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Open Intrameniscal Examination and Reduction of Depressed Tibial Plateau Fracture

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Abstract: In the Schatzker classification, approximately 60.5% of tibial fractures can potentially involve depression fractures of the plateau, on average in types II, III, and IV, and are particularly prevalent among the elderly population. A significant challenge in managing these fractures is achieving optimal visualization of the depressed fracture segments during surgical intervention. Traditional management techniques include intraoperative fluoroscopy, submeniscal arthrotomy, and arthroscopic-guided reduction. However, each of these methods presents specific drawbacks: exposure to radiation, the requirement for advanced equipment, limited access to the fracture site, increased technical complexity, and the risk of damaging the meniscotibial ligaments. In light of these challenges, we describe a distinctive intrameniscal approach for the repair of depressed tibial plateau fractures. This technique effectively addresses the limitations of traditional methods by eliminating the necessity for intraoperative radiation, simplifying the surgical procedure, and preserving the integrity of the meniscotibial ligaments. Importantly, our approach maintains excellent visualization and surgical exposure, enhancing the overall efficacy and safety of the intervention.

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The proximal tibia is particularly susceptible to injury due to its anatomical orientation and the complex nature of traumas that can occur in this area, which impact both bone and soft tissue structures, such as the knee's articular cartilage, ligaments, and menisci. Tibial plateau fractures (TPFs) specifically involve the metaphyseal region of the proximal tibia and its articular surface, accounting for approximately 1.2% of all fractures, with this figure rising to nearly 8% among the elderly population.[1] According to the AO/OTA classification of tibial fractures, depression fractures of the tibial plateau account for approximately 32% of all tibial fractures (B category). In the Schatzker classification, approximately 60.5% of tibial fractures can potentially involve depression fractures of the plateau, averagely in types II, III, and IV.[2] These findings underscore the importance of a careful and comprehensive approach to the management of depressed TPFs.

Current surgical protocols for managing split depression fractures of the tibial plateau typically involve a triad of interventions: first, the elevation of the depressed articular fragment; second, the replacement of any bone voids; and finally, the stabilization of the structure using plate and/or screw constructs.[3]

One of the main challenges in the management of depressed TPFs is intraoperative assessment of the quality

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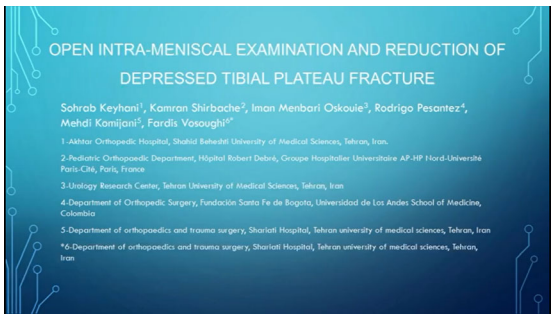
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VIDEO 1 Step-by-step intrameniscal examination technique for the management of depressed tibial plateau fractures (left knee). Video content can be viewed at https://doi.org/10.1002/atn2.70046.

of articular reduction for which some solutions have been previously proposed. Most common conventional techniques include intraoperative fluoroscopy, submeniscal arthrotomy, and arthroscopic guided reduction and internal fixation (ARIF).[4]

Intraoperative fluoroscopy serves as the main tool for assessing the quality and accuracy of reduction in tibial plateau fixation. However, this method often underestimates the extent of articular depression. A significant drawback of this approach is that the central sections of the lateral plateau continue to have restricted visibility.[5] In as many as 45% of our cases, using fluoroscopic guidance alone did not result in satisfactory reconstruction. Additionally, both the surgeon and patient are exposed to radiation.[6] Eventually, the accuracy of this method is not high. Ultimately, some studies have questioned the accuracy of fluoroscopy in TPFs.[7]

The second method is submeniscal arthrotomy. During surgery, employing a submeniscal arthrotomy along with joint distraction using a universal distractor can significantly enhance the visibility of the articular surface. This involves cutting the meniscotibial (coronary) ligament below the meniscus and retracting the meniscus upwards, thereby enabling direct visualization of the joint.[8] However, this technique has notable limitations such as the risk of nonhealing of the coronary ligament. Because this ligament is delicate, its anatomic repair is technically challenging, if not impossible. Moreover, repair typically requires the use of an anchor suture, which increases both procedural cost and the likelihood of imprecise outcomes.[9] This technique provides a restricted field of view, making it often difficult to adequately visualize the central depression of the tibial plateau.[8,9] The third approach is ARIF. This technique not only requires arthroscopic setup, but also an experienced knee or sports surgeon with a steep learning curve. Additionally, it necessitates an intact capsule for successful implementation. Another potential complication associated with this method is the risk of compartment syndrome in cases of capsular rupture or prolonged surgery.[10]

The aim of surgical treatment is to achieve precise anatomic reduction of the fracture and ensure rigid internal fixation, whilst minimizing trauma and morbidity. The surgical approach should avoid causing additional damage, particularly to the local blood supply, yet it must enable clear visualization and precise maneuvering to reposition bone fragments and address related soft tissue injuries. Treatment outcomes can be compromised by restricted joint movement, failure to restore articular congruence, stability, or alignment, and potential complications such as malunion, complex regional pain syndrome, residual instability, infection, or osteoarthritis. Unsatisfactory reconstruction of the joint surface or improperly placed screws are often identified through postoperative CT scans, which may necessitate further surgical intervention or acceptance of an increased risk for the future development of degenerative arthritis.[2,4,7]

We describe an intrameniscal (iatrogenic bucket handle) surgical technique that involves the deliberate creation of a red-red zone bucket-handle tear in the meniscal body. This approach offers several advantages: it eliminates the need for fluoroscopy, thereby avoiding radiation exposure and reducing procedural complexity. In addition, it is a coronary ligament-sparing technique that requires no specialized equipment while providing excellent exposure and visualization of the articular surface (Figure 1). The potential limitations of this technique are also discussed.

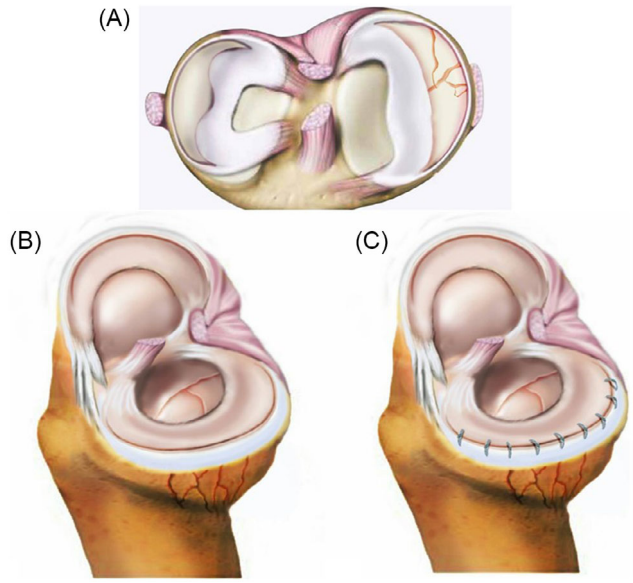


FIGURE 1 Schematic illustration of the intrameniscal examination technique for depressed tibial plateau fractures. (Figures show examples of a right knee medial plateau fracture).

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SURGICAL TECHNIQUE

The patient is placed in the supine position on an orthopaedic table. After removal of the foot section of the table, the operative leg is left hanging freely off the edge. A nonsterile pneumatic tourniquet is applied to the ipsilateral thigh. To evaluate the articular reduction, a mini-lateral longitudinal skin incision is made over the anterolateral aspect of the knee (Video 1). Joint exposure is then obtained superior to the meniscus by incising the meniscofemoral ligament. At this point lateral meniscus body is identified a sharp complete longitudinal vertical incision is performed 2 mm from the joint capsule into the meniscus tissue (red-red zone). The central portion of the lateral meniscus is then displaced into the intercondylar notch area, creating a fresh lateral meniscal bucket handle tear, through which optimal vision and access are provided. The amount of articular depression and quality of reduction can be assessed through the intrameniscal approach.

For depressed lateral plateau fractures, this procedure employs a metaphyseal medial window. In cases of depression in the tibial plateau's intraarticular fracture, the tunnel bone tamping method is utilized to reset the fracture fragment. A 2.5 mm Kirschner wire is initially used to locate the depressed fracture area. A power-driven trephine reamer is then employed to create a cortical bone window in the proximal tibia, and a bony tunnel is established for the insertion of a specialized metal tamp. Through a series of retrograde impacts using a hammer and cylindrical metal tamps of varying diameters, the depressed articular fragments are incrementally elevated to their correct position.

After achieving adequate elevation, slight over-correction, and reduction of the articular surface, the central portion of meniscus is reduced into with native site and inside-out repair of the meniscus is performed with two or three sutures using FiberWire No. 5 (Arthrex, Naples, FL). With the bone tamp held in place, a Kirschner wire (Synthes, Raynham, MA) is inserted transversely for temporary provisional fixation. Subsequently, a rafting cannulated screw is placed over the Kirschner wire (Synthes). Afterward, the bone tamp is removed, and the remaining bone tunnel cavity is filled with bone allografts.

The procedure concludes with the reduction and suturing of the meniscus using FiberWire No. 5. (Arthrex, Naples, FL) sutures, followed by closure of the capsule, subcutaneous, and cutaneous layers, and appropriate dressing of the surgical site (Figure 2).

Postoperative Physiotherapy

Postoperatively, the patient remains nonweight-bearing on the operated limb for the first month. Protected and progressive weight-bearing is then initiated, depending on radiologic evidence of healing and clinical tolerance. Range of motion exercises are started immediately after surgery, typically from 0° to 90°, to prevent joint stiffness and promote early mobility. Quadriceps-strengthening and proprioceptive training are gradually introduced as tolerated, following standard rehabilitation protocols for TPFs.

DISCUSSION

This technique is proposed as an advancement over conventional methods for the reduction and internal fixation of depressed TPFs, particularly in open surgical indications and rim depressions. It may also serve as a useful alternative to arthroscopy for managing localized anteromedial and/or anterolateral depressions of the tibial plateau, where visualization is often limited during arthroscopic procedures.

Although traditional approaches have achieved significant success in reconstructing knee structure and improving functional outcomes, they have been less effective in addressing the specific challenges associated with depressed TPFs.[11] Undercorrection and postoperative depression of the plateau surface have remained notable complications, often leading to persistent pain at the defect site and mechanical malalignment, as documented in long-term follow-up studies.[12] The average rate of postoperative malalignment in patients with TPFs is 2%, with a range of 0%-26%.[13]

The primary causes of postoperative articular depression are underestimation of the defect size and improper reduction during surgery.[12,14] Therefore, techniques used to assess the tibial plateau defect intraoperatively must be scrutinized. Fluoroscopy, a widely used imaging technique, allows surgeons to evaluate joint surface alignment during reduction.[15] However, its limitations—such as poor-quality radiographs, limited visualization of soft tissues like cartilage, and misleading images caused by overlapping structures and anatomical distortion—undermine its utility in such cases.[7]

Submeniscal arthrotomy, an alternative technique, offers direct visualization of the tibial plateau surface, enabling more accurate assessment and correction of the depressed defect. This method has led to significant improvements in surgical outcomes.[8] However, concerns remain about the long-term function of the meniscus after arthrotomy. During this procedure, the meniscotibial ligament (MTL), or named as coronary ligament, that connects the meniscus to the tibial plateau, is cut to allow the meniscus to be retracted for better access to the underlying surface.[5,11,12]

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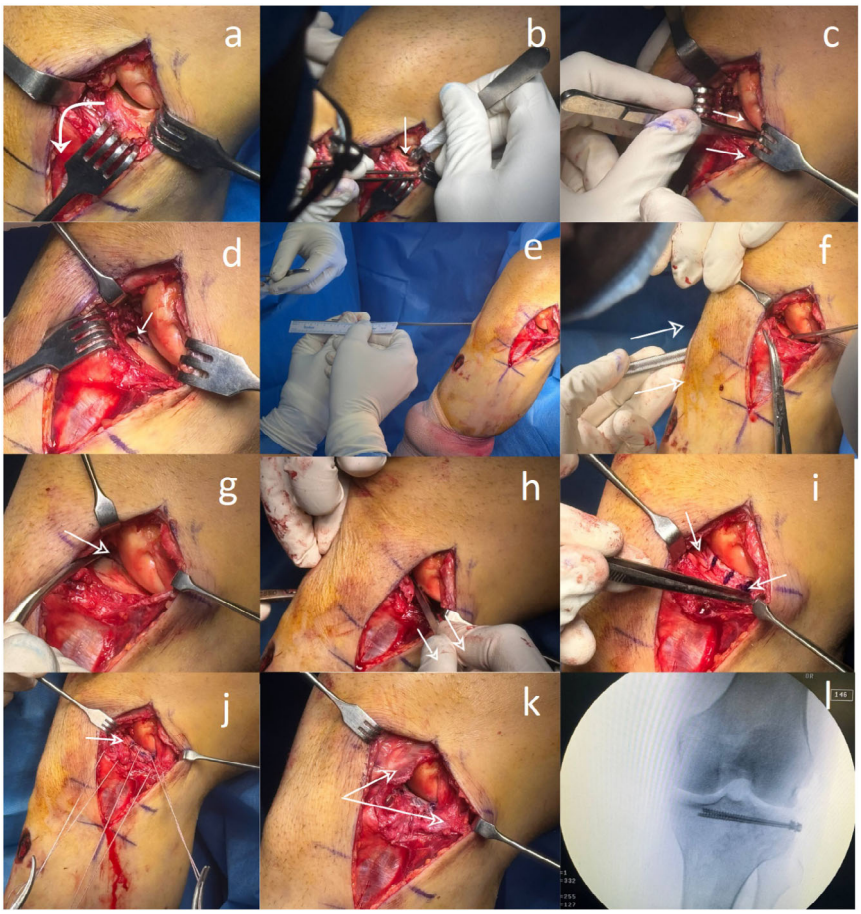


FIGURE 2 Step-by-step photograph of the intrameniscal examination technique for depressed tibial plateau fractures in a left knee, with the leg hanging from the operaing table. (a) Joint capsule exploration (white arrow). (b) Creation of a controlled bucket-handle tear (white arrow: incision). (c) Meniscal detachment into the intercondylar notch (white arrow: force direction). (d) Exposure of the depressed tibial plateau fracture (white arrow). (e) Measurement of fracture depression. (f) Bone tunnel creation and tamping (white arrow: force direction). (g) Fracture elevation with anatomical reduction (white arrow). (h) Meniscal repositioning (white arrow: force direction). (i) Restoration of meniscus to anatomical position (white arrow). (j) Repair of the bucket-handle tear (white arrow). (k) Capsule repair (white arrow: capsular joint); (l) Postoperative radiographic control confirming accurate reduction.

The medial tibial ligament (MTL), a component of the deep medial collateral ligament (dMCL), plays a vital role in controlling meniscal mobility during knee movement, thereby reducing contact pressure between the femur and tibia. The stiffness of the dMCL underscores its significant role in maintaining tension, and its relatively short length causes it to tighten quickly with tibial rotation.[16]

The MTL is anatomically and histologically complex, with distinct characteristics that make its repair challenging. Divided into medial (MMTL) and lateral (LMTL) components, the ligament has unique structural differences. The MMTL consists of a continuous network of collagen fibers, while the LMTL is discontinuous. Given the intricate structure and thinness of the MTL, restoring its original histological arrangement and physiological tension during repair is difficult. Some surgeons opt to suture the remaining meniscus tissue to the joint capsule, although this often results in suboptimal attachment and additional complications, such as capsular suture pain postoperatively.[17]

Knee joint laxity studies reveal that transecting dMCL leads to increased external rotation at 60°-90° of knee flexion, indicating its role as a secondary restraint against valgus forces.[18] The dMCL also plays a crucial role in regulating medial meniscus mobility; disruption of its meniscotibial portion results in increased mobility of the medial meniscus.[16] Biomechanical research has further shown that MTL lesions are associated with significant increases in ACL strain, as well as heightened anterior laxity at 0°, 30°, and 90° of flexion.[17] MTL injuries also contribute to increased valgus and external rotation laxity within the knee. However, the specific effects of dMCL deficiency on meniscal function remain underexplored in current literature.[19]

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Some studies suggest that transecting and repairing the MTL may alter meniscal motion, potentially leading to postoperative complications.[20] Following MTL repair, changes in the contact area and pressure within the knee joint have also been observed. It is important to note that even minor alterations in meniscal biomechanics can contribute to degenerative changes over time. This underscores the critical need for precise, physiologic repair to preserve joint integrity and function in the long term.[11,16]

Additionally, submeniscal arthrotomy involves cutting the semimembranosus tendon and its associated capsular branch arteries, which nourishes the surrounding tissues.[21] The long-term effects of this are unclear due to a lack of studies, but disruption of these structures could impact the healing process.[9,11]

In contrast to conventional techniques, the described intrameniscal technique involves a longitudinal incision in the meniscus, allowing it to be retracted for better access to the tibial plateau without compromising the meniscotibial junction. This approach minimizes the risk of postoperative meniscal dysfunction while enabling accurate reduction and fixation of the fracture. The type of incision and meniscus repositioning in this technique closely resembles the bucket-handle tear in meniscal pathology, allowing us to approximate the outcomes of this incision to those observed in bucket-handle repairs.[22]

The failure rate for bucket-handle tear repairs is reported to be between 9% and 14.8% in the literature,[22,23] although one systematic review cites a 29.3% overall failure rate for all-inside repair techniques.[24] The healing success rate is influenced by several factors, including patient age, gender, race, BMI, time between injury and surgery, location of the tear (lateral or medial meniscus), suture technique, and the number of stitches used. Medial tears and isolated repairs are particularly associated with higher failure rates in bucket-handle tear repairs.[25,26]

In our technique, the healing process following the meniscal incision is expected to be more predictable, given that a fresh incision is made in the vascularized red-red zone of the meniscus, which has a higher healing potential than the other zones (red-white and white-white).[27] The literature supports the idea that meniscal tears in the red-red zone have a significantly higher healing rate than those in the less vascularized zones.[22,24,26] Kanto et al. reported a failure rate of 12.5% for red-red zone repairs, compared to 45.4% in other zones.[28] Additionally, the red-red zone of the meniscus is significantly thicker than the other zones, allowing the surgeon to obtain a substantial portion of tissue for effective suturing and repair. As a result, the incision leads to a healing rate that surpasses those commonly reported in the literature.[17]

The sharp, clean nature of the incision in the intrameniscal technique is also expected to improve healing outcomes by reducing the risk of fibroblast misalignment and collagen production errors, as often seen in traumatic meniscal injuries.[29] The immediate repair of the meniscal incision in our technique is another crucial factor that significantly contributes to an improved healing rate. Kanot et al. reported a 13.2% failure rate in meniscal injuries repaired within 4 months, compared to a 48.7% failure rate in those repaired after 4 months.[28] Nishida et al., in a histological study of bucket-handle repairs in dogs, found that fibrochondrocytes remained in the meniscus up to 12 weeks postinjury, but the cell count significantly decreased by 48 weeks.[30] These indicate that early suture repair is crucial for achieving a more physiologic healing process in bucket-handle meniscal tears[24,26] (Figure 3).

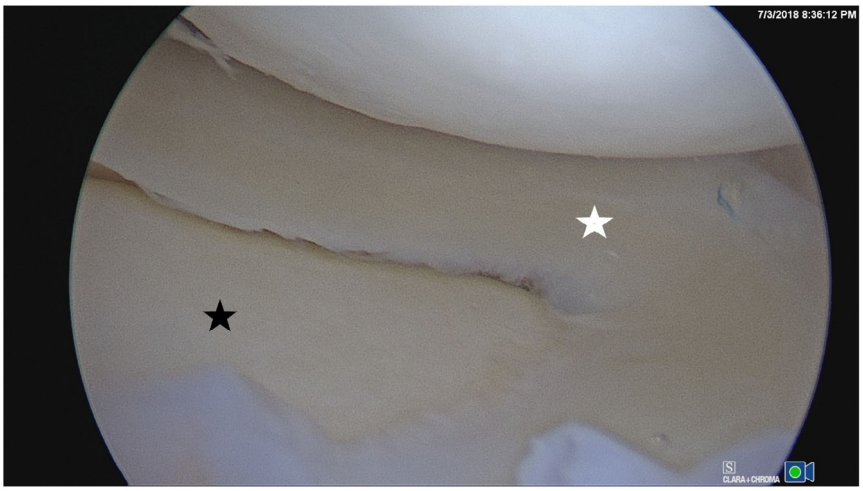


FIGURE 3 Second-look arthroscopy 1 year after application of the intrameniscal examination technique for a depressed tibial plateau fracture and complete meniscal repair in a left knee (white star: medial meniscus, black star: tibial plateau).

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TABLE 1 Advantages and Disadvantages of the Intrameniscal Examination Technique

Intrameniscal Technique
Advantages • Enhanced visualization of the tibial plateau • Reduced risk of undercorrection • Preserved knee biomechanics with coronary ligament preservation • Improved healing of iatrogenic meniscal injury (ensures higher healing rates due to the incision being made in the well-vascularized red-red zone of the meniscus, presence of stem cells from the associated bone fracture, healing mediators, increased blood supply, clean incision edges, and immediate repair during surgery) • Reduced risk of long-term degenerative changes • High accuracy • Reduced radiography exposure • High-quality direct exposure
Disadvantages • High level of surgical expertise required for precise selection of the red-red zone for incision • Risk of incomplete healing or failed meniscal repair

TABLE 2 Pearls and Pitfalls in Intrameniscal Examination Technique

Pearls	Pitfalls
• Use a size 11 surgical bistoury for precise incision • Make incisions parallel to the curvature of the meniscus to optimize access to the red-red (R-R) vascular zone • Intraoperatively assess knee range of motion, meniscal movement, presence of any clicking sounds, and ensure smooth meniscal surfaces postrepair • Mark the incision edges prior to cutting for precise repair • Enforce postoperative nonweight-bearing protocols to facilitate recovery • Employ FiberWire No. 5 (Arthrex, Naples, FL) for durable meniscal repair • Use the inside-out technique to position the ends of sutures outside the joint space for secure fixation • Ensure complete joint distraction prior to intervention to create sufficient working space	• Resection of the internal or external meniscal root • Induction of radial meniscus lacerations • Incisions outside the red-red (R-R) vascular zone • Inadequate fixation of the meniscus • Malreduction during meniscal repair • Meniscal impingement • Cartilage damage on the femoral side

Moreover, this technique benefits from the presence of stem cells and healing factors associated with TPFs, such as interstitial material from bone marrow and cytokines like IL-1, IL-6, TGF-β, and FGF.[17] These factors enhance the healing process, akin to the improved outcomes seen in meniscal repairs associated with ACL injuries or TPFs, where increased blood flow promotes healing.[19,26,28] Tables 1 and 2 summarize the advantages and disadvantages of this technique, as well as its associated pearls and pitfalls, respectively.

Briefly, this technique offers a promising approach to the reduction and fixation of depressed TPFs. By providing clear visualization of the joint surface and minimizing damage to critical meniscal structures, this technique improves both fracture repair and meniscal healing. The evidence suggests that with careful execution, this method can achieve substantially high healing rates, supported by superior tissue quality, precise meniscus reduction, enhanced healing stimuli, and secure fixation.

DISCLOSURES

The authors (S.K., K.S., I.M.O., R.P., M.K., F.V. declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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