Technical Note

Two-Stage Revision Anterior Cruciate Ligament Reconstruction Using Silicate-Substituted Calcium Phosphate

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Abstract: Revision surgery after failed primary anterior cruciate ligament reconstruction is technically demanding. In cases in which the tunnels of the primary anterior cruciate ligament reconstruction are widened to greater than 10 mm and/or are incorrectly positioned, a 2-stage procedure enables restoration of bone stock and thus free placement of the tunnels during the revision. The gold standard for tunnel augmentation is an autologous iliac crest cancellous bone graft. However, harvesting the graft is associated with high morbidity. This article describes an alternative method for managing bone deficiencies using the synthetic bone graft substitute silicate-substituted calcium phosphate.

Primary anterior cruciate ligament reconstruction (ACLR) is a safe and reliable procedure to restore sagittal stability 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.[3-5] In addition to traumatic rupture of the graft, graft failure is the most common cause of primary ACLR failure.[6] The main reasons for ACL graft failure are nonanatomic tunnel placement, failed graft integration, and infection.[6,7]

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The revision procedure requires a precise analysis of the cause of failure of the primary ACLR. Assessment of the tunnels placed during the primary procedure is crucial. Nonanatomic tunnel placement requires the creation of entirely new tunnels, which carries the risk of the old and new tunnels converging.[8] Tunnel enlargement presents another problem for the revision surgical procedure.[9-11] Tunnel diameters of greater than 10 mm make stable fixation of the graft technically challenging. An alternative to a 1-stage revision ACLR is a 2-stage procedure with filling of the tunnels placed during primary surgery.[7,12,13] The gold standard for tunnel augmentation is an autologous iliac crest cancellous bone graft. However, harvesting the graft is associated with high morbidity.[14-16] A variety of alternative methods for managing these bone deficiencies have been developed recently. One option is using the synthetic bone graft substitute silicate-substituted calcium phosphate (Si-CaP). Si-CaP is a synthetic porous bone graft substitute with a trabecular structure similar to that of cancellous bone.[17] In this surgical technique description, we describe a method for the management of the bone deficiencies using Si-CaP in staged ACLR.

Surgical Technique

Preoperative Evaluation

Before revision, analyzing the cause of failure of the primary ACLR and knowing the exact position and diameter of the tunnels are important. A preoperative

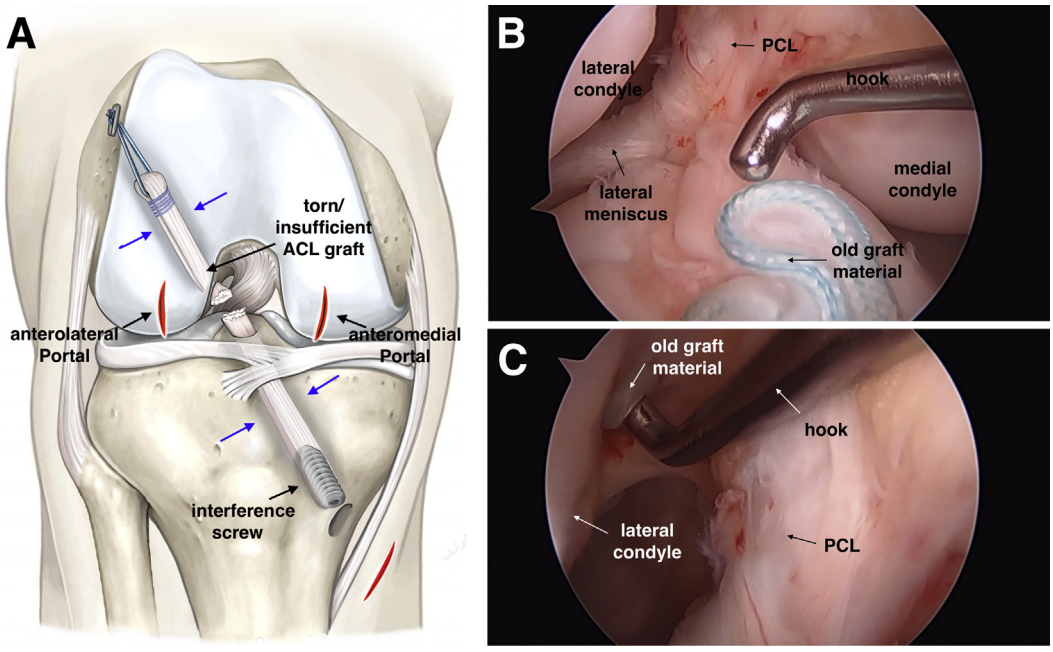

Fig 1. An arthroscope placed in the anterolateral portal in the patient's right knee is used to perform the diagnostic arthroscopy. The anteromedial portal is used as a working portal to facilitate use of the various arthroscopic instruments including hooks, shavers, and Kirschner wires. (A) During diagnostic arthroscopy, the diagnosis of a torn or insufficient anterior cruciate ligament (ACL) graft is confirmed. Tunnel widening of greater than 10 mm may be present after primary ACL reconstruction (blue arrows). In the case of insufficiency of the primary ACL graft, old graft material such as wires can be found at the tibial insertion (B) and/or femoral insertion (C). (PCL, posterior cruciate ligament.)

whole-leg standing radiograph to determine the axial alignment is therefore essential, as are magnetic resonance imaging and computed tomography (CT) of the affected knee. The lead surgeon needs to know which type of graft and which fixation technique were used in the primary ACLR. Placement of the tunnels can be classified according to Weiler et al.[8] as (1) correct, (2) incompletely incorrect, and (3) completely incorrect. The risk of the old and new tunnels converging is particularly high if the tunnels are incompletely

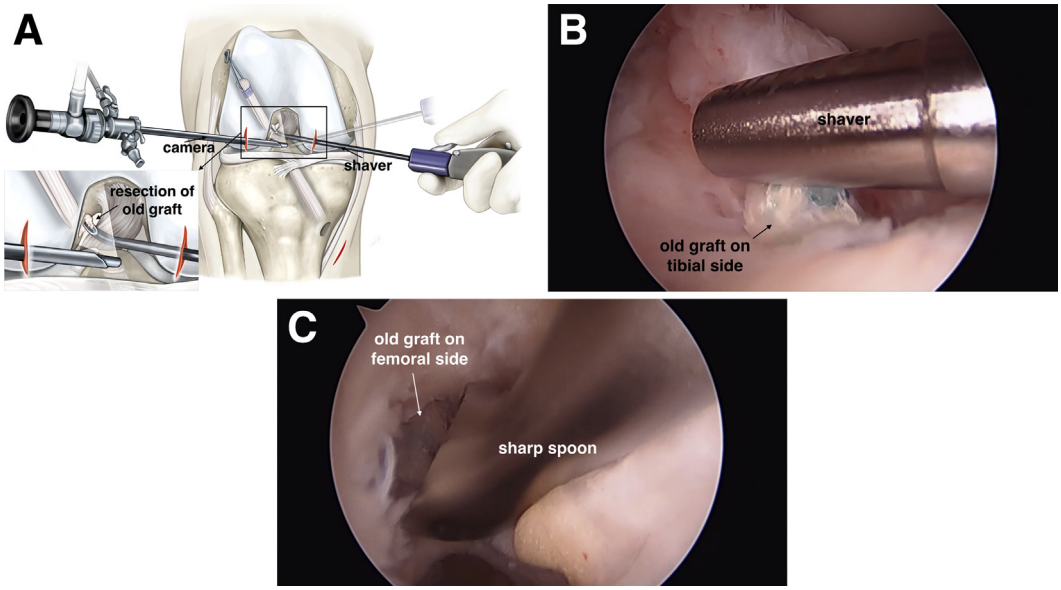

Fig 2. An arthroscope placed in the anterolateral portal in the patient's right knee is used to visualize the remnants of the primary anterior cruciate ligament graft. The standard anteromedial portal is used as a working portal, and the shaver is used to remove old graft material on the femoral side (A) and tibial side (B). (C) The entrance of the old femoral bone tunnel can be prepared with a sharp spoon.

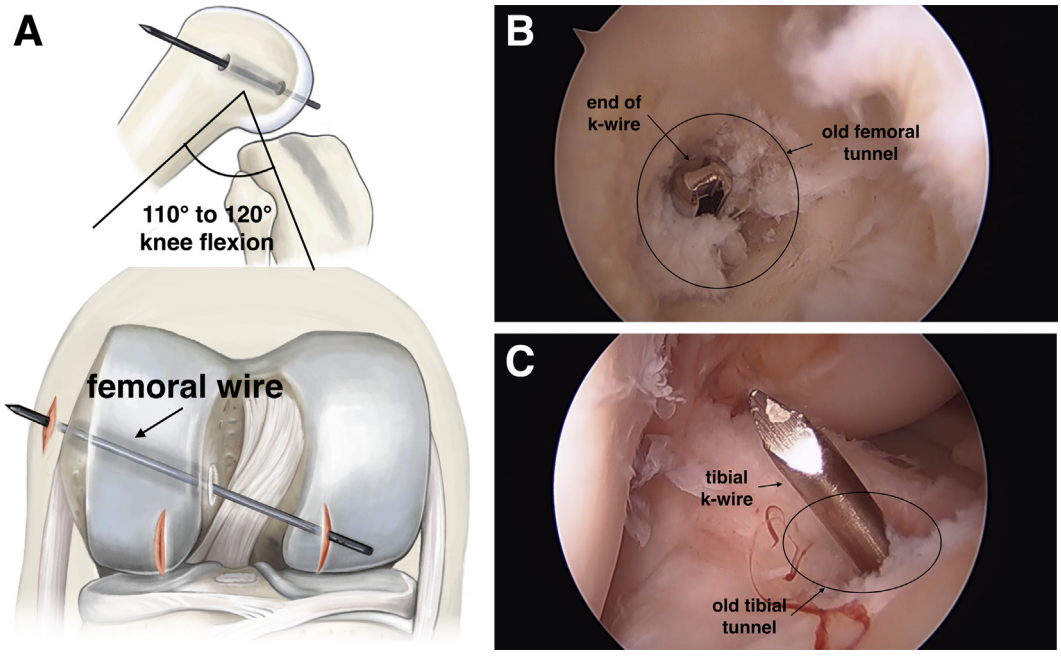

Fig 3. The femoral bone tunnel is marked with a Kirschner wire inserted through the anteromedial portal. (A) The knee must be flexed more than 100° in most cases to facilitate the insertion of the Kirschner wire into the old femoral bone tunnel. (B) Under arthroscopic control with the arthroscope placed in the anterolateral portal, the Kirschner wire (k-wire) is inserted into the old femoral bone tunnel until the distal end of the wire is visible at the beginning of the femoral bone tunnel. (C) The tibial Kirschner wire is inserted into the old tibial bone tunnel over the tibial incision under arthroscopic control.

incorrectly positioned. In these cases, a 2-stage procedure may be required even if the tunnel diameter measures less than 10 mm.

First-Stage Procedure

Video 1 and Figures 1 to 9 summarize the most important steps of the first-stage procedure. The first-stage procedure includes an examination of the patient under anesthesia and diagnostic arthroscopy to confirm ACLR failure or graft rupture. Any chondral and/or meniscal lesions discovered are repaired during this procedure. If (chronic) infection of the primary graft is suspected, all of the foreign materials should be removed initially and several microbiological samples taken to exclude this. Tunnel augmentation should take place only when the absence of any infection has been confirmed. The tunnels can be filled as planned if there is no suspected infection. First, both of the prior femoral and tibial tunnels are explored. Any remnants of the old sutures and fixation material (e.g., interference screw) must be removed completely (Fig 1). The femoral tunnel is prepared first. Its entry is located and opened with a shaver and spoon curette (Fig 2). A Kirschner wire (K-wire) can then be inserted into the tunnel in a retrograde manner via the femoral drill guide (Fig 3). If the position of the femoral tunnel makes this impossible, an anterograde approach with overdrilling of the tunnel with a K-wire can also be

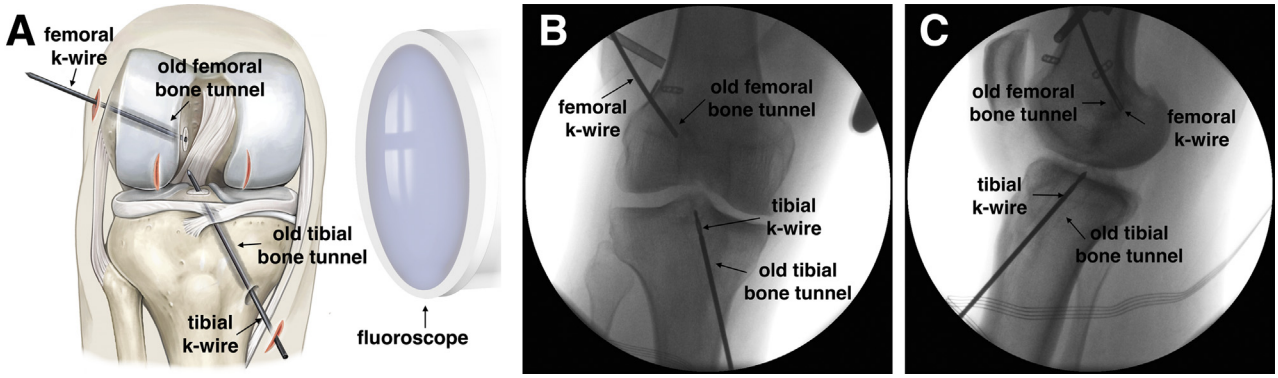

Fig 4. (A) Placement of the Kirschner wires (k-wires) in the old femoral and tibial tunnels. Anteroposterior (B) and lateral (C) intraoperative fluoroscopy of a patient's right knee confirms correct placement of the Kirschner wires in the old femoral and tibial bone tunnels.

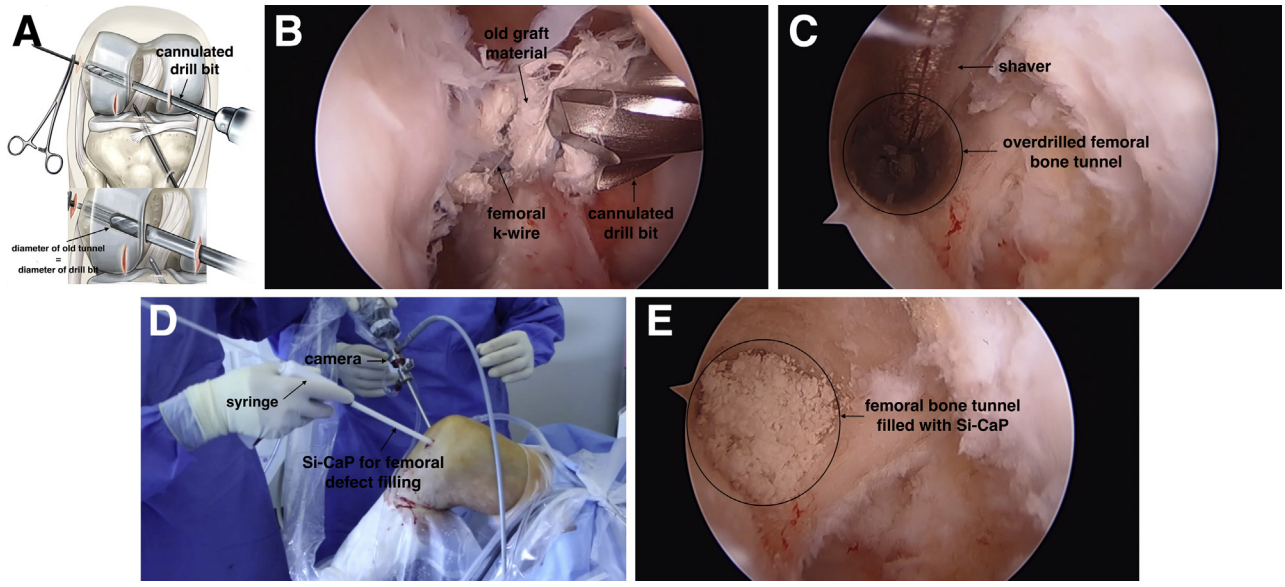

Fig 5. (A) The femoral Kirschner wire is overdrilled with a cannulated drill bit, starting from 4 mm, until the diameter of the old femoral bone tunnel has been reached. (B) An arthroscope placed in the anterolateral portal in the patient's right knee is used to visualize the Kirschner wire (k-wire) and drill bit. (C) After the diameter of the femoral bone tunnel has been reached, the drill bit and femoral Kirschner wire can be removed. A shaver, which is inserted into the anteromedial working portal, can be used to clean remnants of the old graft from the femoral bone wall. (D) The bone graft substitute silicate-substituted calcium phosphate (Si-CaP) is inserted through the anteromedial working portal into the femoral bone tunnel with a syringe. (E) Complete filling of the femoral bone tunnel can be verified arthroscopically.

used. Next, the tibial tunnel is located via the prior tibial incision. Again, a K-wire is inserted into the prior tunnel under arthroscopic control. Once both of the old tunnels have been marked with K-wires, intraoperative fluoroscopy is used to confirm correct placement of the wires in the center of the prior tunnels (Fig 4). Their position can be adjusted at this point if necessary. The femoral tunnel is then gradually overdrilled with a

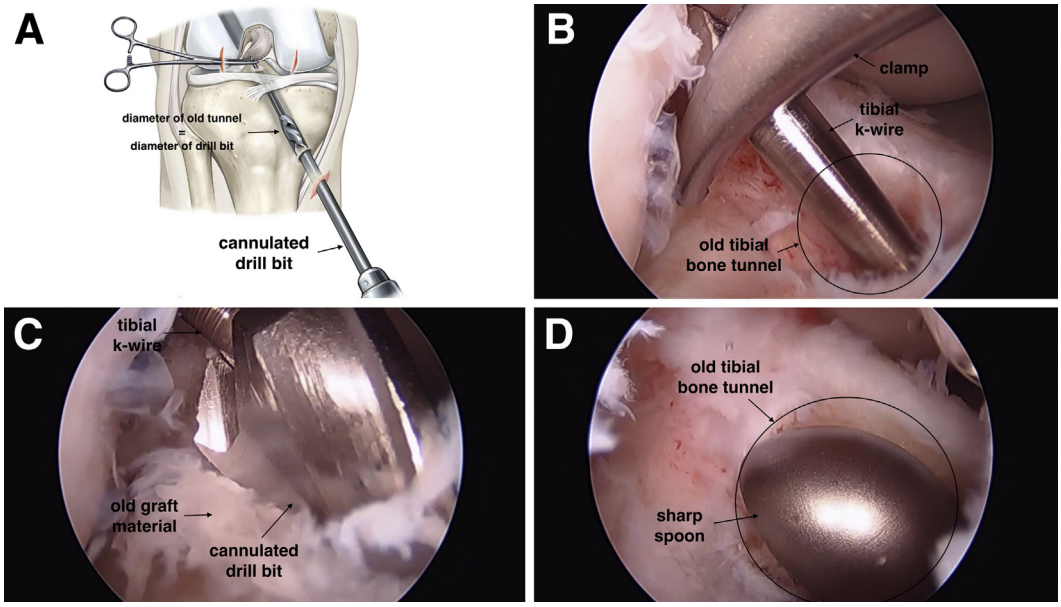

Fig 6. (A) The tibial Kirschner wire is overdrilled with a cannulated drill bit, starting from 4 mm, until the diameter of the old tibial bone tunnel has been reached. (B) An arthroscope placed in the anterolateral portal in the patient's right knee is used to visualize the tibial Kirschner wire (k-wire). A clamp can be used through the standard working portal to secure the tibial Kirschner wire during overdrilling. (C) The cannulated drill bit should be used under arthroscopic control to prevent damage to the femoral cartilage and the posterior cruciate ligament. (D) After the diameter of the tibial bone tunnel has been reached, the drill bit and tibial Kirschner wire can be removed. In the case of remaining remnants and/or sclerosis on the tibial tunnel wall, a shaver or sharp spoon can be used through the tibial incision.

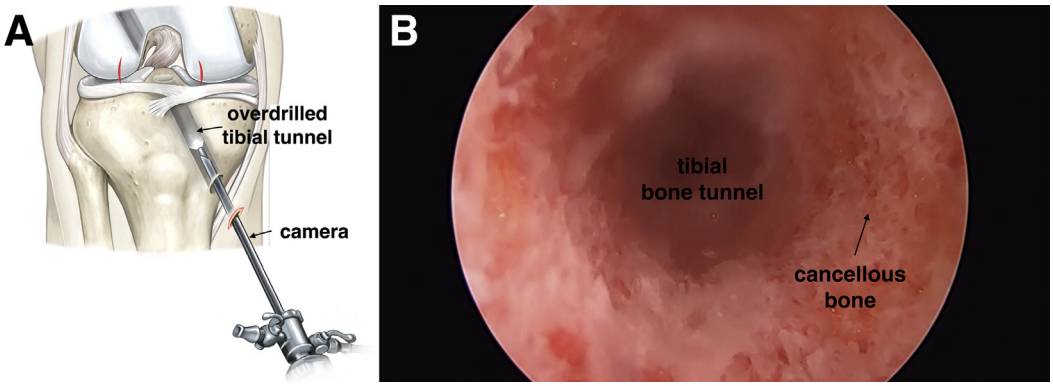

Fig 7. (A) After the tibial tunnel has been overdrilled until reaching the diameter of the old tibial bone tunnel, the arthroscope can be introduced into the tibial bone tunnel through the tibial incision to look for remaining graft material and/or sclerosis. (B) An arthroscope placed in the overdrilled old tibial bone tunnel in the patient's right knee shows bleeding and cancellous bone.

cannulated drill bit, starting from 4 mm, until the tunnel diameter is reached (Fig 5). This will remove any remnants of the primary graft and sclerotic margins. The femoral tunnel can be filled with the bone graft substitute Si-CaP once it has been completely overdrilled and all sclerotic tissue removed. For tunnel

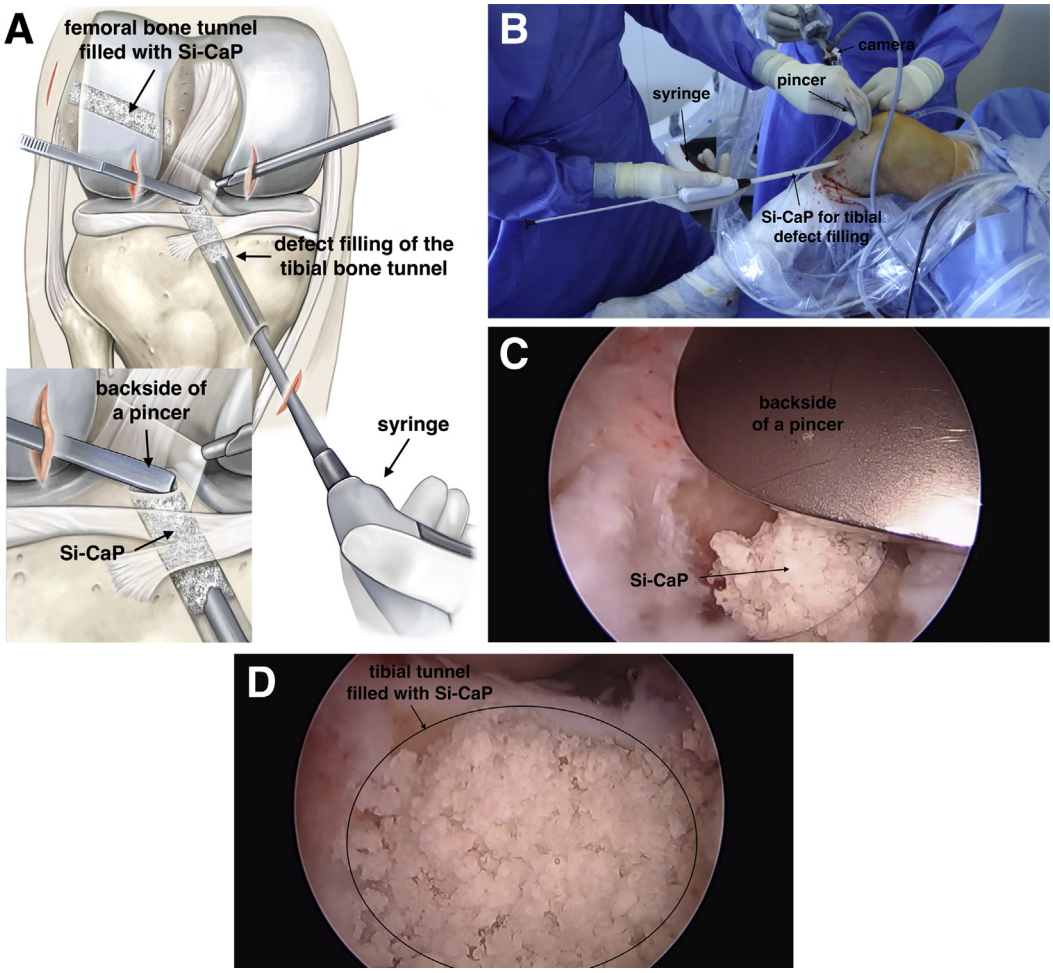

Fig 8. (A) Defect filling of the tibial tunnel with silicate-substituted calcium phosphate (Si-CaP). (B) The bone graft substitute Si-CaP is inserted through the tibial incision into the tibial bone tunnel with a syringe. (C) An arthroscope placed in the anterolateral portal in the patient's right knee is used to visualize the entrance of the overdrilled tibial bone tunnel and syringe. The backside of a pincer is used through the anteromedial portal to protect the articular side of the tibial bone tunnel to prevent Si-CaP slippage into the joint during the application with the syringe. (D) Complete filling of the tibial bone tunnel can be verified arthroscopically.

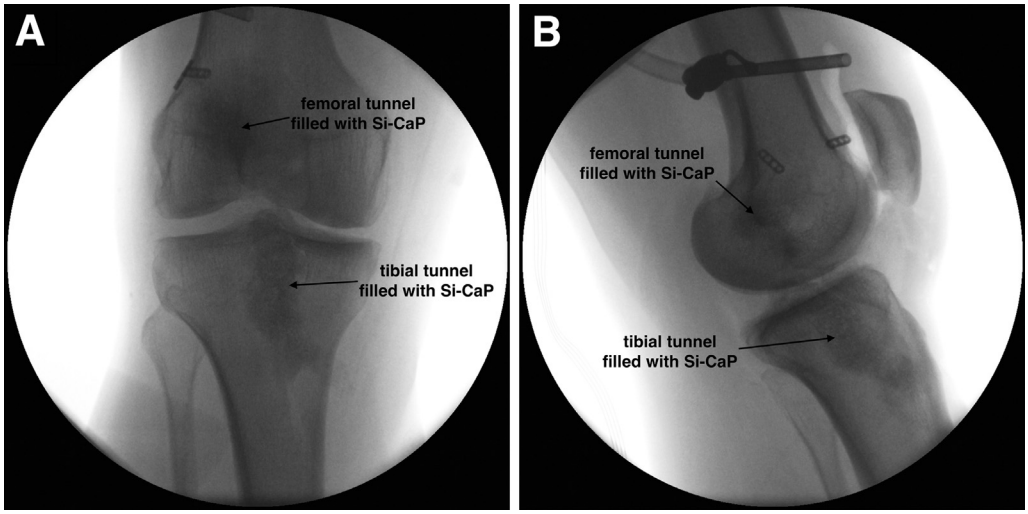

Fig 9. Anteroposterior (A) and lateral (B) intraoperative fluoroscopy of a patient's right knee confirms correct defect filling of the old femoral and tibial bone tunnels with silicate-substituted calcium phosphate (Si-CaP).

augmentation, Si-CaP in the form of microgranules that are able to be sculpted (Actifuse MIS System; Baxter, Unterschleißheim, Germany) as a bone graft substitute is used. As with bone cement, the tunnel is filled using a syringe. Care must be taken to avoid granulate spilling into the joint. Any excess granulate needs to be removed with the shaver. The tibial canal is filled using the same procedure (Fig 6). As before, the K-wire is overdrilled from 4 mm to the prior tunnel diameter. After the tibial tunnel has been overdrilled until reaching the diameter of the old tibial bone tunnel, the arthroscope can be introduced into the tibial bone tunnel through the tibial incision to look for remaining graft material and/or sclerosis (Fig 7). If necessary, any remaining sclerotic margins can be broken up and removed with a spoon curette or shaver. The tibial tunnel is then filled with the bone graft substitute Si-CaP (Fig 8). This must always be carried out under arthroscopic control. The backside of a pincer is used to cover the articular end of the tibial tunnel to prevent any granulate from being spilled into the joint. Finally, intraoperative fluoroscopy is used to confirm and document that the tunnels are completely filled with the bone graft substitute (Fig 9).

Weight bearing is limited to 20 kg during the first 6 weeks postoperatively, without restrictions on range of motion. Any activities putting a strain on the knees must be avoided until the second-stage operation. Five months after the first-stage procedure, consolidation of the bone graft substitute is verified by CT, followed by the second-stage operation at 6 months.

Second-Stage Procedure

The second-stage procedure also begins with a diagnostic arthroscopy of the affected knee with the patient under general anesthesia. Any concomitant meniscal or

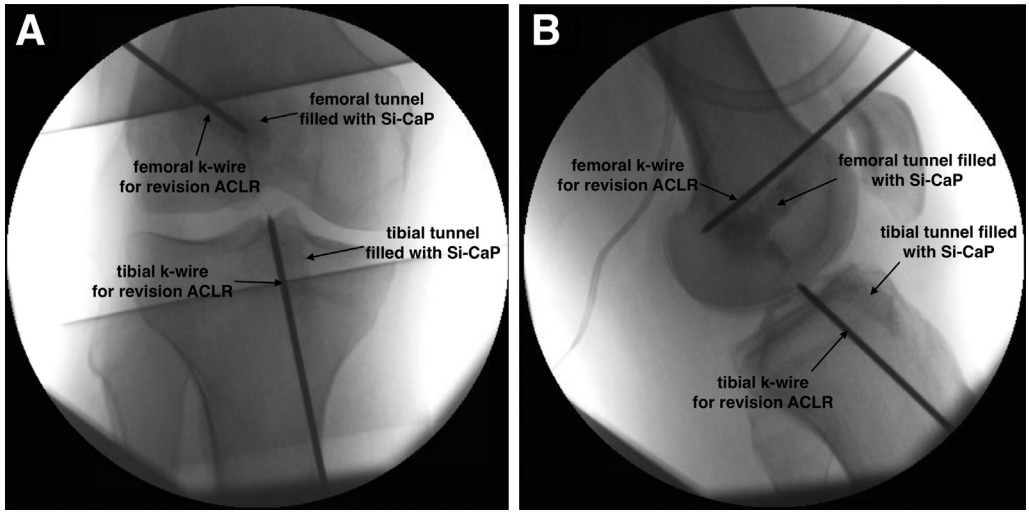

Fig 10. Intraoperative anteroposterior (A) and lateral (B) fluoroscopy of a patient's right knee shows the correct placement of the new Kirschner wires (k-wires) for revision anterior cruciate ligament reconstruction (ACLR). The position of the prior tunnels has no bearing on where the wires are placed during the second-stage procedure. (Si-CaP, silicate-substituted calcium phosphate.)

Table 1. Pearls and Pitfalls of Surgical Technique

Pearls
Bear in mind that preoperative assessment of the primary tunnels by CT is essential.
Mark the old tunnels with Kirschner wires.
Overdrill the Kirschner wires to the diameter of the prior tunnel.
Completely remove any remaining graft tissue and sclerotic margins present.
Completely fill the tunnels with Si-CaP bone graft substitute.
Verify and document tunnel augmentation with intraoperative fluoroscopy.
Pitfalls
Bear in mind that any spilled granulate must be completely removed from the joint.
Instruct the patient to limit weight bearing to 20 kg for the first 6 wk after tunnel augmentation.
Instruct the patient to avoid any activities straining the knee until ACL regrafting occurs.

ACL, anterior cruciate ligament; CT, computed tomography; Si-CaP, silicate-substituted calcium phosphate.

chondral lesions need to be identified and repaired. Revision ACLR can then be carried out as normal. The new tunnels can be positioned freely. We proceed as follows: First, the tibial and femoral tunnels are positioned with K-wires. Anatomic placement is then verified by intraoperative fluoroscopy (Fig 10). The ipsilateral semitendinosus tendon is the preferred ACL graft. If this has been used for the primary surgical procedure, we use the contralateral semitendinosus tendon for grafting. We currently use the FlipCutter (Arthrex, Naples, FL) to ream 20- or 25-mm blind sockets with the same diameter as the graft. Femoral fixation of the graft is achieved with a TightRope RT implant (Arthrex), and tibial fixation is performed with a TightRope ABS Implant and Button (Arthrex). The graft is tensioned with the knee in a neutral position, followed by intraoperative fluoroscopy to verify correct tension and document the position of the Buttons (Arthrex). The pearls and pitfalls of this surgical technique are summarized in Table 1.

Follow-up after second-stage surgery is identical to that after primary ACLR. The aim is full weight bearing within 1 week. Knee flexion is restricted to 90° during the first 10 days postoperatively. Full range of motion is then permitted. Return to contact sports is allowed after 6 months if the patient has no effusion and has full range of motion, the knee is stable, and muscle strength is at least 90% of that of the contralateral leg. Exercise is restricted to low impact (i.e., with ground contact) for 6 weeks if microfracturing has been carried out and 8 weeks if meniscal repair has been performed.

Discussion

As the number of primary ACLRs is increasing, revision ACLR is becoming increasingly important.[18,19] Failure analysis is a vital element of preoperative planning for revision ACLR. According to the current literature, incorrect tunnel placement is the most common cause of primary ACLR failure.[6] Ascertaining the position of the primary tunnels must therefore always be part of the preoperative evaluation before any planned revision. No attempt should be made to use incompletely or completely incorrectly positioned tunnels for the revision, irrespective of their diameter.[8] We therefore recommend a 2-stage procedure with tunnel augmentation in cases in which there is any doubt. This enables new placement of the tunnels during the second procedure. Furthermore, we routinely mark the tunnel positions with K-wires during both primary and revision ACLR and verify the placement with intraoperative fluoroscopy to avoid malpositioning.

Numerous studies on alternatives to conventional autologous bone graft for tunnel augmentation have been published in recent years.[10,13] As well as autologous bone, allogeneic bone and synthetic bone graft substitutes can be used. Technical descriptions are available for most procedures, but satisfactory clinical data and histologic results are lacking. The technique using the synthetic bone graft substitute Si-CaP described in this article was investigated in a published prospective, randomized controlled trial.[20,21] The tunnels were filled with autologous iliac crest cancellous bone in the control group. A preliminary study was conducted for both histologic and radiologic analyses of the bone graft substitute Si-CaP.[20] Punch biopsy specimens from the augmented tunnels were taken during the second-stage procedure, and histologic examination included quantitative analysis of the area of immature bone formation, lamellar bone, and bone marrow. In the aforementioned study, we showed that use of Si-CaP as a bone graft substitute for tunnel augmentation in 2-stage revision ACLR yielded good histologic and radiographic findings comparable to those of autologous bone. Analysis of the clinical outcomes after an average follow-up period of 3 years showed significant improvement in sagittal stability and functional scores in both groups, without any difference between the 2 groups.[21] Compared with other methods, the described technique of filling the tunnels

Table 2. Advantages and Disadvantages of Surgical Technique

Advantages
No harvesting morbidity
Simple application into bone deficiency
Shorter operation time
Intraoperative assessment with fluoroscopy possible
New bone formation from bone substitute material
Free placement of new tunnels possible
Disadvantages
Higher costs in comparison to autologous cancellous bone
6-mo interval required between the 2 procedures

with the bone graft substitute Si-CaP is straightforward and has few complications (Table 2). In addition, we showed that blood loss during tunnel augmentation, determined by measuring perioperative hemoglobin levels, was significantly lower in the intervention group. No Si-CaP–related complications occurred during the study.

One potential limitation of the described technique is that it is difficult to assess the degree of bone consolidation in the bone graft by postoperative CT. Our protocol prescribes a minimum period of 6 months between tunnel augmentation and revision ACLR. In our experience, the bone graft substitute was always fully integrated at the time of revision ACLR, which enabled stable fixation of the new graft. The results of the prospective, randomized controlled study showed promising 3-year outcomes with this method.[21] Further studies are needed to describe the long-term outcomes of this technique.

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