Technical Note

Economic Reliable Technique for Tunnel Grafting Using Iliac Crest Bone Graft in Two-Staged Revision Anterior Cruciate Ligament Surgery

Ahmed Abdel-Aziz, M.Sc., M.D., Mohamed Refaat Waly, M.Sc., M.D., M.R.C.S., Mahmoud Ahmed Abdel-Aziz, M.Sc., M.D., Mohamed Mamdouh Sherif, M.Sc., Hazem Elhaddad, M.Sc., and Begad Hesham Mostafa Zaky Abdelrazek, M.Sc., M.D., F.R.C.S.

Abstract: Revision anterior cruciate ligament surgery is a technically demanding procedure. Mal-positioned tunnels together with bone loss and its management are some of the difficulties and challenges faced. Two-staged procedures have successfully been used to tackle those challenges. We present a technique that is safe, reliable, reproducible, and economic in the management of bone defects faced in anterior cruciate ligament revision surgery by using iliac crest bone graft. Preoperative assessment of tunnel position and size is done by computed tomography. Tri-cortical iliac crest bone graft is harvested through a trap door. It is then shaped to fit the tunnels to be filled. It is tapered at the advancing end to facilitate introduction. Mounted on a passing pin and a drill bit, the graft is arthroscopically introduced into the femoral and tibial tunnels. The second stage is performed after the graft has incorporated, as seen on postoperative computed tomography, done at approximately 3 months after the first stage. Iliac crest provides a natural abundant reservoir for bone graft and has all the advantages of being an autograft. With good meticulous technique, complications can be avoided with less donor-site morbidity. This technique is safe, reliable, and reproducible. It provides an ample amount of graft and harvest does not rely on implants; hence, it is economic.

Primary anterior cruciate ligament reconstruction (ACLR) is a safe and reliable, widely performed procedure to restore sagittal and rotational stability of the knee after rupture of the anterior cruciate ligament (ACL).[1,2] Despite good long-term outcomes, approximately 4% to 13% of patients require revision surgery with regrafting of the ACL tunnels.[3-5] As the number of primary ACLRs is increasing, revision ACLR is becoming increasingly important.[6,7]

Revision procedures require precise analysis of the cause of failure. A missed associated medial and/or lateral collateral ligament or posterolateral corner injury as a cause of failure should be excluded. Revision

Table 1. Pearls and Pitfalls of the Technique

Pearls	Pitfalls
Notchplasty is performed if needed to avoid graft impingement	Avoid using mal-positioned tunnels from the index procedure
Preserve the native bone stock as possible	Loose bodies are left behind in the knee, therefore; the knee is meticulously examined after graft is inserted
Incision for ICBG harvest should be lateral to the bone edge to avoid later irritation by clothes	Graft dowel breaks during introduction and impaction; hence, introduce it mounted on a guide pin and drill bit
Closure of the trap door reduces blood loss	Excessive tunnel debridement causing more bone loss
Harvested graft is 1 mm larger in size than the tunnel to allow for a press fit	Missing concomitant pathology that should be addressed

ICBG, iliac crest bone graft.

From Trauma and Orthopaedics, Kasr-Alainy Faculty of Medicine, Cairo University (A.A.A., M.R.W., M.A.A.A., H.E., B.H.M.Z.A.), Student Hospital, Cairo University (M.A.A.A.), Trauma and Orthopaedics, El Sahel Teaching Hospital, El Sahel (M.M.S.), and Cairo Fatemic Hospital (H.E.), Cairo, Egypt.

The authors report that they have 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 13, 2020; accepted August 16, 2020.

Address correspondence to Mohamed Refaat Waly, M.Sc., M.D., Lecturer of Trauma and Orthopaedics, Kasr-Alainy Faculty of Medicine, Cairo University, Mathaf El-Manial St., Cairo, Egypt, 11553. E-mail: mraw1987@cu.edu.eg or mraw1987@yahoo.com

2212-6287/20942

https://doi.org/10.1016/j.eats.2020.08.024

ACLR presents a unique set of challenges and is a technically demanding procedure. This includes dealing with bone loss, mal-positioned tunnels, arthrofibrosis, and limitation in graft choice, which makes single-stage revision very difficult.

Incorrect tunnel placement is the most common cause of primary ACLR failure.[8] If tunnels were nonanatomic in the index procedure, creation of entirely new tunnels is required. This carries the risk of the tunnel convergence and collision.[9]

Two-stage revision ACLR is a safe treatment option that should be considered in the setting of bone loss and mal-positioned tunnels. It allows restoration of bone stock and allows tunnel placement in the second stage.[8] Managing bone deficiencies is challenging. A variety of alternative methods and materials have been described recently. These include autograft (iliac crest or tibial), allograft, and synthetic bone substitutes (silicate-substituted calcium phosphate [Si-CaP]).[10]

There is no gold standard procedure for dealing with bone deficiencies. However, iliac crest autograft is the most superior type of bone graft because of its osteoconductive, osteoinductive, and osteogenic properties. This explains why it require less incorporation time than allograft and synthetic alternatives.[11-14] This technique provides easy, simple, and economic way (no need for special instruments) of tunnel grafting. Moreover, it provides corticocancellous autograft that allows reliable structural support for revision ACL surgery.

Surgical Technique

Preoperative

Meticulous analysis of cause of primary ACLR failure is crucial. This is achieved by thorough history-taking and clinical and radiologic examinations (radiographs and computed tomography scan). The diameter of femoral and tibial tunnels is measured in sagittal, coronal, and axial planes. Ligamentous graft options including contralateral graft should be explored. Informed consent is obtained for a staged procedure, iliac crest bone graft (ICBG) in the first stage, with the possibility of contralateral ligamentous graft harvesting. Detailed postoperative rehabilitation after each stage should clearly be communicated to the patient.

Intraoperative (With Video Illustration)

The procedure is performed with the patient under regional and/or general anaesthesia in the supine position. In the first stage, a sand bag is placed under the ipsilateral iliac wing. Regular prep and drape are performed, including iliac crest region for graft harvesting. All procedures are performed under tourniquet and started by examination with the patient under anaesthesia to confirm and document degree of laxity, knee jerk, and any associated injuries.

Diagnostic arthroscopy is performed to identify and document any concomitant pathology that should be addressed. Tibial and femoral remnants of the ACL graft are debrided and removed. Hardware is removed as needed. This may be difficult; hence, a removal kit should be kept handy. Notchplasty is performed if needed to avoid graft impingement (Table 1).

After hardware removal, the tunnels are debrided by introducing a guidewire and sequential reaming of tunnels by drill bits of incrementing diameters till exposure of raw cancellous bone. The remnants of soft tissues are removed by shaver and sclerotic bone is abraded by a curette. Native bone stock should be preserved as much as possible (Video 1 and Table 1). Then, the diameter of both femoral and tibial tunnels is measured to prepare sufficient dowels of cortico-cancellous ICBG. Attention is turned to graft harvesting.

The incision is started 1 cm posterior to anterior superior iliac spine and extends to the iliac tubercle. It should be lateral to bony prominence to avoid irritation by tight clothes (Table 1). The dissection proceeds through the subcutaneous tissue until Scarpa's fascia is reached and medial to tensor fascia lata and glutieus medius lateral to iliacus and external abdominal muscles. A trap-door technique is performed. The superior cortex is osteomized and elevated with its soft-tissue attachments, then base and depth of the dowel is dictated by diameter of ACL tunnel to be grafted (Fig 1). Two corticocanellus wedges are obtained (Fig 2A), for a press fit into the ACL tunnels; their size is taken 1 mm more than the measured tunnel size. One end of the dowels is tapered to facilitate introduction and impaction. The trap door is closed and meticulous layered closure is performed to minimize postoperative hematoma and seroma formation (Table 1).

The two dowels are prepared (soft tissues are removed and cortical bone is abraded) (Fig 2B). The prepared dowel is mounted over a guidewire and tibial drill bit to facilitate its impaction in the femoral tunnel (Figs 3 and 4). The graft may be inserted arthroscopically via an enlarged anteromedial portal (Video 1 and Fig 5). After insertion of the graft, the knee is thoroughly examined to ensure no loose pieces are left behind (Table 1).

We believe that impacting a dense, structural allograft dowel into freshly reamed femoral and tibial tunnels (Fig 6) is a reliable technique to adequately build up deficient bone stock.

Postoperative Regimen

Patients are allowed protected weightbearing with 2 crutches for balancing and support. Range of motion

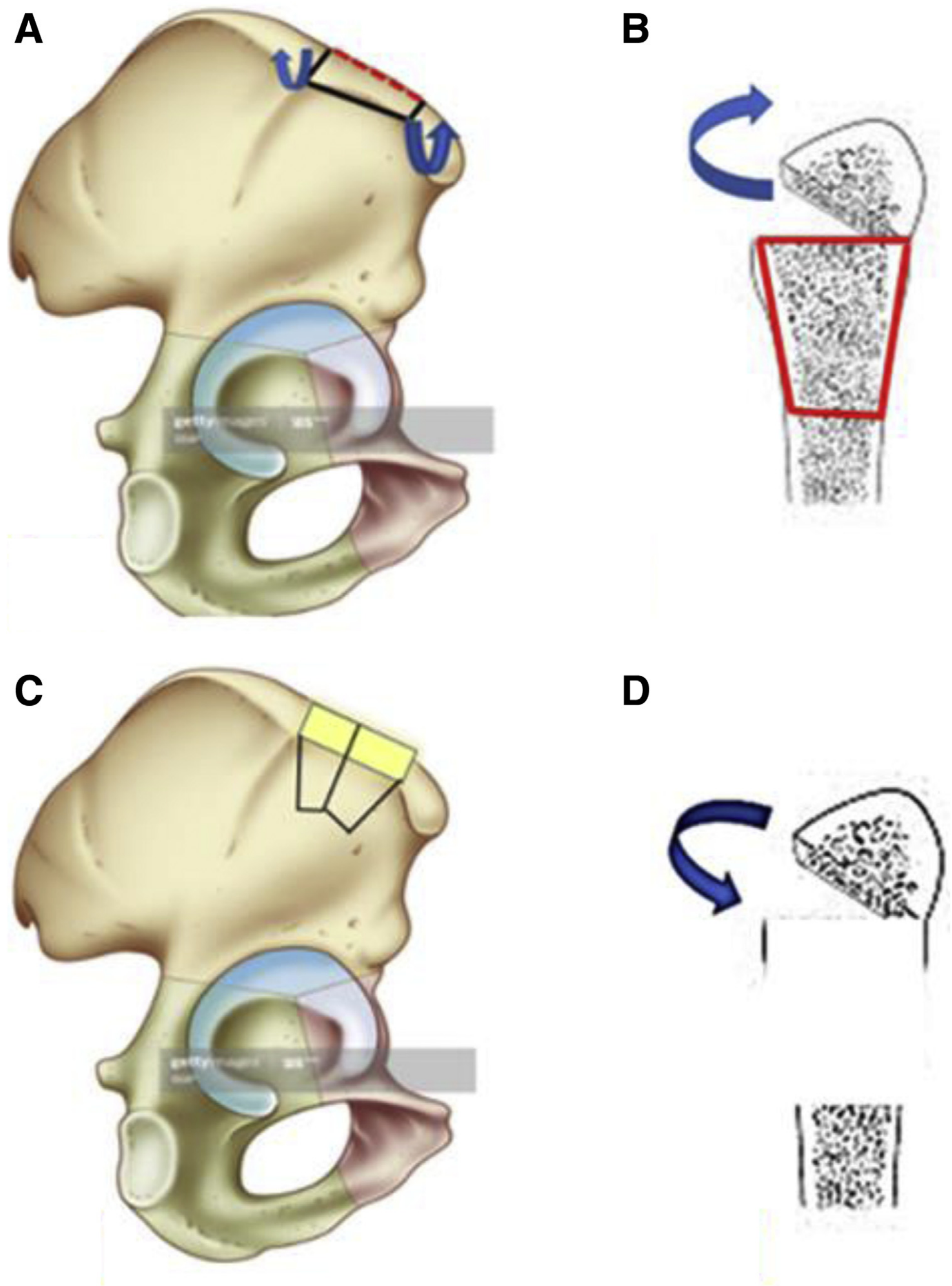

Fig 1. Diagram showing trap-door technique of iliac crest graft. (A) Superior cortex of iliac crest is opened. (B) Sagittal view of iliac crest showing technique of trap door. (C) Cortico-canellous wedges are osteotomized in form of dowels to fit the tunnels. (D) Sagittal view of iliac crest after harvesting the graft.

and isometric quadriceps exercises are begun immediately. Venous thromboembolism chemical prophylaxis is given for 2 weeks.

Serial radiographs (Fig 7) are obtained to follow up bone grafting incorporation and a computed tomography scan (Fig 8) at approximately 3 to 4 months postoperatively to ensure graft is still in situ and incorporating. Once the tunnels are filled with bone and the patient has normal range of motion, the second-stage ACLR can be performed.

Discussion

Revision ACL is technically demanding surgery, especially with widened and/or incorrectly positioned primary tunnels. There are many challenges including but not limited to bone loss, associated ligamentous injury, limitations of bone and ligamentous graft options, arthrofibrosis, and infection. These usually impede single-stage revision. Both location and angles of tunnels are thought to correlate with tunnel enlargement because of windshield-wiper and bungee

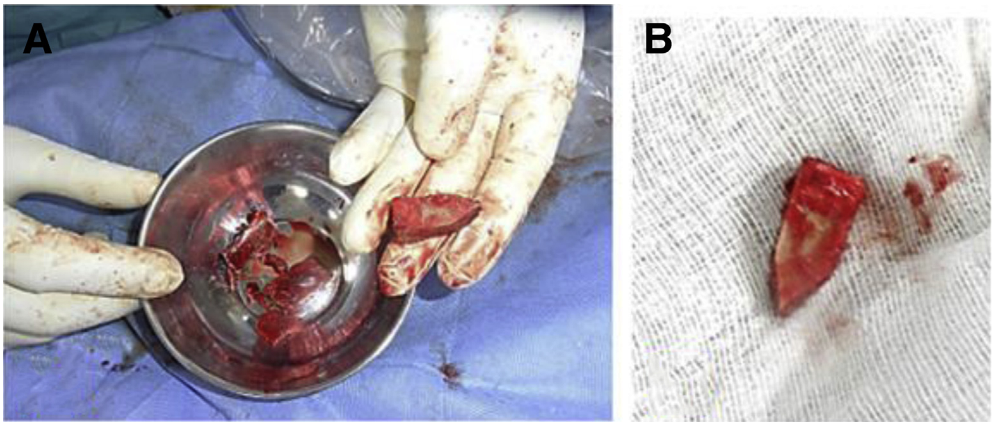

Fig 2. Two wedges are prepared to fill tunnels. (A) Showing 2 wedges. (B) After tapering the end of graft to facilitate its lodging in the tunnel.

cord motion of the graft, which may be exaggerated by tunnel malposition.[15]

No attempt should be made to use non-anatomic malpositioned tunnels for revision.[16] Severe tunnel widening and bone loss may pose further difficulty, and the surgeon should consider a 2-staged revision.

Despite the presence of many options for tunnel grafting staged ACL revision, there is no consensus regarding the optimal choice of bone graft material or surgical technique in revision ACL surgery. The gold standard for tunnel augmentation is an autologous iliac crest cancellous bone graft. However, it is argued that harvesting the graft is associated with high morbidity.[11,17,18]

Sources of autologous graft could be iliac crest or anterior tibia. It is osteoconductive, osteoinductive, and osteogenic. A wide variety of growth factors have been identified in ICBG but were found to be absent in demineralized allograft bone preparations; hence, ICBG is more superior[19,20] (Table 2). Moreover, many authors used autograft from ipsilateral iliac crest or proximal tibia. They relied on a guide system (commercial, single-use cylindrical graft harvest and delivery) to harvest cylindrical bone dowels and to arthroscopically insert them into the debrided tunnels.[11,12,21-23]

Bone graft harvested from the iliac crest has been shown to have significantly greater levels of anabolic osteogenic gene expression compared with bone harvested from the tibia. Autologous bone may be associated with a lower risk of ligament graft failure compared with allograft bone.[24] Iliac crest acts as an abundant reservoir for plenty of tri-cortical bone dowels (Table 2). Thomas et al.[11] reported on their results using dowels of iliac crest autograft for grafting the tibial tunnels for revision ACL surgery. Scores for laxity achieved were similar to those after primary ACL reconstructions. However, they believe that harvesting of an ICBG is invasive and carries risk of donor-site morbidity[11] (Table 2).

The use of commercial, single-use cylindrical graft harvest and delivery system has the advantage of offering different sizes, harvests cylindrical dowels, and being easy and familiar to use both to harvest and to

Fig 3. Lodging the graft over the guidewire to allow easy control.

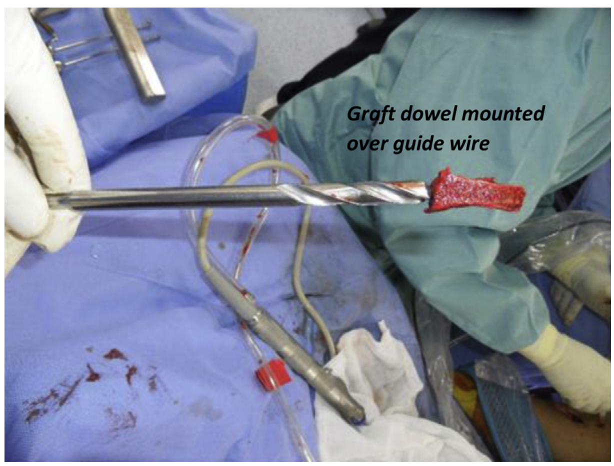

Fig 4. Drill bit is coupled to wire to press fit the graft into femoral tunnel.

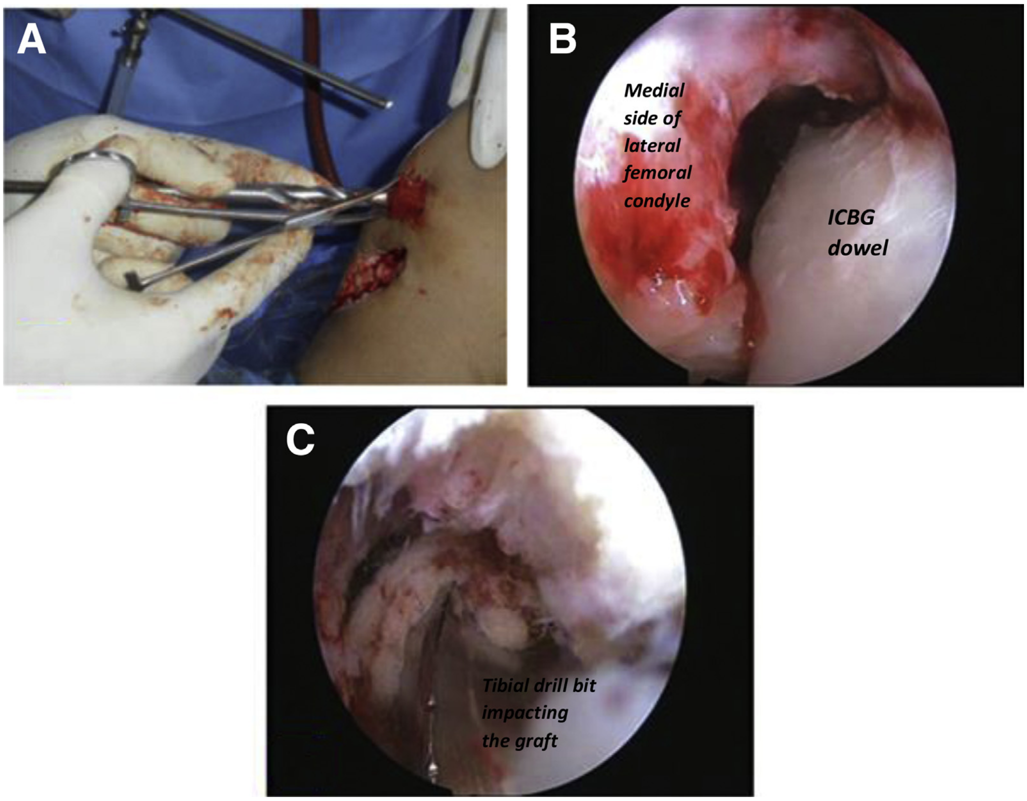

Fig 5. Right knee, anteromedial portal view with knee flexed 120 degrees. (A) Inserting the graft through widened anteromedial portal. (B) Inserting the taper end of the graft through the femoral tunnel. (C) Impacting the graft.

insert the graft. However, it has limited sizes, is not always available, and is expensive. To avoid high risk of donor-site morbidity associated with ICBG, Franceschi et al.[22] proposed using an Osteochondral Autograft Transfer System harvester to obtain dowels from tibial metaphysis. The technique has a limitation in the size of grafts obtained. Therefore, larger defects pose a challenge and an alternative must be considered.[22]

Allografts have been described as a source of bone graft. They offer a number of advantages. Bone dowels are structural allografts commercially available in different lengths and diameters to fill the bone defect with varying sizes. They are easy to use and avoid donor-site morbidity. Furthermore, they afford sufficient stability for the graft fixation at the second-stage revision. A potential limitation of using allograft bone dowels is that the maximum diameter of dowels is 20 mm, which may limit their use in larger defects. Also, they carry a greater risk of ligament graft failure as compared with autografts.[25]

A review of bone graft options for tunnel augmentation suggested the following: (1) with the available data, ICBG for bone tunnel grafting in 2-stage ACLR revision may be associated with a lower risk of revision ACLR graft failure compared with allograft bone; (2) no consensus is available regarding the duration of time that should elapse between the first and second stages or regarding the imaging or clinical modality that should be used to determine whether the knee is ready for revision; and (3) the results of this review expose a paucity of high-quality studies comparing available bone graft materials for revision ACLR.[26]

Schnetzke et al. described an alternative technique for managing bone deficiencies using the synthetic bone graft substitute Si-CaP. They published a randomized controlled trial reporting the results of using this technique.[27,28] Si-CaP demonstrates slow biodegradation and excellent resistance to compressive forces. The technique is straightforward, has the advantage of shorter operative time, less blood loss and fewer complications, and avoids donor-site morbidity. No Si-CaP—related complications occurred during the study. However, it has the following limitations: intraoperative assessment with fluoroscopy is needed, it has greater costs in comparison with autologous cancellous bone, it is difficult to assess the degree of bone consolidation in the bone graft by postoperative computed tomography, and a 6-month interval is required between the 2 procedures, which is usually longer than autologous bone graft. Moreover, these materials have been shown to lack resistance to tensile forces.[6] Conceivably, weakness under tension may not be conducive to securing a graft that is responsible for dynamic stabilization of the knee.[29] This study shows a simple and reproducible technique that is used for any defect regardless of its size. Moreover, there is no need

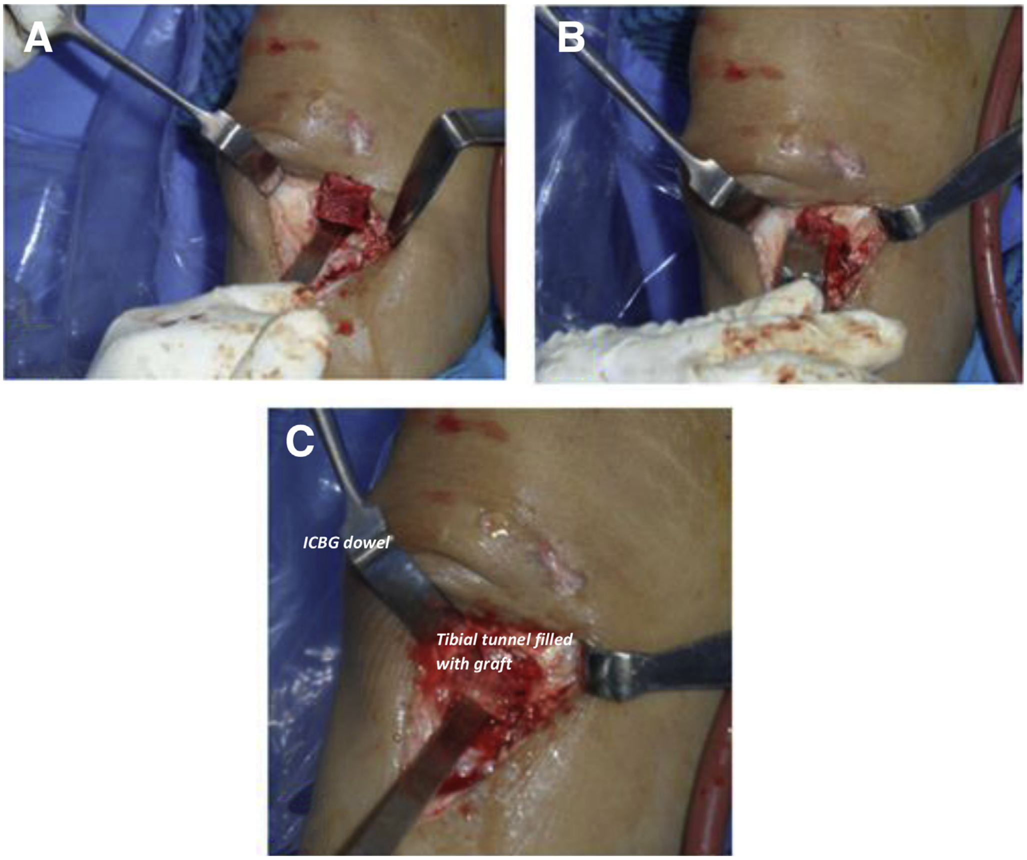

Fig 6. Grafting the tibial tunnel. Right knee, outside view with knee flexed 30 degrees. (A) Insertion of the graft into the tunnel. (B) Impaction of the graft. (C) Ensuring the graft is sitting well in the tunnel.

for special instruments. Compared with other methods, the technique described in this study technique provides an easy, economic, efficient, and reliable method of tunnel grafting with corticocancellous ICBG with no limitation regarding size of tunnel widening and need of special instruments. In addition, it provides structural

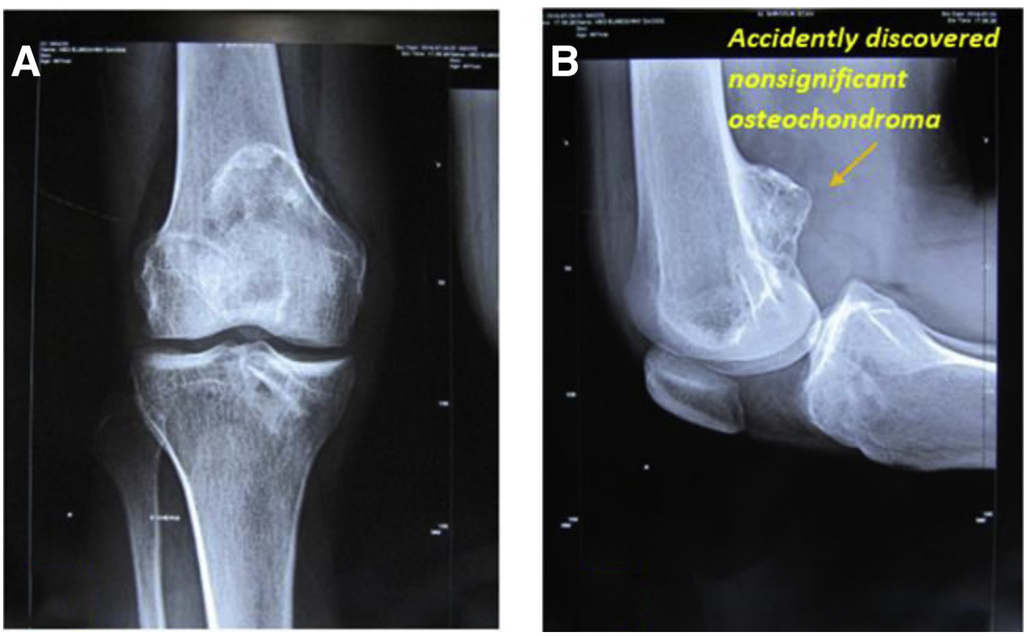

Fig 7. Anteroposterior and lateral radiographs after 3 months to ensure filling and incorporation of the tunnels.

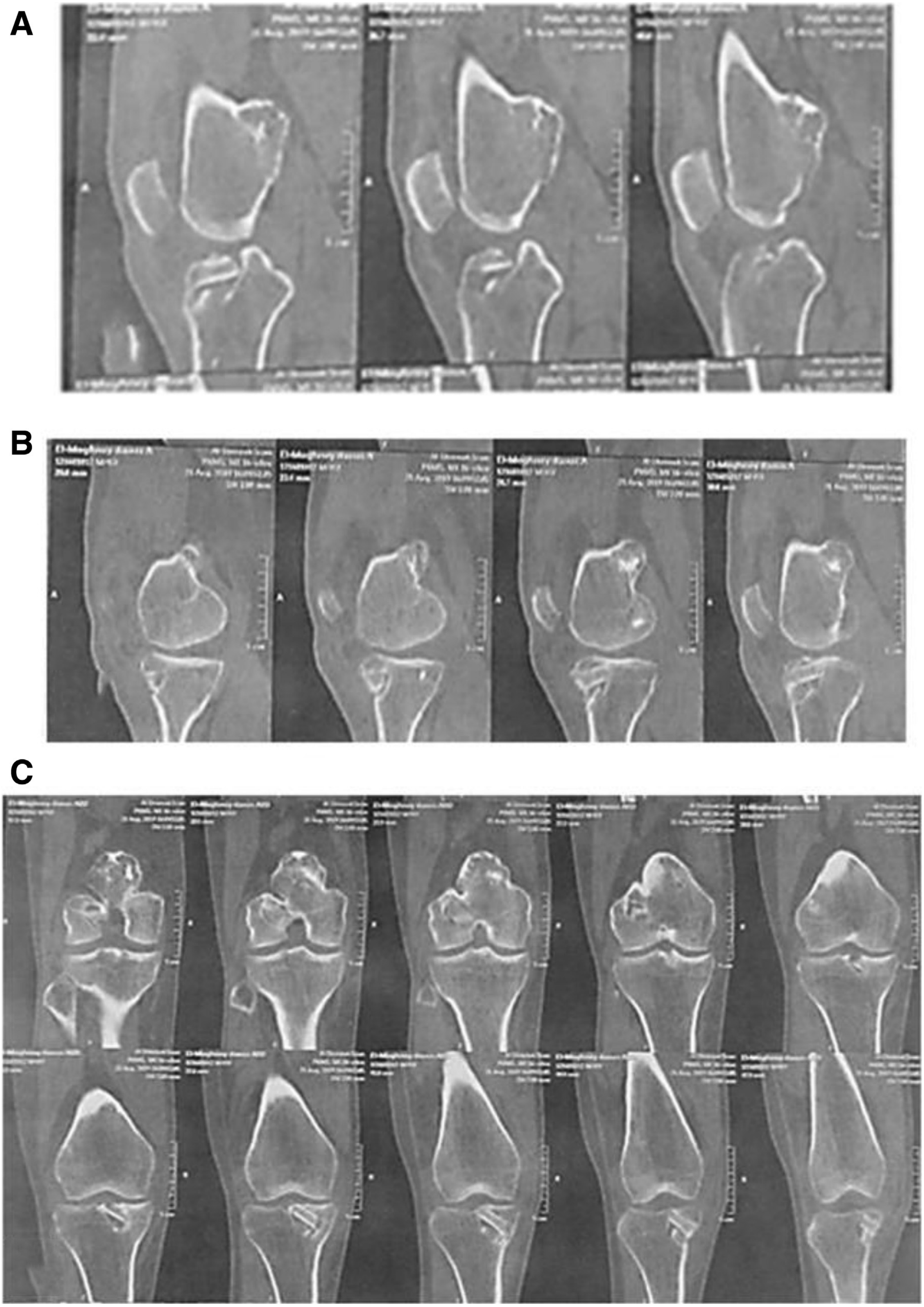

Fig 8. Computed tomography after 3 months. (A) Sagittal cuts showing graft incorporation into the tibial tunnel. (B) Sagittal cuts showing graft incorporation into femoral tunnel. (C) Coronal cuts showing graft incorporation into tibial tunnel.

Table 2. Advantages and Disadvantages of the Technique

Advantages	Disadvantages
Easy technique, no sophisticated instruments required	Donor-site morbidity as pain, bleeding, wound complications
Autograft has osteoconductive, osteoinductive, and osteogenic properties	Time-consuming compared with readily prepared allograft dowels
Being tri-cortical, it provides structural support	Needs sizing and fashioning intraoperatively
Ample amount of graft is available with no limits; hence, it is suitable for large defects	Patients may be reluctant; graft is taken from the hip for knee surgery
Being an autograft, it is not immunogenic and there is no risk of disease transmission	

support of tunnels that shortens the interval to second stage of revision and allow subsequent better fixation of ACL graft in the second stage.

References

1. Poehling-Monaghan KL, Salem H, Ross KE, et al. Long-term outcomes in anterior cruciate ligament reconstruction: A systematic review of patellar tendon versus hamstring autografts. *Orthop J Sports Med* 2017;5.
2. Chalmers PN, Mall NA, Moric M, et al. Does ACL reconstruction alter natural history? A systematic literature review of long-term outcomes. *J Bone Joint Surg Am* 2014;96:292-300.
3. van Eck CF, Schkrohowsky JG, Working ZM, Irrgang JJ, Fu FH. Prospective analysis of failure rate and predictors of failure after anatomic anterior cruciate ligament reconstruction with allograft. *Am J Sports Med* 2012;40:800-807.
4. Crawford SN, Waterman BR, Lubowitz JH. Long-term failure of anterior cruciate ligament reconstruction. *Arthroscopy* 2013;29:1566-1571.
5. Vap AR, Persson A, Fenstad AM, Moatshe G, LaPrade RF, Engebretsen L. Re-revision anterior cruciate ligament reconstruction: An evaluation from the Norwegian Knee Ligament Registry. *Arthroscopy* 2019;35:1695-1701.
6. Lynch TS, Parker RD, Patel RM, et al. The impact of the Multicenter Orthopaedic Outcomes Network (MOON) research on anterior cruciate ligament reconstruction and orthopaedic practice. *J Am Acad Orthop Surg* 2015;23:154-163.
7. Leathers MP, Merz A, Wong J, Scott T, Wang JC, Hame SL. Trends and demographics in anterior cruciate ligament reconstruction in the United States. *J Knee Surg* 2015;28:390-394.
8. Jaecker V, Zapf T, Naendrup JH, Kanakamedala AC, Pfeiffer T, Shafizadeh S. Differences between traumatic and non-traumatic causes of ACL revision surgery. *Arch Orthop Trauma Surg* 2018;138:1265-1272.
9. Weiler A, Schmeling A, Stohr I, Kaab MJ, Wagner M. Primary versus single-stage revision anterior cruciate ligament reconstruction using autologous hamstring tendon grafts: A prospective matched-group analysis. *Am J Sports Med* 2007;35:1643-1652.
10. Lerner T, Liljenqvist U. Silicate-substituted calcium phosphate as a bone graft substitute in surgery for adolescent idiopathic scoliosis. *Eur Spine J* 2013;22:S185-S194.
11. 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.
12. Said HG, Baloch K, Green M. A new technique for femoral and tibial tunnel bone grafting using the OATS harvesters in revision anterior cruciate ligament reconstruction. *Arthroscopy* 2006;22:796.e1-796.e3.
13. 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.
14. Wilde J, Bedi A, Altchek DW. Revision anterior cruciate ligament reconstruction. *Sports Health* 2014;6:504-518.
15. Segawa H, Omori G, Tomita S, Koga Y. Bone tunnel enlargement after anterior cruciate ligament reconstruction using hamstring tendons. *Knee Surg Sports Traumatol Arthrosc* 2001;9:206-210.
16. 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.
17. Banwart JC, Asher MA, Hassanein RS. Iliac crest bone graft harvest donor site morbidity. A statistical evaluation. *Spine (Phila Pa 1976)* 1995;20:1055-1060.
18. Arrington ED, Smith WJ, Chambers HG, Bucknell AL, Davino NA. Complications of iliac crest bone graft harvesting. *Clin Orthop Relat Res* 1996:300-309.
19. Li H, Pujic Z, Xiao Y, Bartold PM. Identification of bone morphogenetic proteins 2 and 4 in commercial demineralized freeze-dried bone allograft preparations: Pilot study. *Clin Implant Dent Relat Res* 2000;2:110-117.
20. Wildemann B, Kadow-Romacker A, Haas NP, Schmidmaier G. Quantification of various growth factors in different demineralized bone matrix preparations. *J Biomed Mater Res A* 2007;81:437-442.
21. Diermeier T, Herbst E, Braun S, et al. Outcomes after bone grafting in patients with and without ACL revision surgery: A retrospective study. *BMC Musculoskelet Disord* 2018;19:246.
22. 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.
23. 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.
24. Jing W, Smith AA, Liu B, et al. Reengineering autologous bone grafts with the stem cell activator WNT3A. *Biomaterials* 2015;47:29-40.
25. Battaglia TC, Miller MD. Management of bony deficiency in revision anterior cruciate ligament reconstruction using allograft bone dowels: Surgical technique. *Arthroscopy* 2005;21:767.

26. Salem HS, Axibal DP, Wolcott ML, et al. Two-stage revision anterior cruciate ligament reconstruction: A systematic review of bone graft options for tunnel augmentation. *Am J Sports Med* 2019;48:767-777.
27. von Recum J, Schwaab J, Guehring T, Grutzner PA, Schnetzke M. Bone incorporation of silicate-substituted calcium phosphate in 2-stage revision anterior cruciate ligament reconstruction: A histologic and radiographic study. *Arthroscopy* 2017;33:819-827.
28. von Recum J, Gehm J, Guehring T, et al. Autologous bone graft versus silicate-substituted calcium phosphate in the treatment of tunnel defects in 2-stage revision anterior cruciate ligament reconstruction: A prospective, randomized controlled study with a minimum follow-up of 2 years. *Arthroscopy* 2020;36:178-185.
29. Schnetzke M, Vetter S, von der Linden P, Grützner PA, von Recum J. Two-stage revision anterior cruciate ligament reconstruction using silicate-substituted calcium phosphate. *Arthrosc Tech* 2019;8:e1239-e1246.