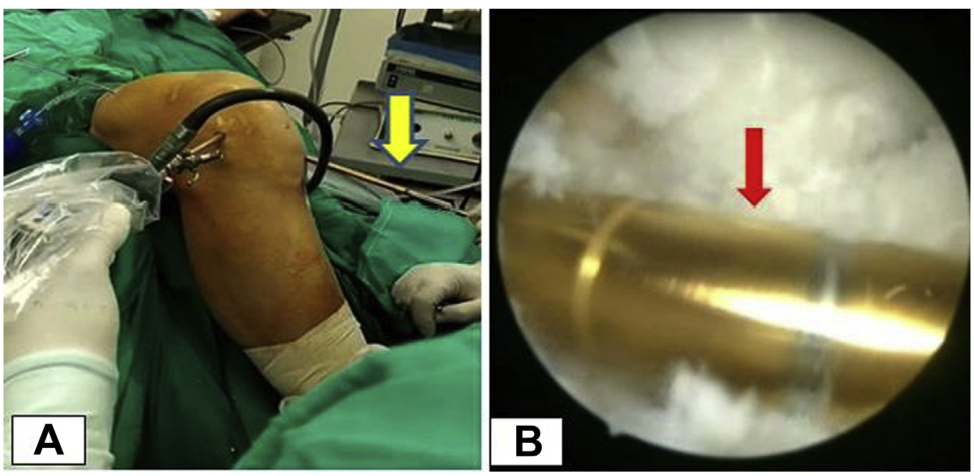
First, preparation of the ACL footprints (Fig 1) is performed. The entry point of the femoral tunnel is determined on the lateral intercondylar and bifurcate osseous landmarks on the posterior aspect of the medial wall of the lateral femoral condyle. It is located between the anatomic insertion of the AM and PL bundles or on the resident's ridge close to the insertion of the AM bundle.

With the knee flexed 120° and through the standard AM portal, a 2.5-mm double-tipped K-wire is drilled through the entry point of the femoral tunnel to create a hole of 2 to 3 mm depth (Fig 2 A and C). Then, the K-wire is withdrawn, reintroduced through the medial parapatellar (paramedian) portal into the prepared hole, and drilled (Fig 2 B and C); the wire makes an angle about 30° to the sagittal plane and 20° to the horizontal plane.

The K-wire is advanced through the medial parapatellar portal in the prepared hole until it exits the skin at the PL aspect of the thigh. A 4.5-mm reamer (Arthrex, Naples, FL) is used over the K-wire to enlarge the femoral entry and so allows free motion and manipulation of the wire in the notch. The K-wire is withdrawn from its proximal end under arthroscopic vision until its distal end is just protruding from the entry point at the edge of the intercondylar notch (Fig 3 A and C). The knee is then flexed to 90°; the K-wire is advanced in an antegrade manner in the knee until it hits the suspected and marked tibial tunnel aperture site (Fig 3 B and C).

The distal end of the wire may not reach the intra-articular anatomic point of the tibial tunnel; it may pass medial to this point, or it may precede or exceed this point. If the K-wire passes medial to the anatomic point, slight internal rotation of the tibia helps capture

Fig 4. Transtibial reaming of right knee intraoperatively. (A) With 90° of knee flexion, transtibial reaming is performed using the appropriately sized reamer (yellow arrow). (B) An arthroscopic view of the right knee through the lateral portal with 90° of knee flexion shows intra-articular transtibial reaming using the appropriately sized reamer (red arrow).



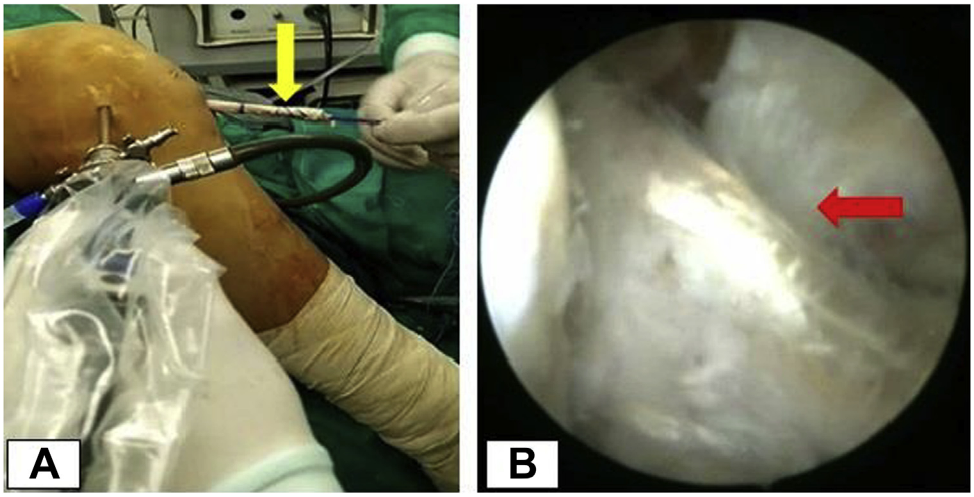


Fig 5. Transtibial graft passage in right knee intraoperatively. (A) With 90° of knee flexion, transtibial graft passage (yellow arrow) is performed. (B) An arthroscopic view through the lateral portal with 90° of knee flexion shows the graft (red arrow) after passage and fixation.

this point, and when the graft is fixed in this position, it gives the advantage of slight twisting of the graft externally with flexion, simulating the double-bundle reconstruction in graft tension. If the K-wire precedes and passes posterior to the anatomic point, slight flexion of the knee helps capture this point, and this provides the advantage of increasing the tibial tunnel length. If the K-wire exceeds and passes anterior to the anatomic point, slight extension of the knee helps capture this point but presents the disadvantage of

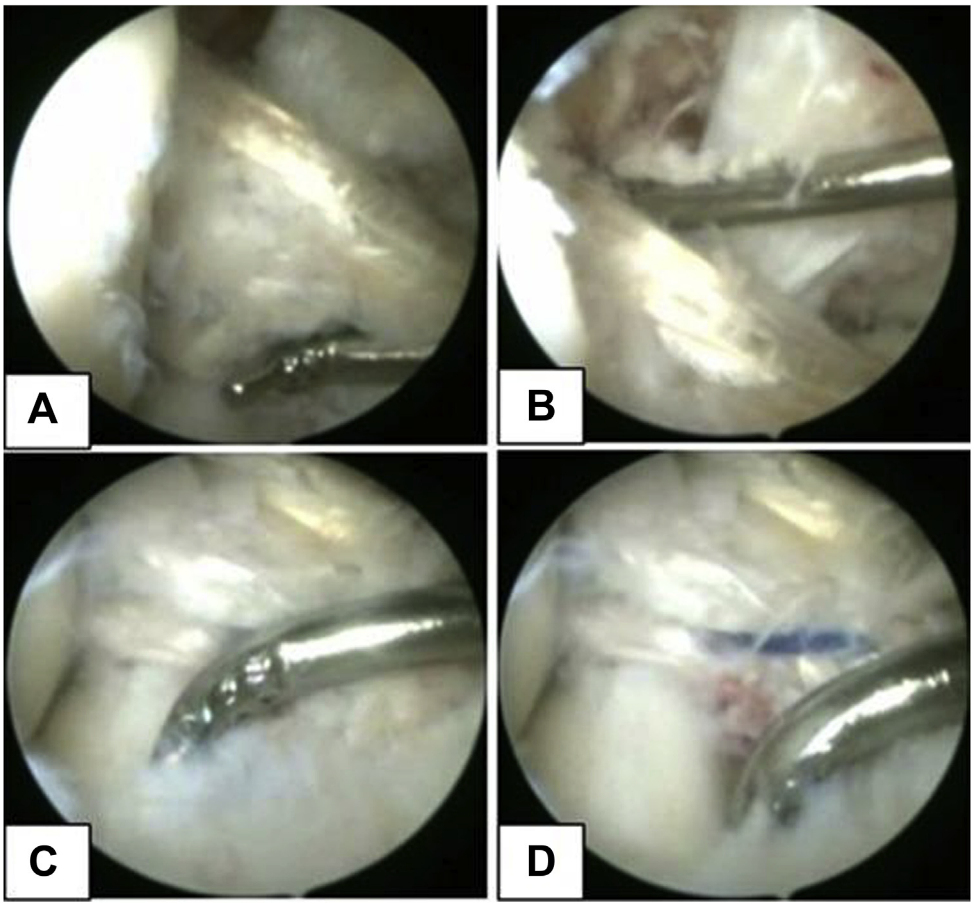


Fig 6. Arthroscopic views of the right knee through the lateral portal show assessment of the graft after anterior cruciate ligament reconstruction. (A) Assessment of graft tension. (B) Graft relation to posterior cruciate ligament. (C, D) Graft relation to anterior horn of lateral meniscus.

Table 1. Advantages, Risks, Limitations, and Disadvantages of Technique

Technique
Both the anatomic tibial and femoral ACL footprints are captured.
Articular cartilage violation of the medial femoral condyle is avoided.
Femoral tunnel
The femoral tunnel has an anatomic position owing to independent drilling.
A sufficient length is achieved because drilling is performed in 120° of knee flexion.
The posterior wall of the lateral femoral condyle is preserved.
The femoral tunnel is in line with the tibial tunnel owing to transtibial reaming.
Steep slopes of the graft at the tunnel are avoided.
Graft attrition and tunnel expansion are avoided.
Graft
The graft is more lateral in the sagittal plane.
The graft is horizontally oriented in the coronal plane.
The graft is more anatomically positioned.
Reconstruction
Range of motion improves.
Rotatory stability is restored.
Graft mismatch is avoided.
Graft impingement is avoided.
Recurrent synovitis and effusion are avoided.
Method of fixation
At the femoral tunnel, different methods of graft fixation can be used. RigidFix (DePuy Mitek, Raynham, MA), TightRope (Arthrex), and interference screw fixation (Arthrex) can be used.
On the tibial side, interference screw fixation can be used.
Risks, limitations, and disadvantages
Skeletal immaturity is a limitation to this technique because of possible injury to the physis.
The technique requires a surgeon with expertise in ACL reconstruction.
A short or medial tibial tunnel may occur and can be avoided by changing the knee flexion angle.
If the tibial tunnel is short, weak graft fixation may result at the tibial tunnel.
If the tibial tunnel is medial and anterior, breakage of the anterior wall of the tibial tunnel may occur.
During antegrade drilling, the tibial tunnel aperture site may be difficult to capture, in which case the procedure can be completed as an anteromedial portal technique.

ACL, anterior cruciate ligament.

decreasing the tibial tunnel length. Thus, when needed, moving the knee around its longitudinal and/or horizontal axis helps the distal end of the K-wire to reach the intra-articular anatomic point of the tibial tunnel. With the knee flexed to 90°, the K-wire is advanced to the intra-articular anatomic point of the tibial tunnel (Fig 3B) and drilled to exit the tibial cortex and the skin to the exterior at the AM aspect of the leg, passing through the oblique skin incision used for graft harvest.

TT Tunnel Reaming

With the knee in the aforementioned fixed position, TT tunnel reaming is started using the appropriately sized reamer (Arthrex) (Fig 4) according to the graft diameter. The length of the tibial tunnel is measured. A femoral tunnel of 25 or 30 mm in length is reamed over the K-wire.

K-Wire Exchange

After creation of the tibial and femoral tunnels and with the reamer still in the femoral tunnel, the K-wire is exchanged with a 2.7-mm ACL guide pin (Arthrex). The reamer is withdrawn, leaving the guide pin in place to be used for graft passage.

TT Graft Passage and Fixation

The graft is passed first through the tibial tunnel and then through the femoral tunnel and is subsequently fixed (Fig 5). Arthroscopic views through the lateral portal are used to assess the graft position (Fig 6).

The advantages, risks, limitations, and disadvantages of the technique are shown in Table 1; surgical steps, pearls, and pitfalls are shown in Table 2. Video 1 describes the technique.

Discussion

Anatomic Tunnel Placement

Anatomic tunnel placement is required for anatomic single-bundle ACL reconstruction. It results in better knee kinematics[1-3] and significantly superior clinical results compared with those of nonanatomic tunnels.[4,5,18] The tibial footprint of the ACL is oval in the transverse plane. Its length is 18.5 mm, and its width is 10.3 mm. The distance from the posterior cruciate ligament (PCL) notch to the posterior fibers of the ACL is 5.7 mm. The closest point from the medial aspect of the ACL insertion to the medial tibial articular cartilage is 1.9 mm.[13] The center of the tibial footprint is 15 mm anterior to the PCL notch,[13] 2 to 3 mm AM to the posterior margin of the anterior horn of the lateral meniscus, and 5 mm lateral to the medial tibial spine.[19] The femoral footprint of the ACL is oval in the sagittal plane. Its length is 18.4 mm, and its width is 9.5 mm. The footprint is rotated 28.8° to the shaft of the femur and has a posterior boundary that parallels the articular cartilage of the femoral condyle, and anteriorly, there is some variability in its contour.[13]

The center of the femoral footprint is present along the osseous landmarks on the lateral intercondylar and bifurcate ridges on the posterior aspect of the medial wall of the lateral femoral condyle. It is located between the anatomic insertion of the AM and PL bundles or on the resident's ridge close to the insertion of the AM bundle.[20-22]

The anatomic femoral tunnel aperture is located at 28.5% of the posterior border condyle along the Blumensaat line (t value is the value on transverse axis) in the proximal-to-distal (deep-to-shallow) direction and 35.2% of the inferior border of condyle perpendicular to the Blumensaat line (h value is the value horizontal

Table 2. Surgical Steps, Pearls, and Pitfalls

Surgical Steps	Pearls	Pitfalls
Skin incision for graft harvest	An oblique skin incision is used for graft harvest. This avoids injury to the infrapatellar branch of the saphenous nerve.	If a vertical incision is used, it may injure the infrapatellar branch of the saphenous nerve.
	An oblique skin incision provides an area for the K-wire to exit if it is passed medially with antegrade drilling.	If a vertical incision is used and the K-wire is passed medially, a second incision may be needed for the exit of the K-wire.
AM portal	The AM portal is used for marking the femoral tunnel. Its uses allows the wash of debris with reaming. Its use allows assessment of the tunnel position. This portal is used for passage of the interference screw (Arthrex) used for graft fixation at the femoral tunnel.	If the medial parapatellar portal is used for marking of the femoral tunnel, the wire may slip on the medial surface of the lateral femoral condyle.
Medial parapatellar portal	The medial parapatellar portal is close to the patellar tendon. It is more central than the standard AM portal. Its use allows lateralization of the femoral tunnel. This portal is used for retrograde K-wire drilling of the femoral tunnel.	If the standard AM portal is used for retrograde K-wire drilling, the distal end of the drilled wire will be directed more medially and so the K-wire will pass far medially during its antegrade passage to capture the site of the tibial tunnel aperture.
K-wire	A double-tipped K-wire is used to engage both aperture sites—first the femoral and then the tibial tunnel aperture site—with easier drilling through the femur and the tibia.	A single-tipped K-wire can engage the femoral and then the tibial aperture sites with easy drilling through the femur but with difficult drilling through the tibia.
	A K-wire of 2.5 mm in diameter is used to create an appropriately sized hole similar to drilling by a 2.7-mm ACL guide pin (Arthrex).	The use of a smaller diameter may lead to difficult K-wire exchange.
	Passage is performed by a freehand technique, which is more feasible.	The use of a guide restricts the wire passage.
Femoral tunnel drilling	The femoral tunnel is marked first by a K-wire passed through the standard AM portal; it is then made by the K-wire drilled through the medial parapatellar portal.	If marking is performed through the medial parapatellar portal, the K-wire may slip to a nonanatomic site on the medial surface of the lateral femoral condyle.
	The tunnel is made by retrograde drilling of the K-wire with the knee flexed 120°.	If the K-wire passes with the knee flexed 90°, the posterior wall may be fractured during reaming.
	The wire is withdrawn from outside until its distal end appears in the notch.	If not withdrawn, the wire may be bent while changing the angle of knee flexion.
Tibial tunnel drilling	The aperture is captured by antegrade passage of the K-wire with the knee flexed 90°. Slightly more flexion or extension around 90° with or without slight internal rotation may be needed. After the K-wire passes through the tibial aperture site and exits the tibial cortex to exterior, the knee is maintained in this position during TT reaming.	If the surgeon does not maintain the knee position obtained after K-wire passage, the wire may be bent or broken during TT reaming.
Tunnel reaming	Reaming starts with the tibial tunnel, followed by the femoral tunnel (TT). The surgeon should start with a small-diameter reamer to free throttled wire i.e., reaming allows some motion of k. wire in its hole. An appropriately sized reamer is then used. If incarceration occurs during reaming, the surgeon should stop reaming and assess the wire for an acute bend.	If incarceration occurs during reaming and the reaming is not stopped, the reaming may produce metallic debris and the K-wire may even be broken.
K-wire exchange	The 2.5-mm K-wire inside the reamer is exchanged with a 2.7-mm ACL guide pin.	If not exchanged, the surgeon cannot pass the passing sutures and the graft.
	The surgeon then withdraws the reamer and suspends the graft by passing sutures in the eyelets of the ACL guidewire.	If the reamer is withdrawn before the exchange, the surgeon will add more step to the procedure and hence more time consuming and the exchange will be difficult.
	The tibial cortex exit is cleaned of any soft tissue.	If not cleaned, the graft passage may be difficult or obstructed.
Tunnel assessment	Through the AM portal, the site of the femoral tunnel is assessed. Through an intra-tunnel arthroscopic view, the tunnel length and the walls of the tunnels are assessed.	

Table 2. *(Continued)*

Surgical Steps	Pearls	Pitfalls
Graft passage and fixation	The graft is passed through the tibial tunnel, intra-articularly, and then to the femoral tunnel. Fixation occurs with the knee flexed 30° with slight internal rotation. The surgeon can use any method of fixation at the femoral tunnel in this technique, with some added steps appropriate for every method of fixation.	

ACL, anterior cruciate ligament; AM, anteromedial; TT, transtibial.

axis) in the anterior-to-posterior (high-to-low) direction.[22] The anatomic tibial tunnel aperture is located 43% to 46% and 44% to 48% from the anterior border and medial border of the tibia, respectively.[23-25]

A nonanatomic tunnel aperture may lead to decreased range of motion of the knee, rotatory instability of the knee, and recurrent synovitis and effusion caused by ACL graft impingement, graft laxity, or vertical graft orientation.[24,26-29] Graft impingement may end in graft failure.[30]

The anatomic femoral tunnel is oblique and lateral and is placed toward the medial wall of the lateral condyle,[18] occupying half of the AM bundle insertion and half of the PL bundle insertion.[31] Lateral placement of the femoral tunnel restores rotatory stability of the knee.[32,33] The angle of the femoral tunnel in the coronal plane and the tunnel obliquity differ according to the technique used[18,15,34,35] (Table 3). For more anatomic ACL reconstruction, the graft should be horizontally oriented in the coronal plane. This decreases the tension across the graft, decreases PCL impingement, and increases motion of the knee.[36,37]

Techniques of Single-Bundle ACL Reconstruction

Different techniques are used for single-bundle ACL reconstruction. The TT technique has a high rate of nonanatomic placement.[6,7] The AM portal technique and OI technique yield better restoration of the anatomic femoral footprint.[8-11] Modified TT techniques are evolving.[17,19]

Gadikota et al.[9] (2012) and Robert et al.[8] (2013) showed better restoration of the anatomic femoral footprint with AM drilling and the OI technique. Matassi et al.[12] (2015) found that with the OI technique, the femoral tunnel aperture location (t value of 31.1% and h value of 30.2%) was in a more anatomic position than with the TT technique (t value of 39.4% and h value of 10.5%).

The AM portal technique is a recently developed procedure that allows the femoral tunnel to be prepared unconstrained.[38,39] Independent drilling of the femoral tunnel through a medial arthroscopic portal with the knee placed in hyperflexion[40] allows for accurate positioning of the femoral socket in the center of the native footprint. Many studies have reported favorable femoral tunnel obliquity using this technique.[41] However, it may cause injury to the medial femoral condyle. The technique is not protective against poor tunnel positioning.[40] It may lead to posterior wall damage to the lateral condyle, as well as a short femoral tunnel and relatively weak graft fixation, and hence late tunnel expansion and graft failure.[32]

The OI technique can produce a longer and more anatomic femoral tunnel. However, the steep slopes of the tunnel and graft result in complications such as graft attrition and damage, as well as tunnel expansion. Furthermore, the additional lateral skin incision required in the OI technique makes it esthetically unpleasing.[42]

Traditional TT single-bundle ACL reconstruction respects the native ACL anatomy but cannot restore it.[41] With the TT technique, the femoral tunnel aperture was reported to be located in a nonanatomic position in relation to the native femoral footprint[12,17,18,35,43-45] (Fig 7, Table 4).

A femoral tunnel position distant from the anatomic footprint results in a higher rate of ACL reconstruction failure.[12] A femoral tunnel aperture away from the footprint center, even down to 2 to 3 mm, with the TT

Table 3. Angle of Femoral Tunnel in Coronal Plane

	Angle of Femoral Tunnel in Coronal Plane, °		
Authors	TT Technique	AM Portal Technique	Modified TT Technique
Dargel et al.,[18] 2009	58.8 ± 8.3	50.9 ± 8.3	
Bedi et al.,[15] 2010	54.1 ± 7.17	45.9 ± 6.9	
Chang et al.,[34] 2011	61.7 ± 5.5	55.9 ± 4.7	
Lee et al.,[35] 2013			50.43 ± 7.04

NOTE. Data are presented mean ± standard deviation.
AM, anteromedial; TT, transtibial.

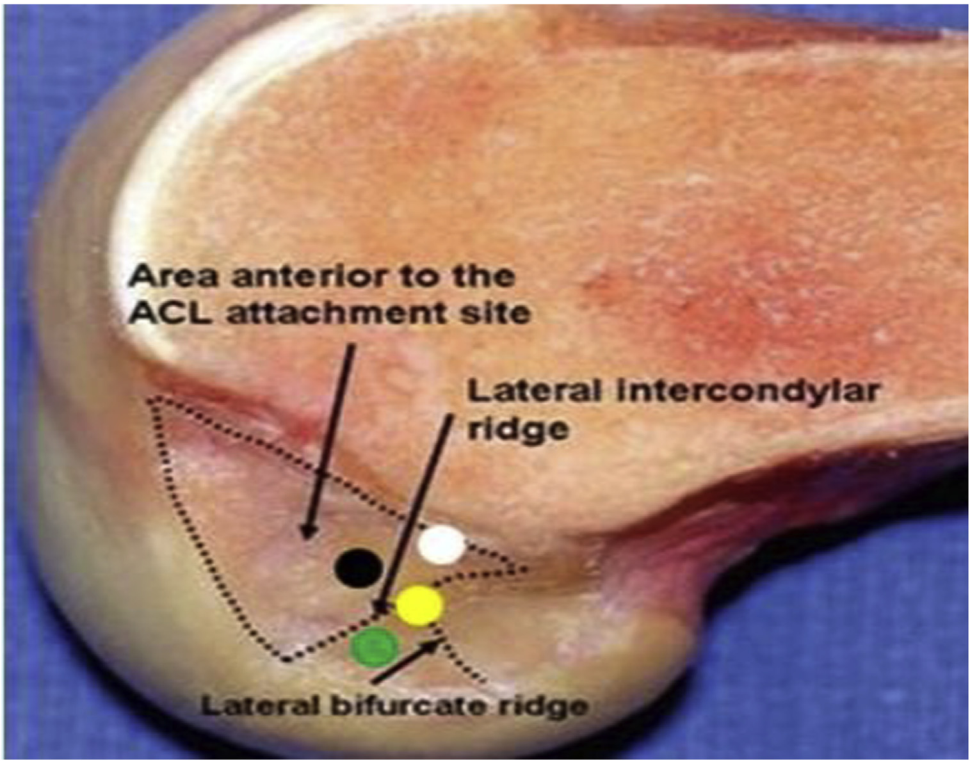


Fig 7. Sagittal cut of right side of distal femur just lateral to center of intercondylar notch showing anterior cruciate ligament (ACL) attachment osseous landmarks at medial surface of lateral femoral condyle. The anatomic femoral tunnel aperture site (yellow circle) is illustrated. The femoral tunnel aperture site may be shallow and high, that is, distal and anterior (black circle)[12,18]; it may be shallow and low, that is, distal and posterior (green circle)[17,35]; or it may be deep and high, that is, proximal and anterior (white circle).[43-45]

technique is sufficient to result in significantly inferior clinical and biomechanical outcomes compared with the AM portal technique.[42]

The nonanatomic tunnel placement with the TT technique affects the graft position and orientation. Brophy et al.[46] (2008) and Pearle et al.[47] (2008) reported that the TT technique predisposes to a mismatch in graft position from the PL tibial footprint to the AM femoral footprint. Other authors reported that the technique results in a vertical graft orientation[32,36,48] and PCL impingement, resulting in persistent rotational instability[19] and high ACL graft tension with knee flexion.[36,37,49]

Modified TT techniques have been described in an effort to improve femoral tunnel obliquity and to restore the native femoral ACL footprint.[36,50] Technical modifications improve the tunnel aperture position to a more optimal anatomic position and not to the exact center of the native footprint. If an anatomic aperture is achieved on the femoral side, this will occur at the expense of the tibial side and vice versa.

Giron et al.[14] (2007) reported on the technical impossibility of restoring both the anatomic tibial and femoral origins of the ACL using the TT technique despite any modifications. Heming et al.[13] (2007), in a cadaveric study, showed that it is possible to achieve anatomic tunnel placement with the TT technique when the starting point of the tibial tunnel is proximal and medial and is located close to the joint line, which may result in a short tibial tunnel and weaken the anterior tibial cortex of the tunnel.

Using postoperative magnetic resonance imaging for single-incision ACL reconstruction through the TT technique, Ahn et al.[51] (2007) showed that the more horizontal the angle of the tibial tunnel, the closer the reconstruction will be to the native ACL. Gougoulias et al.[52] (2008), in a retrospective radiographic study of postoperative TT ACL reconstruction, determined that when the tibial tunnels were positioned posteriorly along the tibial plateau, the femoral tunnels were positioned anatomically in reference to measurements along the Blumensaat line. However, a tibial tunnel aperture that is too posterior causes vertical graft orientation,[27] PCL impingement, and loss of full flexion of the knee.[24]

Bedi et al.[43] (2011) reported the inability to capture the center of the femoral ACL footprint using a TT technique in which the tibial tunnel was anatomically restricted to capture the center of the tibial ACL footprint. They reported that a TT guidewire positioned eccentrically posterior and lateral in the tibial tunnel achieved a position near the femoral ACL footprint. Despite maximal PL eccentric positioning of the guidewire in the tibial tunnel, the wire was always proximal and anterior to the center of the femoral footprint and directed more toward the AM bundle insertion. Moreover, the eccentric position of the guidewire and re-reaming of the tibial tunnel result in

Table 4. Femoral Tunnel Aperture With TT Technique

	Femoral Tunnel Aperture With TT Technique
Matassi et al.,[12] 2015	Shallow and high
Dargel et al.,[18] 2009	Shallow and high
Lee et al.,[35] 2013	Shallow and low
Lee and Kim,[17] 2017	Shallow and low
Bedi et al.,[43] 2011	Deep and high
Abebe et al.,[44] 2009	Deep and high
Kaseta et al.,[45] 2008	Deep and high

TT, transtibial.

iatrogenic injury to the tibial metaphyseal bone with significant secondary tunnel expansion. The tibial aperture was 38% greater in the anteroposterior dimension with TT versus AM portal ACL reconstruction.[43]

El-Kady et al.[19] (2014) described a modified anatomic TT single-bundle ACL reconstruction technique with the aid of an arthroscopic manipulator and/or a pusher to direct the guidewire to reach the anatomic femoral footprint of the ACL using TT tunnel drilling without a major change in the traditional technique. The technique is comfortable for surgeons familiar with the traditional TT technique. It is quite anatomic with no violation of the articular cartilage of the medial femoral condyle, and it may produce a longer femoral tunnel. However, this technique requires special instruments, and the guidewire may be enforced to capture the anatomic point, leading to acute bending of the wire at the femoral entry point.[19]

Lee and Kim[17] (2017) presented a modified TT technique and anticipated that it would provide more anatomic placement of the femoral tunnel during ACL reconstruction than the previous traditional TT techniques. However, possible pitfalls were PL tibial tunnel widening, difficulty in approaching the premade femoral center via the tibial tunnel, and bending of the TT guide pin at the tibial tunnel aperture after engaging it in the femoral anatomic center. Zhao[53] (2020) found that anatomic TT ACL reconstruction can be performed easily and accurately by creating a tibial tunnel with 50° of angulation to the tibial axis and 40° of angulation to the sagittal plane, but breakage of the anterior wall of the tibial tunnel may occur owing to a shallow tibial tunnel.

With the described technique (the freehand technique), the anatomic femoral tunnel aperture site can be reached easily and the anatomic tibial tunnel aperture site can be captured by changing the angle of knee flexion. Anatomic TT single-bundle ACL reconstruction can be performed using the freehand technique. Skeletal immaturity is a limitation to this technique owing to possible injury to the physis. The technique requires a surgeon with expertise in ACL reconstruction. A short or medial tibial tunnel may occur and can be avoided by changing the knee flexion angle. During antegrade drilling, the tibial tunnel aperture site may be difficult to capture, in which case the procedure can be completed as an AM portal technique.

References

1. Sim JA, Gadikota HR, Li JS, Li G, Gill TJ. Biomechanical evaluation of knee joint laxities and graft forces after anterior cruciate ligament reconstruction by anteromedial portal, outside-in, and transtibial techniques. *Am J Sports Med* 2011;39:2604-2610.
2. Musahl V, Plakseychuk A, VanScyoc A, et al. Varying femoral tunnels between the anatomical footprint and isometric positions: Effect on kinematics of the anterior cruciate ligament-reconstructed knee. *Am J Sports Med* 2005;33:712-718.
3. Piefer JW, Pflugner TR, Hwang MD, Lubowitz JH. Anterior cruciate ligament femoral footprint anatomy: Systematic review of the 21st century literature. *Arthroscopy* 2012;28:872-881.
4. Sadoghi P, Kröpfl A, Jansson V, Müller PE, Pietschmann MF, Fischmeister MF. Impact of tibial and femoral tunnel position on clinical results after anterior cruciate ligament reconstruction. *Arthroscopy* 2011;27: 355-364.
5. Hussein M, van Eck CF, Cretnik A, Dinevski D, Fu FH. Prospective randomized clinical evaluation of conventional single-bundle, anatomic single-bundle, and anatomic double-bundle anterior cruciate ligament reconstruction: 281 Cases with 3- to 5-year follow-up. *Am J Sports Med* 2012;40:512-520.
6. Strauss EJ, Barker JU, McGill K, Cole BJ, Bach BR Jr, Verma NN. Can anatomic femoral tunnel placement be achieved using a transtibial technique for hamstring anterior cruciate ligament reconstruction? *Am J Sports Med* 2011;39:1263-1269.
7. Piasecki DP, Bach BR Jr, Espinoza Orias AA, Verma NN. Anterior cruciate ligament reconstruction: Can anatomic femoral placement be achieved with a transtibial technique? *Am J Sports Med* 2011;39:1306-1315.
8. Robert HE, Bouguennec N, Vogeli D, Berton E, Bowen M. Coverage of the anterior cruciate ligament femoral footprint using 3 different approaches in single-bundle reconstruction: A cadaveric study analyzed by 3-dimensional computed tomography. *Am J Sports Med* 2013;41:2375-2383.
9. Gadikota HR, Sim JA, Hosseini A, Gill TJ, Li G. The relationship between femoral tunnels created by the transtibial, anteromedial portal, and outside-in techniques and the anterior cruciate ligament footprint. *Am J Sports Med* 2012;40:882-888.
10. Shin YS, Ro KH, Lee JH, Lee DH. Location of the femoral tunnel aperture in single-bundle anterior cruciate ligament reconstruction: Comparison of the transtibial, anteromedial portal, and outside-in techniques. *Am J Sports Med* 2013;41:2533-2539.
11. Riboh JC, Hasselblad V, Godin JA, Mather RC III. Transtibial versus independent drilling techniques for anterior cruciate ligament reconstruction: A systematic review

meta-analysis, and meta-regression. *Am J Sports Med* 2013;41:2693-2702.
12. Matassi F, Sirleo L, Carulli C, Innocenti M. Anatomical anterior cruciate ligament reconstruction: Transtibial versus outside-in technique: SIGASCOT Best Paper Award Finalist 2014. *Joints* 2015;3:6-14.
13. Heming JF, Rand J, Steiner ME. Anatomical limitations of transtibial drilling in anterior cruciate ligament reconstruction. *Am J Sports Med* 2007;35:1708-1715.
14. Giron F, Cuomo P, Edwards A, Bull AM, Amis AA, Aglietti P. Double-bundle "anatomic" anterior cruciate ligament reconstruction A cadaveric study of tunnel positioning with a transtibial technique. *Arthroscopy* 2007;23:7-13.
15. Bedi A, Raphael B, Maderazo A, Pavlov H, Williams RJ III. Transtibial versus anteromedial portal drilling for anterior cruciate ligament reconstruction: A cadaveric study of femoral tunnel length and obliquity. *Arthroscopy* 2010;26: 342-350.
16. Garofalo R, Mouhsine E, Chambat P, Siegrist O. Anatomic anterior cruciate ligament reconstruction: The two-incision technique. *Knee Surg Sports Traumatol Arthrosc* 2006;14:510-516.
17. Lee DW, Kim JG. Anatomic single-bundle anterior cruciate ligament reconstruction using the modified transtibial technique. *Arthrosc Tech* 2017;6:e227-e232.
18. Dargel J, Schmidt-Wiethoff R, Fischer S, Mader K, Koebke J, Schneider T. Femoral bone tunnel placement using the transtibial tunnel or the anteromedial portal in ACL reconstruction: A radiographic evaluation. *Knee Surg Sports Traumatol Arthrosc* 2009;17:220-227.
19. El-Kady H, Abdel-Hamid M, Abdelhalim M. Anatomic transtibial single-bundle anterior cruciate ligament reconstruction: A new surgical technique. *Egypt Orthop J* 2014;49:254-258.
20. Bedi A, Altchek DW. The "footprint" anterior cruciate ligament technique: An anatomic approach to anterior cruciate ligament reconstruction. *Arthroscopy* 2009;25: 1128-1138.
21. Ziegler CG, Pietrini SD, Westerhaus BD, et al. Arthroscopically pertinent landmarks for tunnel positioning in single-bundle and double-bundle anterior cruciate ligament reconstructions. *Am J Sports Med* 2011;39:743-752.
22. Yagi M, Wong EK, Kanamori A, Debski RE, Fu FH, Woo SL. Biomechanical analysis of an anatomic anterior cruciate ligament reconstruction. *Am J Sports Med* 2002;30: 660-666.
23. Amis AA, Jakob RP. Anterior cruciate ligament graft positioning, tensioning and twisting. *Knee Surg Sports Traumatol Arthrosc* 1998;6:S2-S12 (suppl 1).
24. Pinczewski LA, Salmon LJ, Jackson WF, von Bormann RB, Haslam PG, Tashiro S. Radiological landmarks for placement of the tunnels in single bundle reconstruction of the anterior cruciate ligament. *J Bone Joint Surg Br* 2008;90:172-179.
25. Topliss C, Webb J. An audit of tunnel position in anterior cruciate ligament reconstruction. *Knee* 2001;8:59-63.
26. Howell SM, Taylor MA. Failure of reconstruction of the anterior cruciate ligament due to impingement by the intercondylar roof. *J Bone Joint Surg Am* 1993;75:1044-1055.
27. Stevenson WW, Johnson DL. 'Vertical grafts': A common reason for functional failure after ACL reconstruction. *Orthopedics* 2007;30:206-209.
28. Shen W, Forsythe B, Ingham SM, Honkamp NJ, Fu FH. Application of the anatomic double-bundle reconstruction concept to revision and augmentation anterior cruciate ligament surgeries. *J Bone Joint Surg Am* 2008;90:20-34 (suppl 4).
29. Yamamoto H, Ishibashi T, Muneta T, Furuya K, Mizuta T. Effusions after anterior cruciate ligament reconstruction using the ligament augmentation device. *Arthroscopy* 1992;8:305-310.
30. Kim K-I, Yoo JH. Failed anterior cruciate ligament reconstruction by excessive medial placement of the tibial tunnel. *Curr Orthop Pract* 2010;21:534-537.
31. Rue JP, Ghodadra N, Bach BR Jr. Femoral tunnel placement in single-bundle anterior cruciate ligament reconstruction: A cadaveric study relating transtibial lateralized femoral tunnel position to the anteromedial and posterolateral bundle femoral origins of the anterior cruciate ligament. *Am J Sports Med* 2008;36:73-79.
32. Yamamoto Y, Hsu WH, Woo SL, Van Scyoc AH, Takakura Y, Debski RE. Knee stability and graft function after anterior cruciate ligament reconstruction: A comparison of a lateral and an anatomical femoral tunnel placement. *Am J Sports Med* 2004;32:1825-1832.
33. Scopp JM, Jasper LE, Belkoff SM, Moorman CT III. The effect of oblique femoral tunnel placement on rotational constraint of the knee reconstructed using patellar tendon autografts. *Arthroscopy* 2004;20:294-299.
34. Chang CB, Choi JY, Koh IJ, Lee KJ, Lee KH, Kim TK. Comparisons of femoral tunnel position and length in anterior cruciate ligament reconstruction: Modified transtibial versus anteromedial portal techniques. *Arthroscopy* 2011;27:1389-1394.
35. Lee SR, Jang HW, Lee DW, Nam SW, Ha JK, Kim JG. Evaluation of femoral tunnel positioning using 3-dimensional computed tomography and radiographs after single bundle anterior cruciate ligament reconstruction with modified transtibial technique. *Clin Orthop Surg* 2013;5:188-194.
36. Howell SM, Gittins ME, Gottlieb JE, Traina SM, Zoellner TM. The relationship between the angle of the tibial tunnel in the coronal plane and loss of flexion and anterior laxity after anterior cruciate ligament reconstruction. *Am J Sports Med* 2001;29:567-574.
37. Simmons R, Howell SM, Hull ML. Effect of the angle of the femoral and tibial tunnels in the coronal plane and incremental excision of the posterior cruciate ligament on tension of an anterior cruciate ligament graft: An in vitro study. *J Bone Joint Surg Am* 2003;85:1018-1029.
38. Lubowitz JH. Anteromedial portal technique for the anterior cruciate ligament femoral socket: Pitfalls and solutions. *Arthroscopy* 2009;25:95-101.
39. Lopez-Vidriero E, Hugh Johnson D. Evolving concepts in tunnel placement. *Sports Med Arthrosc* 2009;17:210-216.
40. Cha PS, Brucker PU, West RV, et al. Arthroscopic double bundle anterior cruciate ligament reconstruction: An anatomic approach. *Arthroscopy* 2005;21:1275.

41. Golish SR, Baumfeld JA, Schoderbek RJ, Miller MD. The effect of femoral tunnel starting position on tunnel length in anterior cruciate ligament reconstruction: A cadaveric study. *Arthroscopy* 2007;23:1187-1192.
42. Kim JG, Wang JH, Lim HC, Ahn JH. Femoral graft bending angle and femoral tunnel geometry of transportal and outside-in techniques in anterior cruciate ligament reconstruction: An in vivo 3-dimensional computed tomography analysis. *Arthroscopy* 2012;28:1682-1694.
43. Bedi A, Musahl V, Steuber V, et al. Transtibial versus anteromedial portal reaming in anterior cruciate ligament reconstruction: An anatomic and biomechanical evaluation of surgical technique. *Arthroscopy* 2011;27:380-390.
44. Abebe ES, Moorman CT III, Dziedzic TS, et al. Femoral tunnel placement during anterior cruciate ligament reconstruction: An in vivo imaging analysis comparing transtibial and 2-incision tibial tunnel-independent techniques. *Am J Sports Med* 2009;37:1904-1911.
45. Kaseta MK, DeFrate LE, Charnock BL, Sullivan RT, Garrett WE Jr. Reconstruction technique affects femoral tunnel placement in ACL reconstruction. *Clin Orthop Relat Res* 2008;466:1467-1474.
46. Brophy RH, Voos JE, Shannon FJ, et al. Changes in the length of virtual anterior cruciate ligament fibers during stability testing: A comparison of conventional single-bundle reconstruction and native anterior cruciate ligament. *Am J Sports Med* 2008;36:2196-2203.
47. Pearle AD, Shannon FJ, Granchi C, Wickiewicz TL, Warren RF. Comparison of 3-dimensional obliquity and anisometric characteristics of anterior cruciate ligament graft positions using surgical navigation. *Am J Sports Med* 2008;36:1534-1541.
48. Harner CD, Honkamp NJ, Ranawat AS. Anteromedial portal technique for creating the anterior cruciate ligament femoral tunnel. *Arthroscopy* 2008;24:113-115.
49. Prodromos CC, Fu FH, Howell SM, Johnson DH, Lawhorn K. Controversies in soft-tissue anterior cruciate ligament reconstruction: Grafts, bundles, tunnels, fixation, and harvest. *J Am Acad Orthop Surg* 2008;16:376-384.
50. Chhabra A, Diduch DR, Blessey PB, Miller MD. Recreating an acceptable angle of the tibial tunnel in the coronal plane in anterior cruciate ligament reconstruction using external landmarks. *Arthroscopy* 2004;20:328-330.
51. Ahn JH, Lee SH, Yoo JC, Ha HC. Measurement of the graft angles for the anterior cruciate ligament reconstruction with transtibial technique using postoperative magnetic resonance imaging in comparative study. *Knee Surg Sports Traumatol Arthrosc* 2007;15:1293-1300.
52. Gougoulias N, Khanna A, Griffiths D, Maffulli N. ACL reconstruction: Can the transtibial technique achieve optimal tunnel positioning? A radiographic study. *Knee* 2008;15:486-490.
53. Zhao J. Anatomical single-bundle transtibial anterior cruciate ligament reconstruction. *Arthrosc Tech* 2020;9:e1275-e1282.