Technical Note

An Arthroscopic Procedure for Restoration of Posterolateral Tibial Plateau Slope in Tibial Plateau Fracture Associated With Anterior Cruciate Ligament Injuries

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Abstract: High-energy anterior cruciate ligament (high-energy ACL) injury, occurring in high-energy rotatory trauma of the knee, can accompany a unique fracture pattern that involves depression of the slope of the posterolateral tibial plateau (PLTP). These injuries are challenging to manage due to the lack of a gold-standard arthroscopic procedure that addresses both ACL deficiency and depressed PLTP slope. In such injuries, a one-stage approach may be used to (1) reconstruct the ACL or (2) reduce and fix the avulsed tibial spine, while concomitantly performing an arthroscopy-assisted reduction of a PLTP fracture that restores the anatomic slope of the tibial plateau. To summarize, using combined arthroscopic and fluoroscopic visualization, a tibial tunnel reaching 1 cm distal to the depressed plateau fragment is created using a cannulated drill. The drill is used to punch up the depressed fragment to its anatomic location, restoring the original slope of the PLTP. The corrected slope is then fixed in situ using a press-fit fibular allograft to stabilize the corrected PLTP slope. Use of this minimally invasive arthroscopic technique to restore the PLTP slope may help prevent graft failure of the reconstructed ACL and improve patient outcomes.

Anterior cruciate ligament (ACL) injuries frequently are associated with concomitant ligamentous and meniscal injuries, as well as osseous injuries like tibial plateau fractures and Segond fractures.[1] In cases of ACL ruptures and tibial spine avulsions where the mechanism of injury involves high-energy internal rotation and anterior translation of the tibia, a more traumatic collision of lateral femoral condyle on the posterolateral tibial plateau (PLTP) may occur and cause a fracture of the posterolateral plateau. This type of injury, often seen in high-velocity ski accidents, can lead to a unique fracture pattern that involves depression of the slope of the PLTP ("high-energy ACL" injury). In contrast to the PLTP injuries that coincide with the site of the typical "pivot shift" bone contusions seen in low-velocity injuries, the coronal plane plateau fracture in this particular injury is accompanied by an acute change in the slope of the posterior plateau (Figs 1-3). This fracture pattern does not conform to conventional trauma classification systems of tibial plateau fractures, which typically only take into account combinations of axial loading with varus or valgus forces and describe mainly sagittal plane fractures and central joint depressions. The "high-energy ACL" injuries described here occur with flexion and a rotatory mechanism typical of ACL tears but at greater energy. Clinically, surgical management of "high-energy ACL" injuries are challenging due to the presence of concurrent ACL deficiency and the need to correct the depression of the slope of the PLTP.

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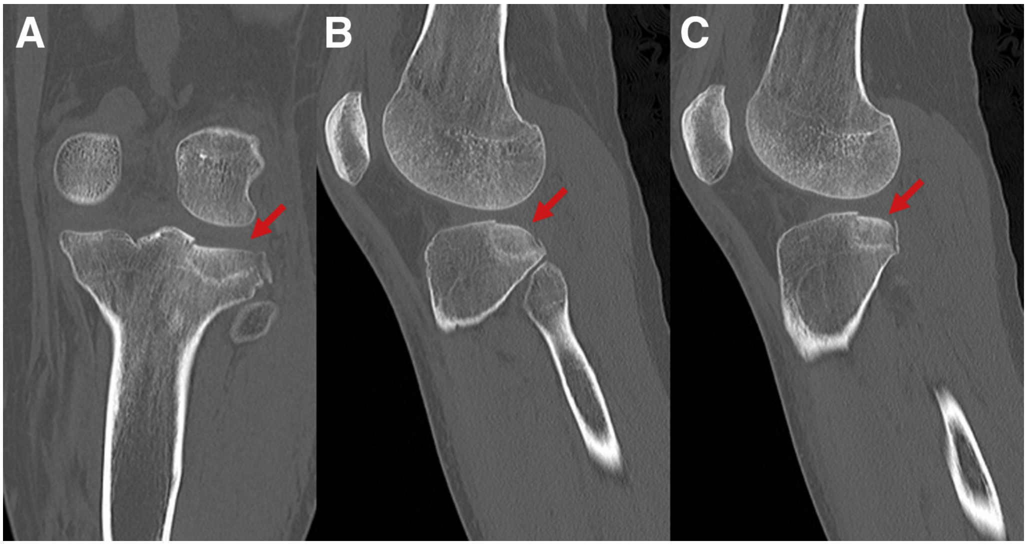


Fig 1. Preoperative computed tomography scan images of a left knee. A fracture of the posterolateral tibial plateau (red arrows) is visualized on the (A) coronal and (B, C) sagittal views. An acute depression of posterolateral tibial plateau slope is visualized on (B), marked by the red arrow.

A growing body of literature has demonstrated the association between steep posterior tibial plateau slope with an increased risk of ACL rupture,[2-4] as well as a significantly increased risk of graft failure of the reconstructed ACL.[3-5] In fact, a recent study by Grassi et al.[4] has shown that the most accurate predictor of ACL graft failure was a steep PLTP slope measuring greater than 7.4°. Therefore, in cases of PLTP fracture occurring in the context of a "high-energy ACL" injury, initial recognition and surgical restoration of the anatomic PLTP slope represents a crucial opportunity to prevent failure of the reconstructed ACL.[4-10]

Presently, there is no consensus on the optimal timing or a gold-standard surgical procedure for this type of tibial plateau fractures associated with "high-energy ACL" injuries.[1,11] This necessitates surgical innovation and development of a procedure that maximizes postoperative functional outcome while minimizing the duration of discomfort and morbidity associated with operative management. A 1-stage, minimally invasive procedure that addresses both the ACL deficiency and

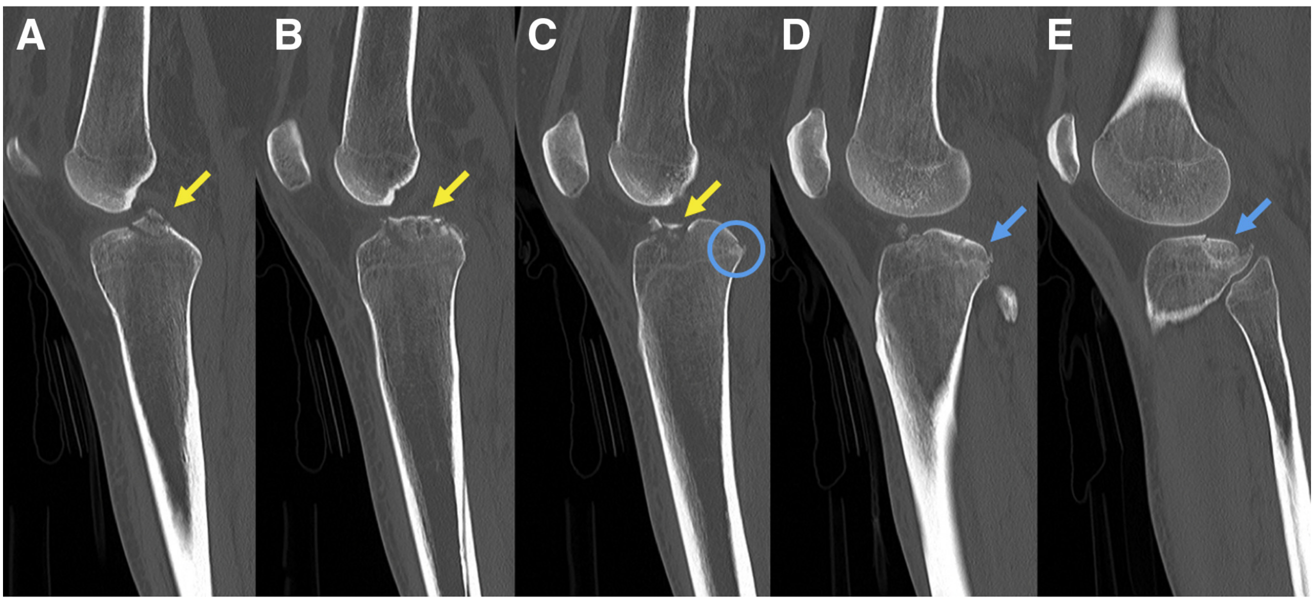


Fig 2. Preoperative computed tomography scan images of a right knee, sagittal view. A complete avulsion fracture of the tibial spine (yellow arrows) is visualized on (A-C). On (C), a fracture of the posterolateral tibial plateau is marked by the blue circle. Extension of the fracture of the posterolateral tibial plateau and its depressed slope (blue arrows) can be seen on (D-E).

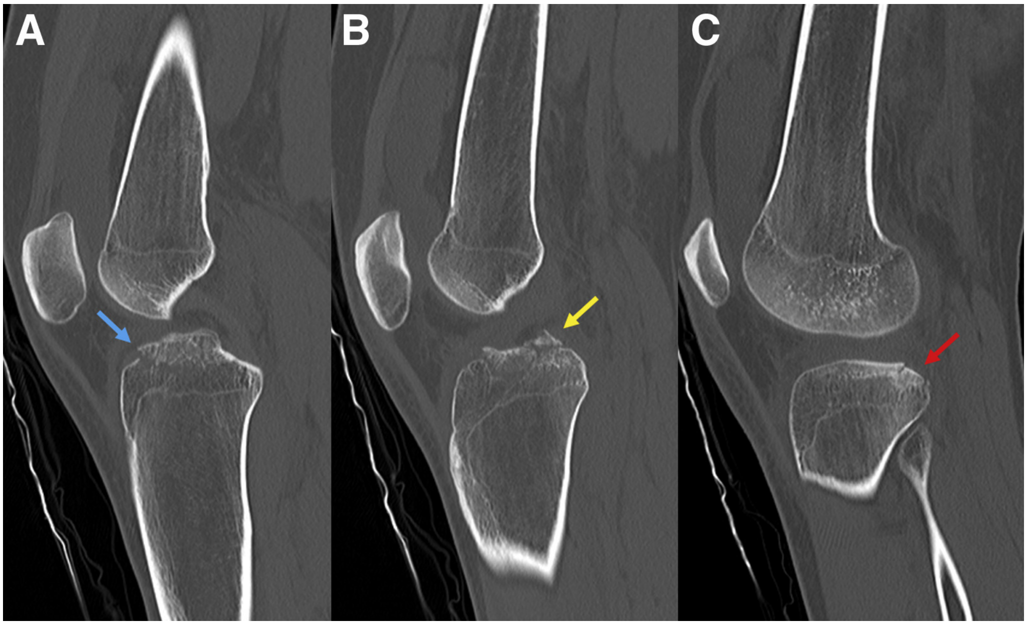


Fig 3. Preoperative computed tomography scan images of a right knee, sagittal view. (A) An avulsion fracture of the tibial spine (blue arrow) is visualized as hinged and lifted up anteriorly. (B) A bony avulsion of the posterior root of the lateral meniscus is identified (yellow arrow). (C) A fracture of the posterolateral tibial plateau is visualized, leading to depression of its slope (red arrow).

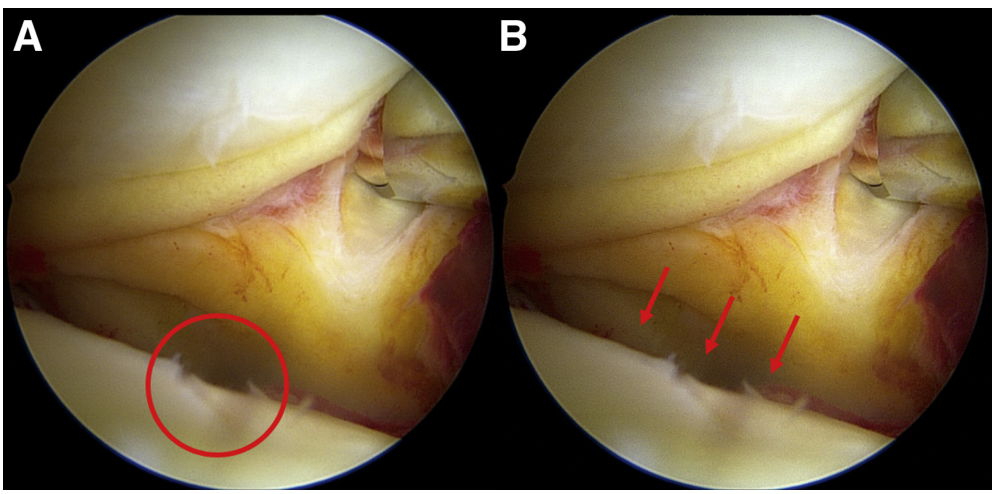
fracture of the PLTP in the acute phase of the injury may be the solution to this important surgical challenge.

Here, we describe a 1-stage procedure that combines (1) arthroscopic ACL reconstruction, (2) arthroscopic tibial spine fixation using the suture bridge technique,[12] or (3) transosseous tibial spine reduction and internal fixation, with a concomitant arthroscopy-assisted restoration of the PLTP slope using a fibula allograft.

Indications, Evaluation, and Imaging

The surgical technique described in this Technical Note is indicated in high-energy rotatory trauma of the knee that result in synchronous ACL deficiency (ACL rupture or tibial spine avulsion) and a coronal plane fracture of the PLTP that accompany an acute depression of its slope, thereby potentially contributing to rotatory instability of the knee. If any evidence of osseous injuries to the tibial plateau is present on plain radiograph in the context of high-energy rotatory trauma, a prompt acquisition of computed tomography is recommended to accurately evaluate the extent of the tibial plateau fracture and to visualize the slope of the PLTP. Computed tomography images will guide surgical planning and can be used as a reference intraoperatively. Magnetic resonance imaging is also

Fig 4. A diagnostic arthroscopy to visualize a fracture of the posterolateral tibial plateau, right knee. (A) The posterolateral tibial plateau fracture is seen as a mild articular step-off (red circle). (B) Posterior to the fracture, posterolateral tibial plateau cannot be visualized arthroscopically, representing a significant abrupt change in its slope (red arrows).



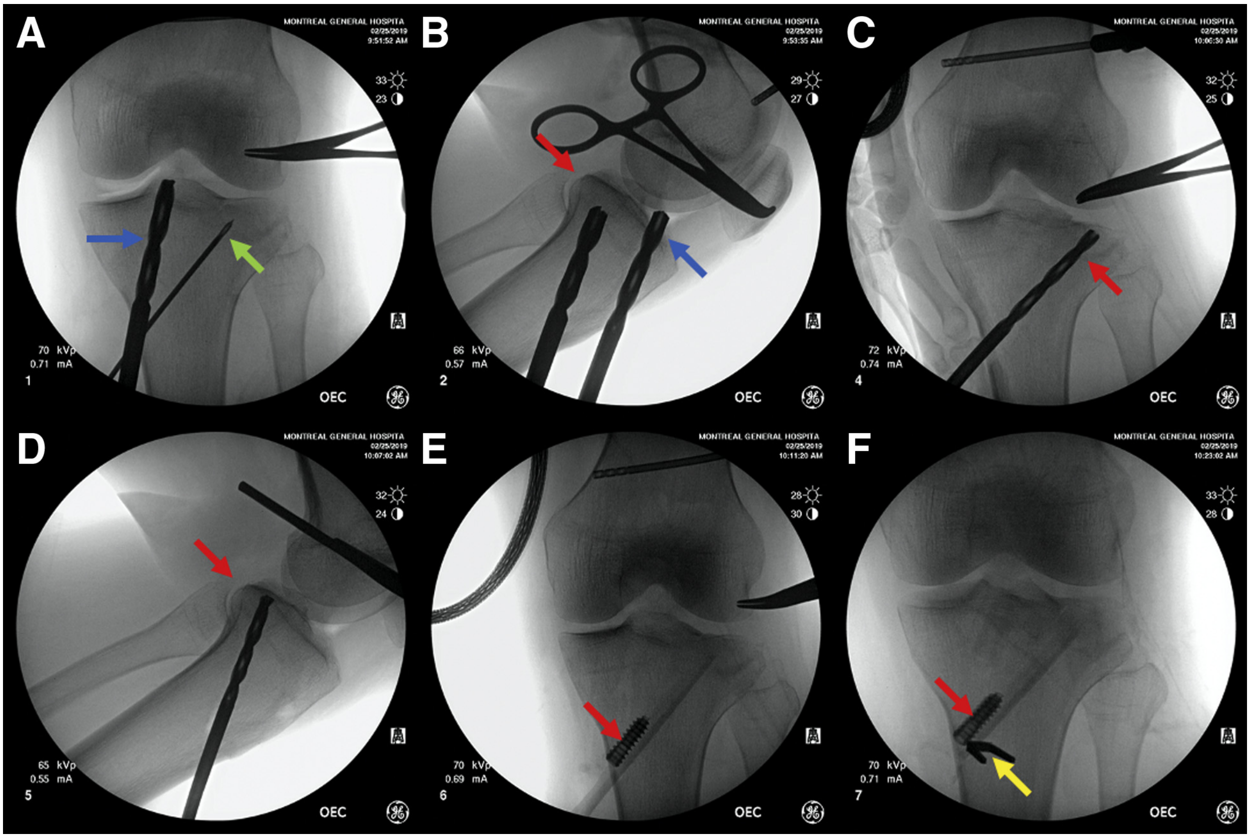


Fig 5. Intraoperative fluoroscopic visualization of the procedure sequence, left knee. (A) A guide pin (green arrow) is drilled from the anteromedial aspect of the tibia to 1 cm distal to the depressed fragment of the posterolateral plateau. The drill used for creating a tibial tunnel for anterior cruciate ligament reconstruction is left in situ (blue arrows in A, B) to prevent convergence with a second tunnel that will be drilled for the restoration of the posterolateral plateau slope. (B) The guide pin is overdrilled with a cannulated drill, which is placed beneath the posterolateral tibial plateau fracture and its depressed slope (red arrow). (C) The cannulated drill (red arrow) is then used to bluntly punch up the depressed plateau fragment. (D) Anatomic restoration of the posterolateral tibial plateau slope (red arrow) is visualized. (E) A fibular allograft is press fitted in the tunnel created by the drill, followed by a placement of an interference screw (red arrow in E, F) to lock the fibular allograft in place, and to prevent loss of reduction of the posterolateral tibial plateau. (F) A final fluoroscopic visualization is performed after fixing the anterior cruciate ligament allograft in the femur and tibia with a staple (yellow arrow).

indicated for the assessment of concomitant associated soft-tissue injuries. The surgical technique is described to follow, with its application in 2 clinical scenarios: a PLTP fracture with an acute depression of its slope (Fig 1), accompanied by (1) a concomitant complete ACL rupture, or (2) an avulsion of the tibial spine (Figs 2 and 3).

Surgical Technique

Operative Management of ACL Deficiency

The procedure begins with a standard 3-portal diagnostic arthroscopy to visualize the PLTP fracture and other intra-articular osseous and ligamentous injuries. The PLTP fracture is often seen as a mild articular step-off (Fig 4A), but a significant abrupt change in posterolateral plateau slope (Fig 4B) is also visualized. After initially addressing any meniscal injuries, attention is brought to injuries responsible for ACL deficiency.

Complete ACL Rupture

In injuries that accompany a complete ACL rupture, the native ACL stump is removed, exposing the tibial and femoral anatomic footprints. The ACL autograft or allograft, depending on the clinical context and the preference of the surgeon and the patient, is simultaneously prepared. An appropriately sized femoral tunnel is drilled (ACUFEX DIRECTOR ACL System; Smith & Nephew, Andover, MA), followed by a tunnel drilled in the tibia. This drill is left in the tibial ACL tunnel to prevent tunnel convergence with the second tunnel that is drilled for the restoration of the PLTP slope (Fig 5; described in detail to follow). Femoral fixation of the graft is performed as per the surgeon's preference (in this case ENDOBUTTON; Smith & Nephew) but is

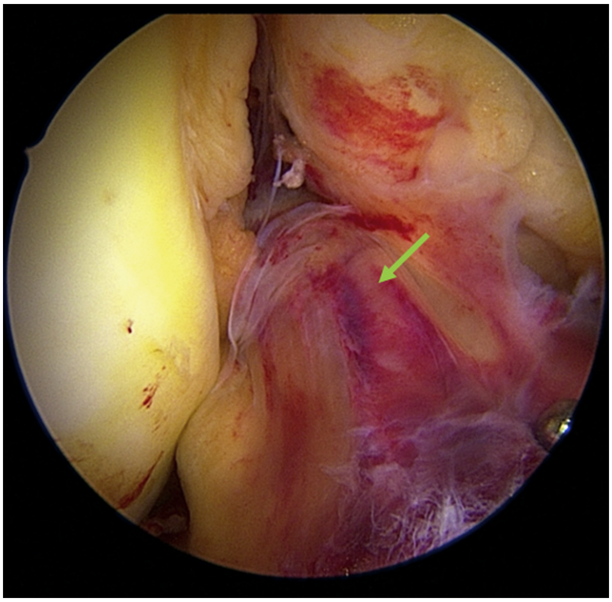


Fig 6. Arthroscopic visualization of the anterior cruciate ligament (green arrow), right knee. In PLTP fracture associated with an avulsion of tibial spine, the anterior cruciate ligament is thoroughly examined to confirm the lack of intrasubstance ligamentous injury.

performed only after the restoration of the PLTP slope is completed.

Tibial Spine Avulsion (With Video Illustration)

"High-energy ACL" injuries may be associated with both complete and partial avulsions of the tibial spine. For complete avulsions, once the absence of an intrasubstance ACL injury is confirmed (Fig 6), the tibial spine avulsion is repaired arthroscopically using the suture bridge technique, as previously described.[12] This suture bridge fixation technique allows for both anatomic reduction and secure fixation of the tibial spine through a minimally invasive, arthroscopic approach.

For partial tibial spine avulsions, that are hinged and lifted up anteriorly (Video 1), the avulsed tibial spine fragment is reduced and held in place with a tibial guide (ACUFEX DIRECTOR Drill Guide; Smith & Nephew; Fig 7A). A guide pin is drilled into the tibial spine (Fig 7B), which is then overdrilled with a cannulated drill (Fig 7C). Two high-tensile sutures (ULTRABRAID Suture #2, Smith & Nephew; FiberWire Suture #2, Arthrex, Naples, FL) are passed through the ACL in a suture hitch configuration (Fig 7D) and one through the

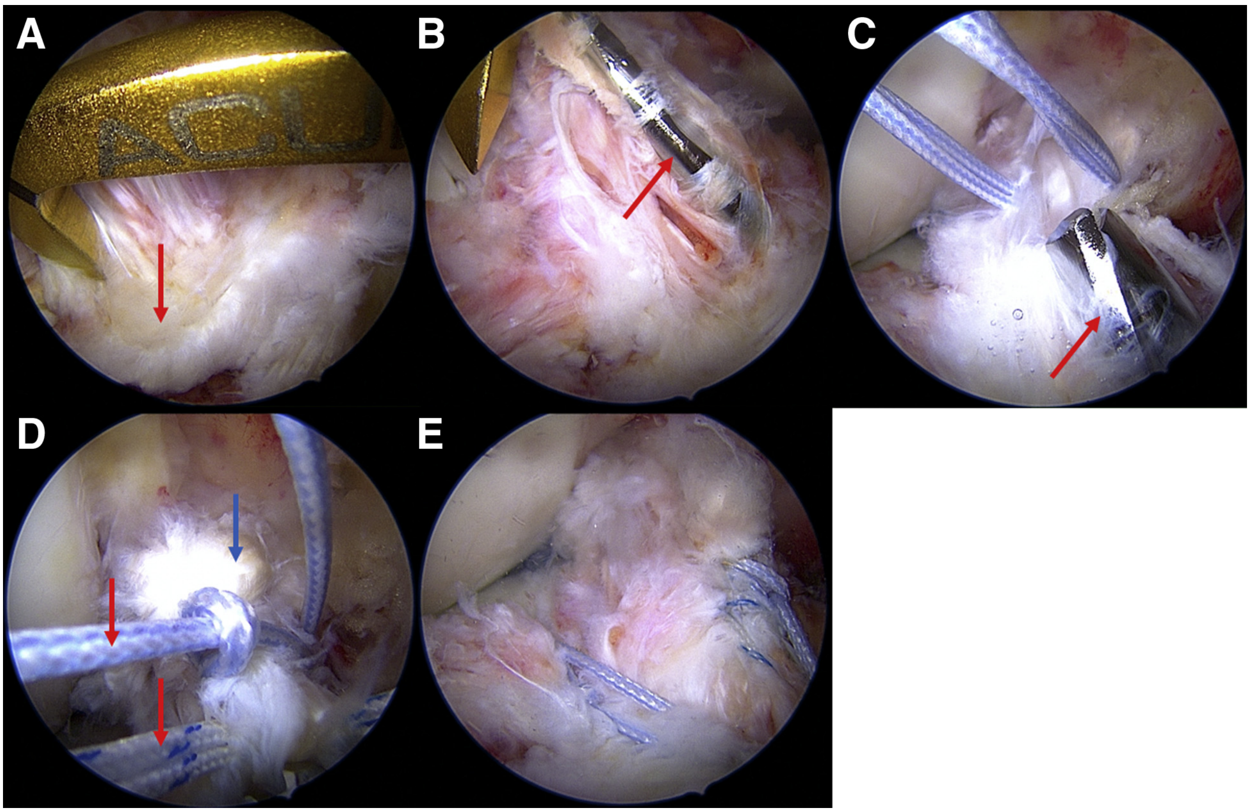


Fig 7. Arthroscopic visualization of procedure sequence for reduction of tibial spine avulsion, right knee. (A) The avulsed tibial spine fragment (red arrow) is reduced and held down in place with a tibial drill guide. (B) A guide pin (red arrow) is drilled through the tibial spine. (C) The guide pin is then over-drilled with a cannulated drill (red arrow). (D) Two high-tensile sutures (red arrows) are passed through the anterior cruciate ligament (blue arrow) in a suture hitch configuration and one through the anterior root ligament of the lateral meniscus. (E) The sutures are then pulled through the created tibial tunnel to achieve anatomic reduction of the avulsed tibial spine.

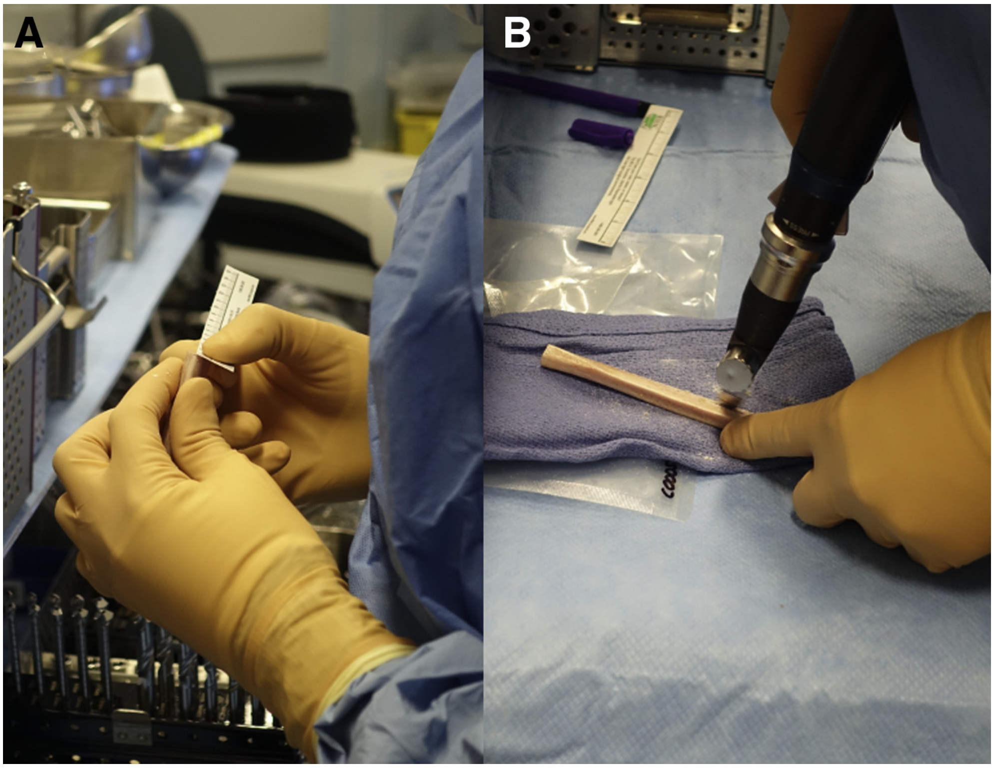


Fig 8. Intraoperative preparation of a fibular allograft. (A) The entire fibular graft is sized to fit the selected drill size. (B) The fibular graft is then cut with a bone saw to the measured dimensions. The subarticular aspect may be cut on an angle flush with the joint level.

anterior root ligament of the lateral meniscus to ensure optimal tension. These sutures are pulled through the tibial tunnel to achieve anatomic reduction of the avulsed tibial spine (Fig 7E). The sutures are then tied over a cortical button (25-mm ENDOBUTTON; Smith & Nephew) on the anteromedial tibia.

Restoration of the Anatomic PLTP Slope

Combined arthroscopic and fluoroscopic visualization is used to accurately restore the PLTP slope (Video 1). A fibula allograft is prepared by cutting the subarticular aspect on an angle flush with the joint level. The entire fibular graft is sized to fit the selected drill size (Fig 8). A guide pin is then triangulated from the anteromedial aspect of the tibia, toward the depressed plateau fragment (Fig 9A). Once the guide pin is positioned within 1 cm of the center of this fragment (Fig 9 B and C), it is then overdrilled with a cannulated drill (Fig 9D). Fluoroscopic guidance is employed to ensure accurate positioning of the drill while avoiding penetration into the joint. The drill is then used to bluntly punch up the depressed fragment back to its original anatomic location, restoring the slope of the PLTP (Fig 9E). Confirmation of the restored PLTP slope is achieved using both fluoroscopy and arthroscopy. This corrected slope is fixed in situ by press fitting the prepared fibula allograft in the tunnel created by the drill (Fig 9F), followed by the placement of an interference screw (7 × 25-mm SOFTSILK screw; Smith & Nephew) to lock the fibula allograft in place (Fig 9G) to prevent loss of reduction of the PLTP, to stabilize the corrected slope, and avoid backing out of the fibula allograft. Finally, reduction of the plateau step-off is visualized on fluoroscopy (Fig 9H), as well as on arthroscopy (Fig 10). The "pearls and pitfalls" associated with each major step of the procedure are highlighted on Table 1.

Postoperative Protocol

Postoperatively, patients are kept non-weightbearing on the operated limb for 12 weeks and are initiated on a postoperative physiotherapy protocol immediately to recover the range of motion of the knee and regain quadriceps function. Patients return for follow-up clinical assessments at 2 weeks, 6 weeks, 3 months, 6 months, and 1 year postoperatively as per our institutional standard post-ACL reconstruction follow-up protocol, in addition to radiological evaluations to confirm stable reduction and maintained slope of the PLTP (Figs 11-13).

Discussion

Despite advances in sports traumatology and arthroscopic techniques, the management of tibial plateau fractures associated with ligamentous injuries poses a major challenge for orthopaedic surgeons. Specifically, "high-energy ACL" injuries that result in the slope-steepening PLTP fracture pattern are particularly difficult to manage. In cases such as this, the coronal

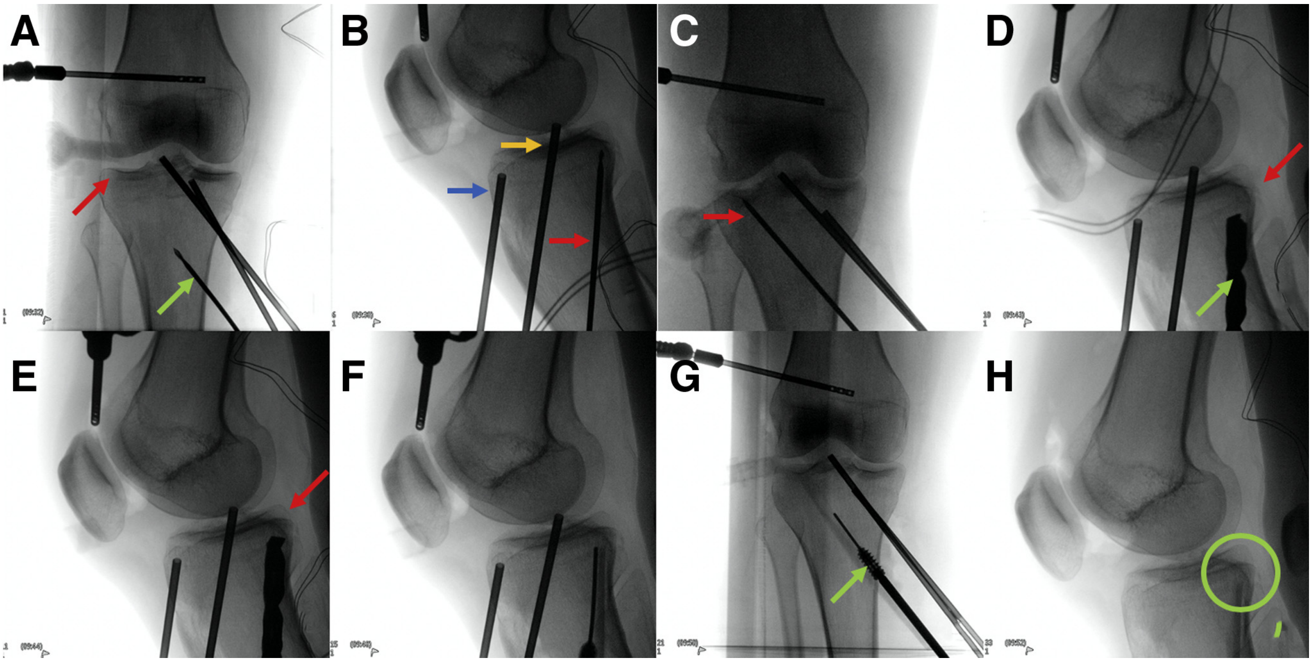


Fig 9. Intraoperative fluoroscopic visualization of the procedure sequence, right knee. (A) A guide pin (green arrow) is drilled from the anteromedial aspect of the tibia, towards the posterolateral tibial plateau (red arrow). (B) The guide pin (red arrow) is positioned within 1 cm distal to the depressed fragment of the posterolateral tibial plateau. The drills used to create tibial tunnels for reduction and fixation of the avulsed tibial spine (blue arrow) and repair of the avulsed lateral meniscal root (yellow arrow) are left in situ to prevent tunnel convergence. (C) Anteroposterior view to visualize accurate placement of the guide pin (red arrow). (D) The guide pin is overdrilled with a cannulated drill (green arrow), which is then placed beneath the depressed posterolateral tibial plateau slope (red arrow). (E) The drill is used to bluntly punch up the depressed plateau fragment, restoring the anatomic slope of the posterolateral tibial plateau (red arrow). (F) Placement of a fibular allograft in the tunnel created. (G) An interference screw (green arrow) is used to lock the fibular allograft in place, to prevent loss of reduction of the posterolateral tibial plateau and to stabilize the corrected slope. (H) A final fluoroscopic visualization of the restored posterolateral tibial plateau slope (green circle).

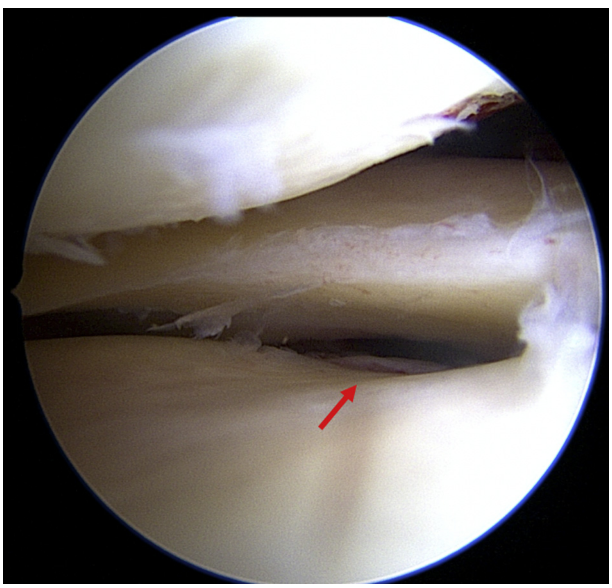


Fig 10. Arthroscopic visualization of successful reduction of posterolateral plateau step-off, right knee. Following fluoroscopy-guided procedure sequence, the reduction of posterolateral tibial plateau fracture (red arrow) and restored posterior slope are visualized arthroscopically.

posterolateral plateau fracture and associated slope depression is often not recognized as significant and therefore treated nonoperatively or simply neglected while ACL injury is treated. This, however, leads to a missed window of opportunity to address a known risk factor for ACL graft failure by restoring the anatomic PLTP slope. Many studies have shown the association between steep posterior tibial plateau slope and risk of ACL graft failure.[5-7,10]

The one-stage arthroscopic approach described here combines (1) ACL reconstruction or (2) reduction and fixation of tibial spine avulsion, with a concomitant arthroscopy-assisted reduction of a PLTP fracture that restores the anatomic slope of the tibial plateau. Performing this one-stage procedure may help avoid the need for a subsequent slope-correcting osteotomy, and can help reduce postoperative morbidity and the overall rehabilitation period. Other key advantages (Table 2) of this procedure include: (1) a minimally invasive technique that still allows for adequate visualization and anatomic reduction of PLTP fracture; (2) no additional incision to the standard ACL reconstruction technique, which may be beneficial to postoperative pain, infection

Table 1. Surgical Steps, Pearls, and Pitfalls of Arthroscopy-Assisted Restoration of Posterolateral Tibial Plateau Slope

Surgical Steps	Pearls	Pitfalls
Graft preparation	Shape fibular allograft to fit in the tibial tunnel. End may be beveled to have a flush surface at the site of disimpaction. Keep graft long and trim excess at the end after fixation.	Avoid crooked, pointy, or short graft.
Triangulation of depressed tibial plateau	Acquire high-quality true lateral fluoroscopy image. Aim for the mid- to posterior aspect of the tilted plateau fragment.	Aiming for fracture line may displace fracture and lead to an intra-articular step-off.
Reduction	Stop drill 1 to 1.5 cm from the subchondral bone, then tap the drill forward gently until reduction achieved. Switching to a smaller drill during the disimpaction stage may allow for fine tuning the angle of the disimpaction if the tunnel is slightly off.	Avoid joint penetration with guide pin or drill. Beware of creating an intra-articular step-off (goal is to tilt the fragment to restore the slope).
Graft fixation	Use metal bone−tendon−bone type interference screw to securely lock graft at tibial cortex to prevent the graft from subsiding.	

risk and cosmesis; and (3) restoration of the anatomic PLTP slope, which is a known protective factor from a subsequent ACL graft failure.[10] Moreover, fixation using a bone allograft allows for limited interference with possible future surgeries. However, the described technique also has its limitations and disadvantages (Table 2). They include (1) the technically challenging nature of the procedure, (2) increased tourniquet and surgical time by approximately 15 to 30 minutes when compared with a standard ACL reconstruction, (3) increased radiation exposure associated with the use of fluoroscopic guidance, and (4) the need for an operative management in the acute phase of the injury, which can potentially increase the risk of arthrofibrosis when combined with acute ACL reconstruction. However, recent evidence supports that patients achieve comparable range of motion without an increased risk of arthrofibrosis, as well as good clinical outcomes, after an acute ACL reconstruction versus a delayed surgery.[13,14] A study directly comparing this one-stage technique versus staged operations is needed to further characterize postoperative clinical and functional outcomes and patient satisfaction.

In conclusion, this Technical Note highlights the importance of addressing the PLTP slope in the acute phase of the injury and the procedure represents a minimally-invasive approach in doing so. It has an important clinical utility in the newly described PLTP

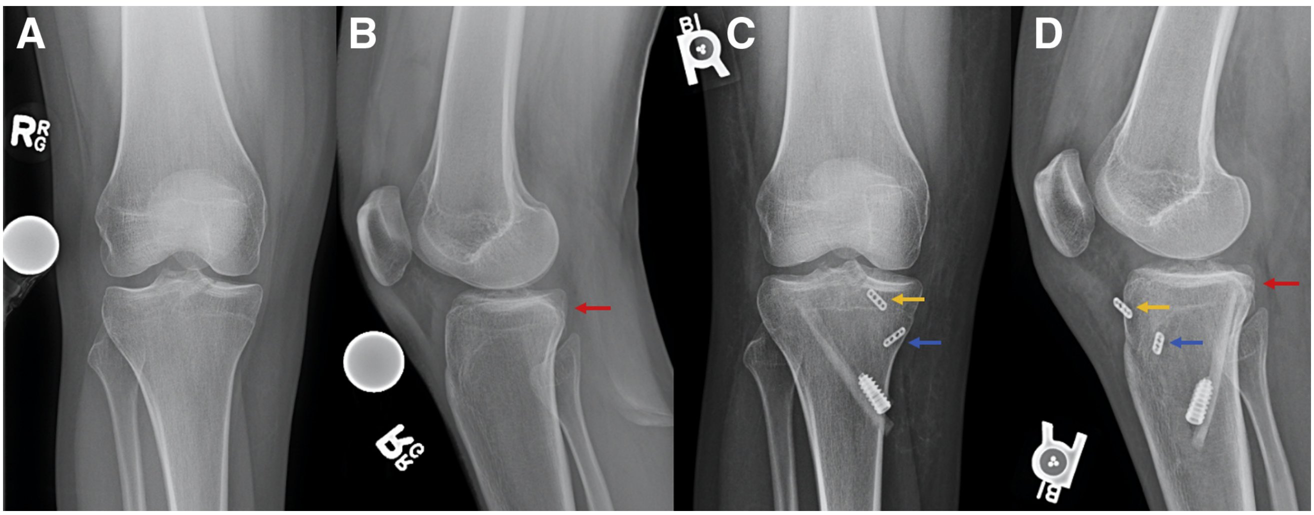


Fig 11. Preoperative and postoperative plain radiographs, right knee. (A-B) Preoperative anteroposterior (A) and lateral (B) views of the knee. (B) The depressed posterolateral tibial plateau slope (red arrow) can be visualized. (C-D) Postoperative anteroposterior (C) and lateral (D) knee radiographs taken at 2 weeks following the procedure. Cortical button proximal to the joint line (yellow arrows) is placed for tibial fixation of high-tensile sutures used in the reduction and fixation of the tibial spine avulsion. Cortical button distal to the joint line (blue arrows) is placed for tibial fixation of high-tensile sutures used in the transosseous fixation of the avulsed posterior root of the lateral meniscus. (D) Visualization of anatomic restoration of the posterolateral tibial plateau slope (red arrow).

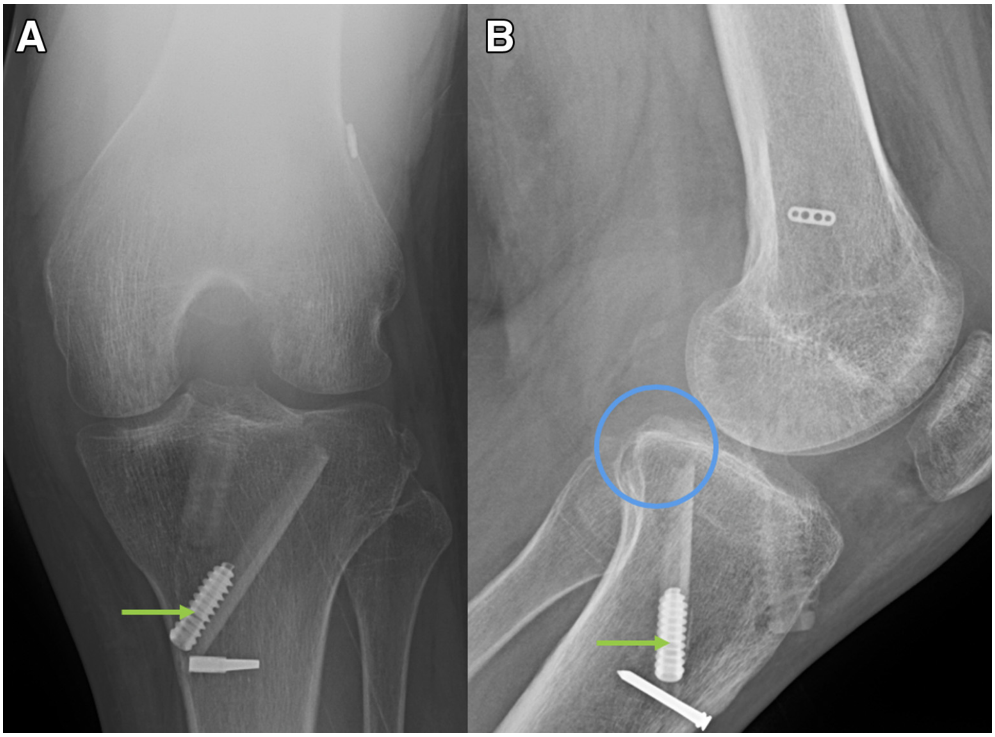


Fig 12. Postoperative plain radiographs, left knee, taken at 3 months following the procedure. Anteroposterior (A) and lateral (B) views. (A) Stable positioning of the interference screw (green arrow) is visualized. (B) Stable positioning of the interference screw (green arrow) and maintained posterolateral tibial plateau slope (blue circle) are visualized.

fracture pattern that appears to only be associated with high-energy rotational trauma of the knee or "high-energy ACL" injuries. Our future study will focus on elucidating the long-term clinical and radiological outcomes associated with this procedure to validate its generalizability.

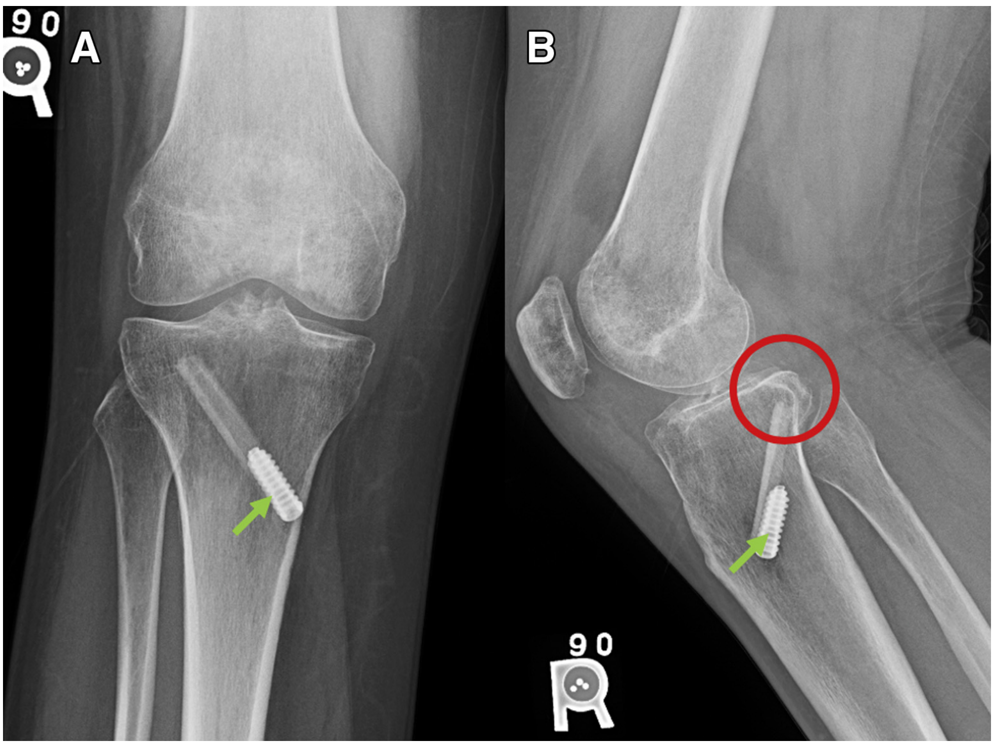


Fig 13. Postoperative plain radiographs, right knee, at 5 months following the procedure. Anteroposterior (B) and lateral (B) views. (A) Stable positioning of the interference screw (green arrow) is visualized. (B) Stable positioning of the interference screw (green arrow) and maintained posterolateral tibial plateau slope (red circle) are visualized.

Table 2. Advantages and Disadvantages of the Featured Technique

Advantages	Disadvantages
One-stage technique that restores the PLTP slope, potentially decreasing the risk of graft failure and avoiding the need for a subsequent slope correcting osteotomy.	Technically challenging.
Reduced morbidity and shorter rehabilitation vs staged surgery.	Increased tourniquet and surgical time.
Minimally invasive technique that still allows for adequate fracture visualization and accurate anatomic reduction.	The need for an operative management in the acute phase of injury.
No additional incision to the standard ACL reconstruction.	Increased radiation exposure with the use of fluoroscopic guidance.
Fixation using a bone allograft allows for limited interference with possible future surgeries.	Potential increased risk of arthrofibrosis if combined with acute ACL reconstruction.

ACL, anterior cruciate ligament; PLTP, posterolateral tibial plateau.

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