

Arthroscopic Bone Graft Technique for Two-Stage Revision Anterior Cruciate Ligament Reconstruction



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Abstract: Revision anterior cruciate ligament reconstruction is an increasingly common procedure, with 2-stage surgery often required to address large bone defects and malpositioned tunnels. The arthroscopic bone grafting technique described herein uses morselized allograft bone to provide reproducible fill of asymmetrical bone defects without autograft harvest or additional loss of native bone. The second stage of the anterior cruciate ligament reconstruction can typically proceed 6 months following bone grafting.

Anterior cruciate ligament (ACL) tears and anterior cruciate ligament reconstructions (ACLRs) are increasing in frequency. There are now 200,000 ACL tears each year in the United States,¹ with between 120,000 and 150,000 reconstructions performed annually.² Retear risk after primary ACLR ranges between 5% and 25%, with multiple variables influencing risk of retear, including age, activity level, and graft choice.^{3,4} It is estimated that there are 13,000 revision ACLRs performed in the United States every year. The main causes of ACLR failure include trauma, technical errors, infection, and biological issues.⁵ Tunnel widening and malposition^{6,7} can present unique challenges for the surgeon (Fig 1). The objective of this

paper is to describe a reproducible bone grafting technique for the first stage of 2-stage revision ACLR.

Technique (With Video Illustration)

Patient Evaluation

A thorough history and physical examination should be performed on all patients. The patient's initial ACL graft, any history of infection, mechanism of injury, feelings of instability, and mechanical symptoms should be obtained. Each patient's age, activity level, and goals should be considered. Physical examination includes an assessment of gait, alignment, range of motion, and a focused knee examination. A complete knee ligament examination is important to identify any associated knee laxity (posterolateral corner in particular), hyperextension, and generalized ligamentous laxity. Previous imaging studies, operative reports, and intraoperative images (if available) should be reviewed. It is important to obtain accurate information on previous graft and hardware as well as other pathology addressed at the time of index procedure. Appropriate hardware removal instrumentation should be ordered as needed.

A complete knee radiograph series, including anteroposterior, lateral, patellofemoral, and Rosenberg views, as well as full-length alignment films should be obtained. Plain radiographs can provide details on previous hardware type, tunnel position, and widening or osteolysis.⁸ Full-length alignment films provide information on varus/valgus alignment of the knee. It is important to assess lateral radiographs for increased tibial slope, which has been implicated in ACL graft failure.⁹

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The authors report the following potential conflicts of interest or sources of funding: D.C.F. reports grants and other from Smith & Nephew, other from Depuy Mitek, grants and other from Zimmer Biomet, grants and other from Vericel, other from MTF, other from KCRN, other from Hyalex, grants and other from CartiHeal, grants and other from Anika Therapeutics, grants and other from Aesculap, and grants and other from Moximed, outside the submitted work. Full ICMJE author disclosure forms are available for this article online, as [supplementary material](#).

Received November 3, 2020; accepted May 24, 2022.

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2212-6287/201812

<https://doi.org/10.1016/j.eats.2022.05.014>

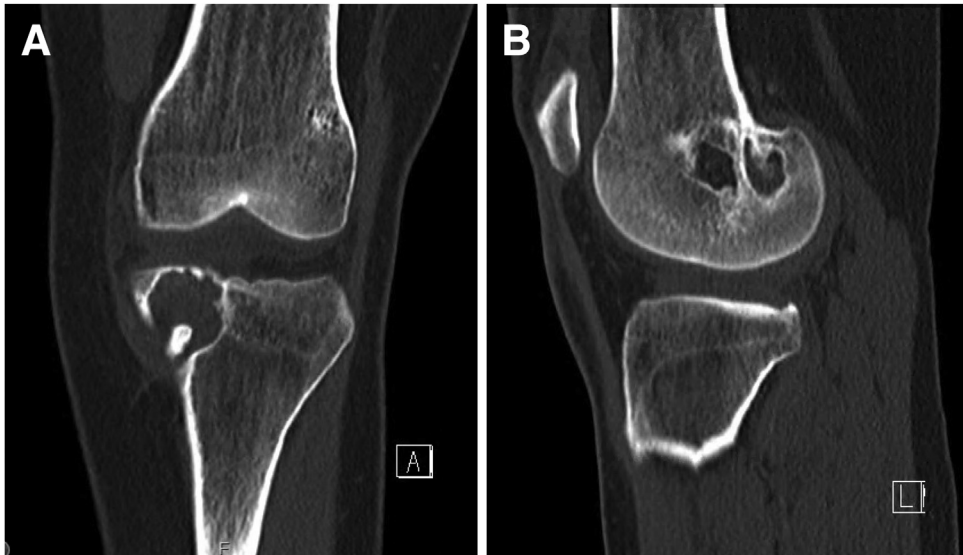


Fig 1. CT images of a patient who presented with a failed revision ACL reconstruction. Coronal CT image (A) of a left knee demonstrating significant tunnel osteolysis and bone loss of the tibia. Sagittal image (B) of a left knee demonstrating 2 previous femoral tunnels. This bone loss poses a challenge for revision ACL reconstruction and its recognition and quantification are important components of preoperative planning. (ACL, anterior cruciate ligament; CT, computed tomography.)

Advanced imaging is routinely ordered. Magnetic resonance imaging (MRI) is commonly used to evaluate the integrity of the previous ACL graft, collateral ligaments, posterolateral corner, posterior cruciate ligament, menisci, and articular cartilage.¹⁰ Tunnel position and widening can be assessed on MRI, and there is some evidence that MRI may demonstrate similar accuracy to computed tomography (CT) in this regard.^{11,12} However, the authors find CT (including 3-dimensional reconstructions) to be very useful for evaluation of tunnel position and consider it to be the gold standard for evaluation of tunnel widening and osteolysis.¹³

Indications for Two-Stage Reconstruction

Most ACL revisions are performed in a single stage, with only 8% to 9% of patients undergoing a 2-stage procedure.⁵ Indications to stage a revision ACLR include active infection, arthrofibrosis causing loss of $>5^\circ$ of extension or $>20^\circ$ of flexion, tunnel widening complicating graft placement or fixation, issues relating to tunnel convergence/placement, and bone loss.¹⁴⁻¹⁸ In our practice, we find tunnel malposition and tunnel enlargement to be the most common reasons for 2-stage revision.

Tunnel malposition has been identified as the most common technical error leading to ACL graft failure.⁶

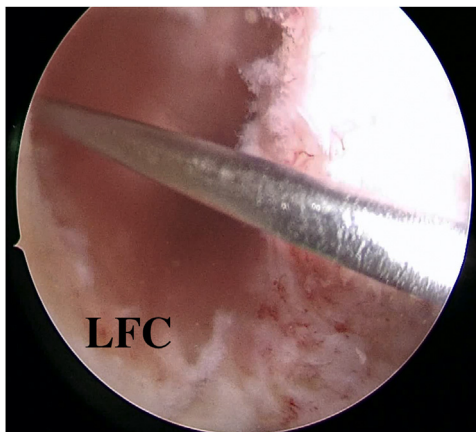


Fig 2. Arthroscopic image of a right knee viewed from an anterolateral portal showing the femoral tunnel in the lateral femoral condyle (LFC). Needle localization is used to identify the correct trajectory to create an accessory medial working portal to debride and bone graft the previous femoral tunnel arthroscopically.

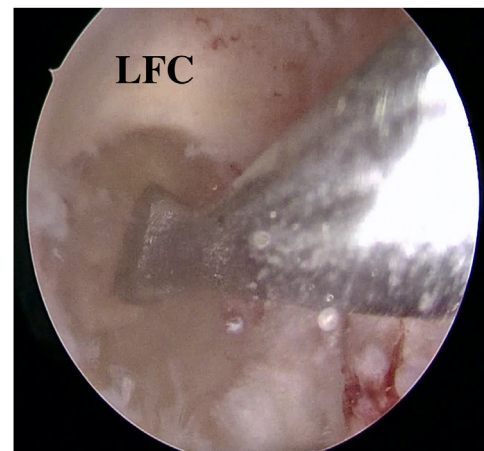


Fig 3. Arthroscopic image of a right knee from the anterolateral portal demonstrating curette debridement of previous femoral tunnel via the anteromedial portal to prepare a healthy bleeding cancellous bone bed in preparation for bone graft placement.



Fig 4. A modified 3-cc syringe used for arthroscopic delivery of bone graft to ACL tunnels. The syringe is modified by cutting off the tip/distal aspect of the barrel while retaining the plunger and seal. (ACL, anterior cruciate ligament.)

Extremely malpositioned tunnels (unless very enlarged) can often be ignored during a single-stage revision ACL surgery as the anatomical graft attachment point is undisturbed. Somewhat counterintuitively, it is the slightly malpositioned tunnel that often leads to a more difficult revision surgery, as a correctly placed tunnel may converge with a previous slightly malpositioned one.¹⁹ Femoral tunnels that are slightly distal and tibial tunnels that are slightly posterior provide particular challenges and must often be staged.

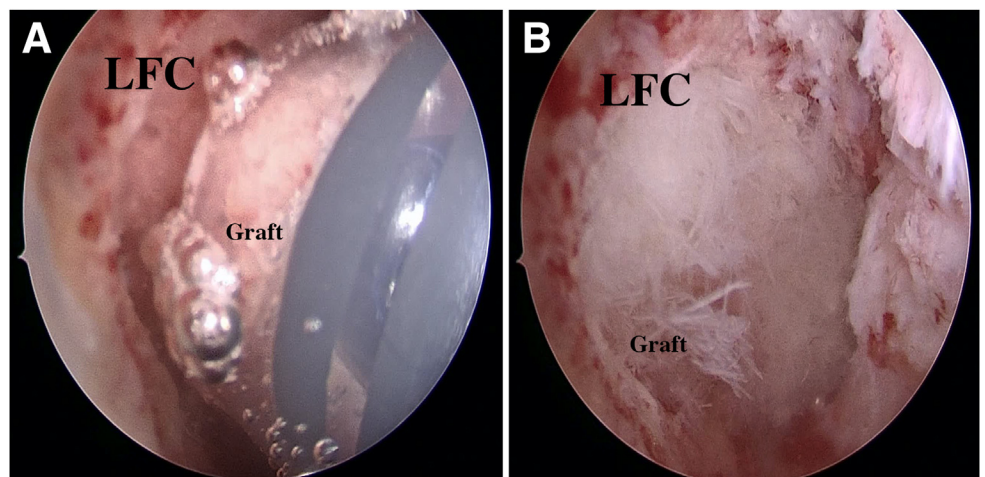
Tunnel widening can lead to the need for a staged reconstruction even if previous tunnels are in relatively good position. While there is not an established threshold for tunnel size that requires a staged approach in all cases, enlargement to the point that it leads to compromise of the positioning or fixation of the revision ACL graft does require a staged approach.¹⁶ Currently the etiology of tunnel widening is not completely understood and is likely multifactorial. Micromotion of the graft within the tunnel described by Segawa et al.²⁰ as the “windshield wiper effect” can lead to tunnel widening. Tunnel widening also may be related to graft choice and surgical technique during the

primary reconstruction. Soft-tissue grafts are associated with a greater risk of tunnel widening.²¹ Tunnel convergence during double-bundle reconstruction also has been associated with tunnel widening—particularly on the tibial side. Bacterial colonization also has been described as a cause of tunnel enlargement. Subclinical infection also may play a role in tunnel enlargement. A recent study by Flanigan et al.²² sampled ACL tunnels in patients with failed ACLRs and found a greater incidence of bacterial colonization in larger tunnels.

Associated Procedures

In the revision ACLR setting, consideration should be given to addressing any factor that may have led to graft failure. Several factors including posterolateral corner injury, meniscal root injury, ligamentous laxity, and limb malalignment can contribute to graft failure. An increased posterior tibial slope has been shown to increase stress on ACL grafts, which can lead to early failure.^{23,24} This population of patients may require a slope decreasing osteotomy to reduce risk of recurrent ACL failure.²⁴ Patients who present with varus alignment with symptomatic medial compartment degenerative change may also require osteotomy. There is evidence that in this patient population a corrective high tibial osteotomy can be clinically beneficial in patients with early degenerative change.^{25,26} While realignment osteotomy can be performed in conjunction with ACL revision in a single or staged fashion, staging the ACLR may be even more warranted.²⁷ Patients with failed ACLR can require meniscal transplant and/or cartilage-restoration procedures. Finally in the revision setting, consideration should be given to anterolateral ligament reconstruction/lateral extra-articular tenodesis, as there is some evidence that these procedures can decrease ACLR failure risk.^{28,29} These complex situations require detailed

Fig 5. Arthroscopic images of a right knee demonstrating bone grafting of the femoral tunnel through an accessory medial portal. A modified 3-cc syringe with tip removed and plunger in place containing graft material (A) is introduced into femoral tunnel via an accessory medial working portal and used to place bone graft within the femoral tunnel defect. Image of the femoral tunnel (B) following completion of bone grafting.



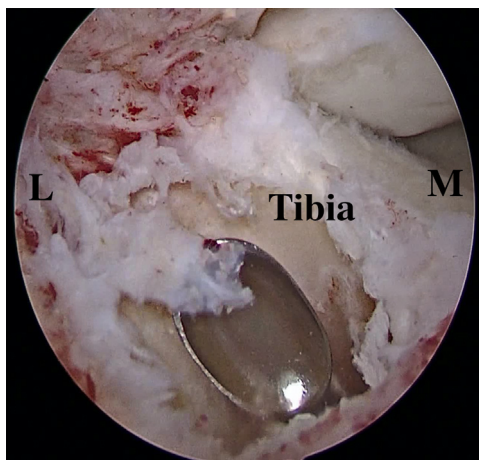


Fig 6. Arthroscopic images of a right knee viewed through anterolateral portal demonstrating debridement of a tibial tunnel using a small curette placed via the medial tibial metaphyseal tunnel.

preoperatively planning and may require a staged approach in some cases.

Surgical Technique

The patient is brought to the operating table and placed in a supine position. A tourniquet is routinely placed but typically not inflated. A lateral thigh post and foot bump are attached to the table for assistance with the knee arthroscopy. Occasionally, it may be necessary to place a bump under the operative hip. An examination under anesthesia is performed. It is important to perform an entire ligamentous knee examination including assessment of ACL, posterior cruciate ligament, posterolateral corner, medial collateral ligament, and lateral collateral ligament. Based on preoperative planning, fluoroscopy may be required to assist in hardware removal. In these instances, a large C-arm is brought in from the contralateral side, and any implant specific screw drivers and guidewires (in the setting of cannulated screw fixation) should be made available.

A standard diagnostic arthroscopy is performed (Video 1). All compartments are thoroughly assessed for cartilage integrity, loose bodies, and specifically for meniscus tears. It is critical to do a thorough assessment of menisci, as tears are common in the revision ACL setting, with special attention to peripheral, ramp, and root tears, as all of these have been implicated in ACL injuries and can affect outcomes. In general, small, partial-thickness, and peripheral tears that are stable can be left alone.³⁰ Larger tears and those that are unstable can be managed surgically depending on the tear type and pattern.

In the notch, the remaining ACL should be identified. Further inspection and careful attention should be paid to the anatomical landmarks usually observed when performing primary ACLR. It should be noted that

these landmarks may be significantly altered from previous surgery. Further debridement of the remaining ACL using a motorized shaver is performed until clear exposure of the lateral notch wall and tibial footprint are identified. Tunnel position and size on both the femur and tibia are assessed. If there is concern for infection at this point, a biopsy of the remaining ACL and synovium can be sent for culture. Any hardware within the notch or in the tunnels should be removed if it interferes with ideal tunnel placement or bone grafting or in cases of suspected infection.

Thorough debridement of the femoral tunnel is required, removing all the previous graft material. Often needle localization is used to ensure correct angle and trajectory to access the femoral tunnel from an accessory medial portal (Fig 2). With the use of shavers and various sized and angled curettes, the debridement is carried back to healthy bleeding cancellous bone (Fig 3).

The authors modify a 3-cc syringe by cutting off the hub while retaining the plunger (Fig 4). This modified syringe is packed with a mixture of cancellous bone chips, cortical fibers hydrated with whole blood, and platelet-rich plasma (Angel PRP System, S/N: ABS-10060; Arthrex, Naples, FL). A mini-open incision in line with the accessory anterior medial portal is created and the syringe is used to direct the graft into the tunnel (Fig 5). Bone tamps are used to impact the graft for a tight fill. Often several syringes of mixture are required to achieve adequate fill of tunnel—typically requiring between 5 and 15 cc. Excessive intra-articular graft can be removed using the arthroscopic shaver.

Attention is then turned to the tibial tunnel. A 2- to 4-cm incision is made over the anteromedial tibial metaphysis in line with previous incisions when possible. Retained hardware is located and removed using fluoroscopy if required. In a similar fashion to the femoral tunnel, all previous ACL graft material is

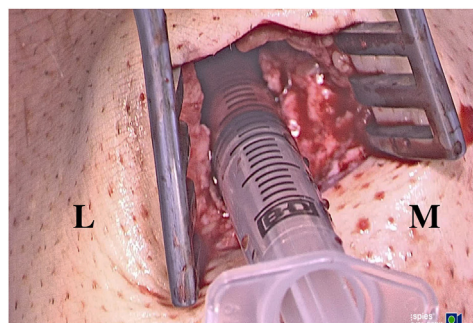


Fig 7. Image of right leg demonstrating bone grafting of the tibial tunnel in an outside-in fashion using a modified 3-cc syringe with tip cut off and plunger retained to place bone graft via medial tibial metaphysis. A key elevator can be placed intraarticularly to occlude the plateau side of the tunnel to prevent graft impaction into the joint space.

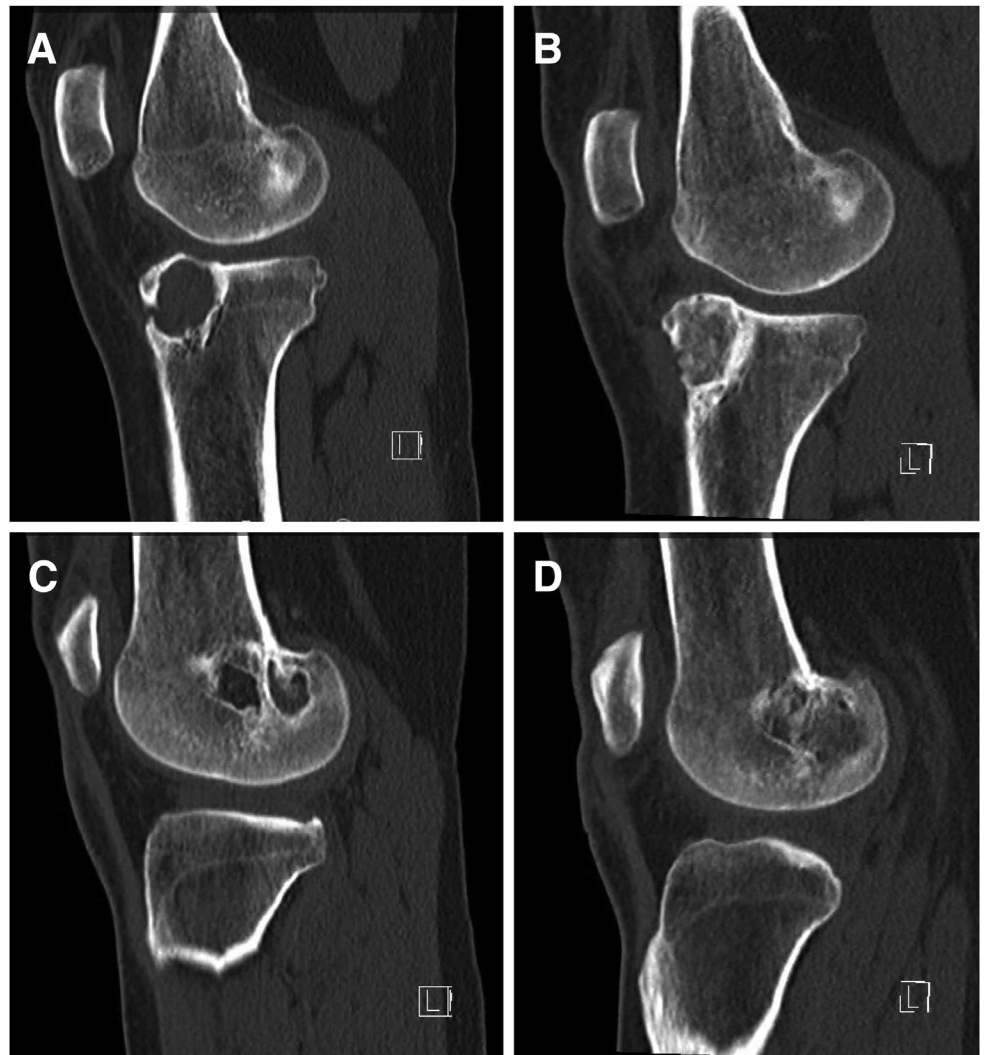


Fig 8. CT images of right knee demonstrating before and 6 months after bone grafting of ACL tunnels. Preoperative sagittal image (A) demonstrating preoperative osteolysis and expansion of the tibial tunnel and 6 months post-bone grafting sagittal image (B) demonstrating excellent fill and consolidation of bone graft within the tunnel. Preoperative sagittal image of prior femoral tunnels (C) and 6 months postbone grafting image (D) demonstrating excellent fill and consolidation of the defect. (ACL, anterior cruciate ligament; CT, computed tomography.)

removed and the tunnel is debrided with the arthroscopic shaver and curettes until a bleeding cancellous bed (Fig 6). The knee is extended and the mixture of cancellous bone chips, cortical fibers mixed with whole blood, and platelet-rich plasma is introduced into the tunnel using a modified 3-cc syringe and impacted with the tamps (Fig 7). A key elevator can be introduced from the anteromedial portal and placed over the tibial tunnel intra-articularly to prevent the graft from being impacted into the joint during placement. Often, tibial tunnels are larger and may require more graft material—typically between 8 and 20 cc.

Once bone grafting has been completed, the knee is copiously irrigated. The femoral and tibial incisions are closed in a layered fashion, and arthroscopic portals closed in a standard fashion. Sterile bandages are applied as well as an ACE wrap and cool pack and the patient is placed in a hinged knee brace.

Postoperative Management

Patients are placed in a hinged knee brace locked in extension when weight-bearing for the first 2 weeks postoperatively. Patients are instructed to remove it for range of motion exercises and are immediately started with passive, active assisted, and active range of motion as tolerated. Typically, at 2 weeks the hinged brace can be discontinued and patients can transfer into the ACL brace. The ACL brace is maintained until the revision ACLR is performed. Consistent use of the brace is of particular importance when a meniscus repair is performed in the first stage to minimize excessive loads on the repair site that can lead to repair failure.

Criteria to Proceed With Stage 2 (Revision ACLR)

The determination of when to proceed with the second stage of a staged ACLR is an important clinical

Table 1. Bone-Grafting Techniques: Advantages and Disadvantages

	Cancellous Bone Chip Allograft	Iliac Crest Dowel, OATS Technique
Advantages	<ol style="list-style-type: none"> 1. Pliable substrate improves tunnel fill 2. No reaming maximizes native bone stock 3. Decreased donor-site morbidity 4. Readily available, inexpensive materials 	<ol style="list-style-type: none"> 1. Autograft provides osteogenic properties
Disadvantages	<ol style="list-style-type: none"> 1. No osteogenic potential 2. Risk of graft migration into joint during impaction 	<ol style="list-style-type: none"> 1. Donor-site morbidity 2. Challenging to get circumferential fit in large asymmetric lesions

OATS, osteochondral autograft transfer system.

decision. Several factors including other procedures performed during the first stage, infection, bone grafting technique, bone graft used, and consolidation of graft on imaging should be considered. Several studies have attempted to identify an ideal window for proceeding with second stage ACLR.^{14,31} One study evaluated patients undergoing iliac crest autografting of ACL tunnels and found that 24 weeks following bone grafting was optimal for ACLR.³¹ Another study recommends following patients with serial radiographs to ensure bony consolidation of tunnels.¹⁴ Typically, radiographs are performed at initial postoperative appointment and every 2 months until tunnels are healed. Often, a CT scan is performed around 6 months postoperatively to ensure consolidation before second-stage ACL revision surgery (Fig 8). It is the authors' experience that most staged revisions can be performed at 6 months after bone grafting. If there was significant tunnel widening requiring a large amount of grafting, bony consolidation can take longer.

Discussion

There are several described techniques for bone grafting ACL tunnels. Buyukdogan et al.² described the

use of allograft bone dowels for reconstruction of ACL tunnels. In a similar technique, Thomas et al.³² describe the use of autograft bone dowel harvested from the iliac crest to fill previous ACL tunnels. Other techniques described include using the osteochondral autograft transfer system (Arthrex) for harvesting autograft from various locations for use in tunnel reconstruction.^{33,34}

There are several potential advantages to the technique presented here (Table 1). A unique aspect of our technique includes filling tunnels with a pliable bone graft matrix. Impaction of this pliable substrate can provide a more complete fill of tunnels and bony defects that are often asymmetric in shape and size. The materials required for graft delivery are inexpensive and readily available, consisting of only a modified 3-cc syringe. Furthermore, with many bone dowel techniques surgeons are required to ream to a desired diameter in order accommodate the bone dowel. This can cause excessive native bone loss in some situations. Eccentric reaming can lead to voids when the final dowel is placed. By using a curette for debridement of tunnels, this technique removes the minimal amount of bone necessary to get back to a healthy bleeding bone bed, thereby maximizing the patient's native bone

Table 2. Pearls and Pitfalls of the Arthroscopic Bone Graft Technique

Pearls	Pitfalls
Perform single-stage revision when possible	Revision tunnel placement malpositioning
Consider 1- stage revision in the setting of:	Debride remnant ACL to visualize lateral notch wall and tibial footprint
Concern for infection	Normal landmarks may be significantly altered from index procedure
Tunnel malposition and/or enlargement that compromises revision graft position or fixation	Remove hardware interfering with ideal revision tunnel placement
Need for advanced cartilage procedures, meniscal transplantation, osteotomy	Inadequate femoral tunnel debridement and grafting
Preoperative planning includes:	Use accessory medial portal placed with needle localization (Fig 2) to ensure appropriate working angle
Assessment of location of tunnels, cysts, hardware	Debride to healthy bleeding cancellous bone
Quantification of bone loss	Insufficient tibial tunnel grafting
Specific equipment required for prior hardware removal	Often requires more graft material (8-20 cc)
Retain hardware if no concern for infection and no interference with tunnel positioning	Use key elevator placed intraarticularly to prevent graft from being impacted into joint

ACL, anterior cruciate ligament.

stock. Finally, there is no requirement for harvest autograft, which can lead to increased surgical time and patient morbidity.

There are important considerations when using this technique. While more pliable than iliac crest bone dowel autograft, this technique relies on allograft to provide an osteoconductive scaffold and osteoinductive properties for bone healing without the osteogenic potential provided with autograft bone. It does use whole blood and platelet-rich plasma for biologic augmentation of the allograft.³⁵ Furthermore, care must be taken to avoid extravasation of graft material into the joint space, especially when impacting graft into the tibial tunnel. An elevator placed intra-articularly during graft impaction can help mitigate this. A full list of pearls and pitfalls to consider with this technique can be found in [Table 2](#).

It is important to consider surgical indications when deciding between 1- versus a 2-staged procedure. Several studies have found that patients with good bone stock, correct tunnel placement, and no concern for infection can be revised in a single stage.^{16,36} However, it should be noted that the most common reason for failure of ACLR is tunnel malposition,⁶ potentially requiring a 2-stage procedure. Other studies have demonstrated that tunnel widening greater than 12 to 14 mm are indications for a 2-stage procedure.^{15,16,18,19} A 2-stage reconstruction can be challenging and time-consuming for patients eager to return to activity. It is important to note that 2-stage procedures can yield excellent results in patients that cannot be adequately treated with a single-stage procedure. A more recent study by Mitchell et al. confirmed that these results are comparable with those achieved in a single stage in appropriately selected patients at 2 years postoperatively.³³

Meniscus tears are commonly encountered during revision ACLR. One study in military patients found that there was an 74.6% rate of tears in patients undergoing revision ACLR.³⁷ Another study found that there was a 40.2% and 33.8% rate of new medial and lateral meniscus tears found during revision ACL surgery, respectively.³⁸ An interesting question in recent years has been whether meniscus tears repaired during the first stage of a 2-stage revision ACLR have capacity to heal well in the ACL-deficient knee. Based on the work of DePhillipo et al.,³⁹ which demonstrated excellent healing rates in this situation, we recommend treatment of meniscal lesions in this setting without reservation.

In conclusion, this Technical Note describes our preferred technique for the initial bone grafting stage of a 2-staged revision ACLR. While clinical studies are needed to evaluate outcomes using this technique, the authors believe this procedure is a reproducible and effective treatment option in patients with a failed

primary ACL reconstruction and tunnel widening, malpositioned tunnels with concern for convergence, or suspected infection.

References

- Gornitzky AL, Lott A, Yellin JL, Fabricant PD, Lawrence JT, Ganley TJ. Sport-specific yearly risk and incidence of anterior cruciate ligament tears in high school athletes: A systematic review and meta-analysis. *Am J Sports Med* 2016;44:2716-2723.
- Buyukdogan K, Laidlaw MS, Miller MD. Two-stage revision anterior cruciate ligament reconstruction using allograft bone dowels. *Arthrosc Tech* 2017;6:e1297-e1302.
- Hettrich CM, Dunn WR, Reinke EK, ; MOON Group/Spindler KP. The rate of subsequent surgery and predictors after anterior cruciate ligament reconstruction: Two- and 6-year follow-up results from a multicenter cohort. *Am J Sports Med* 2013;41:1534-1540.
- Wright RW, Magnussen RA, Dunn WR, Spindler KP. Ipsilateral graft and contralateral ACL rupture at five years or more following ACL reconstruction: A systematic review. *J Bone Joint Surg Am* 2011;93:1159-1165.
- Wright RW, Huston LJ, Spindler KP, et al. Descriptive Epidemiology of the Multicenter ACL Revision Study (MARS) Cohort. *Am J Sports Med* 2010;38:1979-1986.
- Desai N, Andermord D, Sundemo D, et al. Revision surgery in anterior cruciate ligament reconstruction: A cohort study of 17,682 patients from the Swedish National Knee Ligament Register. *Knee Surg Sport Traumatol Arthrosc* 2017;25:1542-1554.
- Carson EW, Anisko EM, Restrepo C, Panariello RA, O'Brien SJ, Warren RF. Revision anterior cruciate ligament reconstruction: Etiology of failures and clinical results. *J Knee Surg* 2004;17:127-132.
- Illingworth KD, Hensler D, Working ZM, Macalena JA, Tashman S, Fu FH. A simple evaluation of anterior cruciate ligament femoral tunnel position: The inclination angle and femoral tunnel angle. *Am J Sports Med* 2011;39:2611-2618.
- Dejour H, Bonnin M. Tibial translation after anterior cruciate ligament rupture. Two radiological tests compared. *J Bone Joint Surg Br* 1994;76:745-749.
- Ahn JH, Lee YS, Chang MJ, Yim HS. Analysis of revision anterior cruciate ligament reconstruction according to the combined injury, degenerative change, and MRI findings. *Knee* 2011;18:382-386.
- Drews BH, Merz C, Huth J, Gulkin D, Guelke J, Gebhard F, et al. Magnetic resonance imaging in evaluation of tunnel diameters prior to revision ACL reconstruction: A comparison to computed tomography. *Skeletal Radiol* 2017;46:1361-1366.
- Grasso S, Linklater J, Li Q, Parker DA. Validation of an MRI protocol for routine quantitative assessment of tunnel position in anterior cruciate ligament reconstruction. *Am. J Sports Med* 2018;46:1624-1631.
- de Beus A, Koch JE, Hirschmann A, Hirschmann MT. How to evaluate bone tunnel widening after ACL reconstruction—a critical review. *Muscles Ligaments Tendons J* 2017;7:230-239.

14. Kamath GV, Redfern JC, Greis PE, Burks RT. Revision anterior cruciate ligament reconstruction. *Am J Sports Med* 2011;39:199-217.
15. Bach BR, Provencher MT. *ACL surgery: How to get it right the first time and what to do if it fails*. Thorofare, NJ: SLACK, 2010.
16. Erickson BJ, Cvetanovich GL, Frank RM, Riff AJ, Bach BR. Revision ACL reconstruction: A critical analysis review. *J Bone Joint Surg Rev* 2017;5:e1.
17. Schulz AP, Götze S, Schmidt HGK, Jürgens C, Faschingbauer M. Septic arthritis of the knee after anterior cruciate ligament surgery. *Am J Sports Med* 2007;35:1064-1069.
18. Chahla J, Dean CS, Cram TR, et al. Two-stage revision anterior cruciate ligament reconstruction: Bone grafting technique using an allograft bone matrix. *Arthrosc Tech* 2016;5:e189-e195.
19. Magnussen RA, Debieux P, Benjamin B, et al. A CT-based classification of prior ACL femoral tunnel location for planning revision ACL surgery. *Knee Surg Sport Traumatol Arthrosc* 2012;20:1298-1306.
20. Segawa H, Omori G, Tomita S, Koga Y. Bone tunnel enlargement after anterior cruciate ligament reconstruction using hamstring tendons. *Knee Surg Sport Traumatol Arthrosc* 2001;9:206-210.
21. Clatworthy MG, Annear P, Bulow J-U, Bartlett RJ. Tunnel widening in anterior cruciate ligament reconstruction: A prospective evaluation of hamstring and patella tendon grafts. *Knee Surg Sport Traumatol Arthrosc* 1999;7:138-145.
22. Flanigan DC, Everhart JS, DiBartola AC, et al. Bacterial DNA is associated with tunnel widening in failed ACL reconstructions. *Knee Surg Sport Traumatol Arthrosc* 2019;27:3490-3497.
23. Christensen JJ, Krych AJ, Engasser WM, Vanhees MK, Collins MS, Dahm DL. Lateral tibial posterior slope is increased in patients with early graft failure after anterior cruciate ligament reconstruction. *Am J Sports Med* 2015;43:2510-2514.
24. Webb JM, Salmon LJ, Leclerc E, Pinczewski LA, Roe JP. Posterior tibial slope and further anterior cruciate ligament injuries in the anterior cruciate ligament-reconstructed patient. *Am J Sports Med* 2013;41:2800-2804.
25. Loia MC, Vanni S, Rosso F, Bonasia DE, Bruzzone M, Dettoni F, et al. High tibial osteotomy in varus knees: Indications and limits. *Joints* 2016;4:98-110.
26. LaPrade RF, Spiridonov SI, Nystrom LM, Jansson KS. Prospective outcomes of young and middle-aged adults with medial compartment osteoarthritis treated with a proximal tibial opening wedge osteotomy. *Arthroscopy* 2012;28:354-364.
27. Cantin O, Magnussen RA, Corbi F, Servien E, Neyret P, Lustig S. The role of high tibial osteotomy in the treatment of knee laxity: A comprehensive review. *Knee Surg Sports Traumatol Arthrosc* 2015;23:3026-3037.
28. Sonnery-Cottet B, Saithna A, Cavalier M, et al. Antero-lateral ligament reconstruction is associated with significantly reduced ACL Graft rupture rates at a minimum follow-up of 2 years: A prospective comparative study of 502 patients from the SANTI Study Group. *Am J Sports Med* 2017;45:1547-1557.
29. Getgood AMJ, Bryant DM, Litchfield R, et al. Lateral extra-articular tenodesis reduces failure of hamstring tendon autograft anterior cruciate ligament reconstruction: 2-year outcomes from the STABILITY study randomized clinical trial. *Am J Sports Med* 2020;48:285-297.
30. Shelbourne KD, Heinrich J. The long-term evaluation of lateral meniscus tears left in situ at the time of anterior cruciate ligament reconstruction. *Arthroscopy* 2004;20:346-351.
31. Uchida R, Toritsuka Y, Mae T, Kusano M, Ohzono K. Healing of tibial bone tunnels after bone grafting for staged revision anterior cruciate ligament surgery: A prospective computed tomography analysis. *Knee* 2016;23:830-836.
32. Thomas NP, Kankate R, Wandless F, Pandit H. Revision anterior cruciate ligament reconstruction using a 2-stage technique with bone grafting of the tibial tunnel. *Am J Sports Med* 2005;33:1701-1709.
33. Mitchell JJ, Chahla J, Dean CS, Cinque M, Matheny LM, LaPrade RF. Outcomes after 1-stage versus 2-stage revision anterior cruciate ligament reconstruction. *Am J Sports Med* 2017;45:1790-1798.
34. Franceschi F, Papalia R, Del Buono A, et al. Two-stage procedure in anterior cruciate ligament revision surgery: A five-year follow-up prospective study. *Int Orthop* 2013;37:1369-1374.
35. Wang F, Rodeo S. Platelet-rich plasma in orthopaedic surgery. *JBJS Rev* 2017;5:e7.1-e10.
36. Johnson DL, Swenson TM, Irrgang JJ, Fu FH, Harner CD. Revision anterior cruciate ligament surgery: Experience from Pittsburgh. *Clin Orthop Relat Res* 1996;325:100-109.
37. Widener DB, Wilson DJ, Galvin JW, Marchant BG, Arrington ED. The prevalence of meniscal tears in young athletes undergoing revision anterior cruciate ligament reconstruction. *Arthroscopy* 2015;31:680-683.
38. Borchers JR, Kaeding CC, Pedroza AD, et al. Intra-articular findings in primary and revision anterior cruciate ligament reconstruction surgery: A comparison of the MOON and MARS study groups. *Am J Sports Med* 2011;39:1889-1893.
39. DePhillipo NN, Dekker TJ, Aman ZS, Bernholt D, Grantham WJ, LaPrade RF. Incidence and healing rates of meniscal tears in patients undergoing repair during the first stage of 2-stage revision anterior cruciate ligament reconstruction. *Am J Sports Med* 2019;47:3389-3395.