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How can the articular surface of the tibial plateau be best exposed? A comparison of specific surgical approaches

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Abstract

Introduction The correct choice of a fracture-specific surgical approach with an articular accessibility in complex tibial plateau fractures to facilitate durable fracture fixation of the anatomic articular reconstruction is under debate, as the most important risk factor for malreduction in complex tibial plateau fractures is an impaired visualization of the articular surface.

Materials and methods Six established surgical approaches were simulated on 12 cadaver knees. The visible articular surface was labeled with an electrocautery device for each approach and subsequently analyzed with ImageJ. Areas of each hemiplateau were compared using the Student's *t* test.

Results In the lateral tibial plateau, the dorsal 19.0 ± 5.8% of the articular surface could be exposed via the postero-lateral approach. Via the antero-lateral arthrotomy, 36.6 ± 9.4% of the anterior articular surface was visible. The additional osteotomy of the lateral femoral epicondyle significantly increased the exposure to 65.6 ± 7.7% ($p < 0.001$). In the medial tibial plateau, the osteotomy of the medial femoral epicondyle significantly improved visualization of the medial articular surface (62.3 ± 8.6%) compared to the postero-medial approach (14.0 ± 7.3%) and the antero-medial approach (36.9 ± 9.2%) of the articular ($p < 0.001$).

Conclusions Visualization of the tibial articular surface is limited through specific surgical approaches. Extension by osteotomy of the femoral epicondyle led to a significant improvement in the articular exposure without, however, obtaining sufficient visibility of the posterior joint segments, which should be included in the preoperative strategy. The proposed surgical approach-specific map of the tibial plateau may constitute an important instrument in the toolbox of an experienced surgeon to treat complex tibial plateau fractures at the highest level.

Level of evidence Level IV.

Keywords Tibial plateau fracture · Accessibility · Surgical approach · 10-Segment classification · Cadaver study

Introduction

Despite modern surgical developments, complex bicondylar tibial plateau fractures still pose a challenge for the trauma surgeon to achieve anatomic articular reconstruction, leg axis preservation and stable fixation while simultaneously treating frequently accompanying considerable soft tissue injuries with care [1]. To limit the increased risk for post-traumatic osteoarthritis and impaired knee function, anatomic reconstruction of the articular surface is crucial

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[2–6]. However, malreduction in complex tibial plateau fractures is common, especially in the posterior segments of the lateral tibial plateau, and the impaired visualization of the articular surface through standard surgical approaches is its most important risk factor [7–9]. While supplemental techniques such as fracturoscopy, application of a distractor, or 3D imaging may improve articular visualization, the correct choice of a fracture-specific surgical approach with an articular accessibility is still required to facilitate durable fracture fixation of the anatomic articular reconstruction [7–10]. Although several surgical approaches to the tibial plateau have been reported, their description focused primarily on the protection of extra-articular concomitant ligamentous and neurovascular soft tissue structures. Currently, there are no data on which area of the fractured articular surface can be exposed with which surgical corridor, which is of utmost importance for the surgical strategy [2, 8, 11–23]. Hence, the purpose of the present study was to compare the depictable articular surface areas exposed by different standard and advanced extended surgical approaches to the tibial plateau among each other. We hypothesized that the depiction of the entire articular surface is limited based on the individual surgical approach.

Materials and methods

Autopsy specimens

All surgical approaches were each performed on 12 knee autopsy specimens [4 males and 2 females, mean age (69.2 ± 20.4 years)] after informed consent was obtained from the family members based on comprehensive information [24]. Patients were eligible for inclusion if they had a body mass index (BMI) between 18 and 30 kg/m^2, and an intact soft tissue envelope around the knee. Exclusion criteria were severe putrefaction, BMI < 18 and > 30 kg/m^2, amputation of the lower limb, evidence of previous knee arthrotomy or knee arthroplasty, and a restricted range of motion due to contractures. The study was approved by the local ethics committee (WF-31/16).

Surgical approaches

Prior to surgical intervention, all knees were flexed and stretched within their full range of motion to loosen rigor mortis. To expose the tibial plateau, established and frequently applied surgical approaches were performed [25].

Postero-lateral approach (PL) [15]

To minimize soft tissue damage due to ethical reasons, we started with the patient in prone position and a single 20-cm-long central skin incision crossing the fossa poplitea with ample subcutaneous dissection to the medial and lateral side. As an adaptation to the original description of the postero-lateral approach by Frosch et al. [15], soft tissue was dissected to the ventral edge of the fibular head. The fascia dorsal to the m. biceps femoris was incised, the n. peronaeus identified at its dorsal edge and was carefully mobilized until its immersion around the m. peronaeus longus (Fig. 1a). Subsequently, a blunt, digital dissection between the lateral edge of the lateral head of the m. gastrocnemius and the m. soleus was performed. The popliteal arteria and vena were secured by retraction of the lateral head of the m. gastrocnemius to the medial side. In the case the muscle tone was too high and the surgical visibility was impaired, the femoral gastrocnemius insertion could be partially incised and mobilized. If necessary, the arteria and vena genicularis lateralis inferior were cauterized.

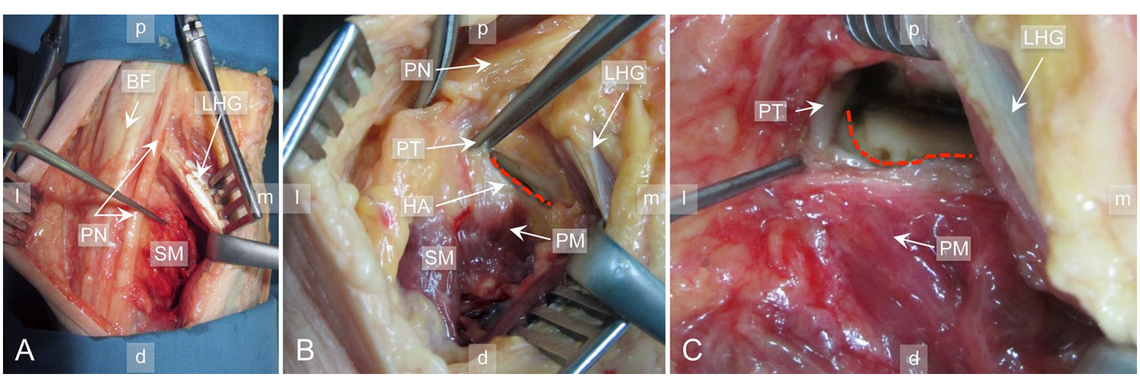

Fig. 1 **a–c** Postero-lateral approach. Midline posterior incision with depiction of the m. biceps femoris (BF) and the accompanying peroneal nerve (PN). The lateral head of the m. gastrocnemius (LHG) is retracted medially to expose the m. soleus (SM) and protect the neurovascular structures (**a**). The m. soleus (SM) is partially detached exposing the m. popliteus (PM) and its tendon (PT). The joint capsule is incised horizontally (HA; red dotted line visible articular surface) (**b**). The m. popliteus (PM) with its tendon (PT) is retracted lateral-distally; *l* lateral, *m* medial, *p* proximal, *d* distal, red dotted line visible articular surface (**c**)

Proximal fibers of the m. soleus were partially detached to expose the m. popliteus, which was then distally retracted (Fig. 1b). After horizontal capsulotomy and retraction of the dorsal lateral meniscus, the articular surface was exposed and labeled using an electrocautery device with a fine and long needle tip (Erbotom K25, ERBE Elektromedizin GmbH, Tübingen, Germany) (Fig. 1c).

Postero-medial approach (PM) [16]

One the medial side (prone position), the fascia of the m. gastrocnemius was incised along its medial head. The medial head of the m. gastrocnemius was retracted to the lateral side and the m. semimembranosus proximally exposing the proximal edge of the m. popliteus, which was partially detached distally from its periosteal insertion to expose the dorsal knee joint capsule. In cases where the tendinous parts of the m. semimembranosus were too prominent, they were also mobilized very cautiously from their periosteal insertion. The dorsal joint capsule was horizontally incised below the joint line and meniscotibial fibers were detached close to the bone to expose the articular surface (Fig. 2). Care was taken not to injure the posterior cruciate ligament laterally and the m. semimembranosus medially. The visible articular surface was labeled using the electrocautery device.

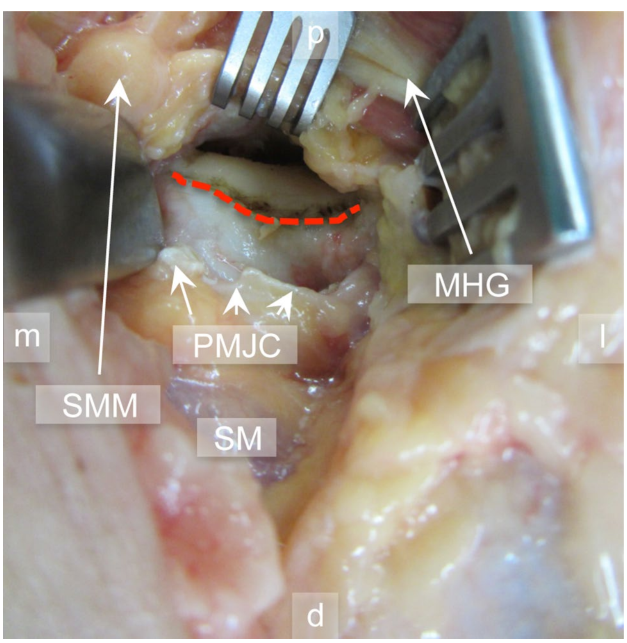

Fig. 2 Postero-medial approach. Retraction of the medial head of the m. gastrocnemius (MHG) laterally and the m. semimembranosus (SMM) and the postero-medial joint capsule (PMJC); *l* lateral, *m* medial, *p* proximal, *d* distal, *SM* m. soleus, red dotted line visible articular surface

Antero-lateral approach (AL) [20]

Subsequently, the patient was turned around into the supine position. We performed a longitudinal incision lateral, starting 5 cm proximal to the joint line, descending anteriorly over Gerdy's tubercle and extending distally staying at least 1 cm lateral to the anterior border of the tibia. Deep subcutaneous dissection was followed by a longitudinal incision of the ilio-tibial tract (IT) directly over the lateral femoral epicondyle with the knee flexed at 30°–40°. The IT band and the concomitant fascia of the m. tibialis anterior were then released from Gerdy's tubercle and posteriorly to the anterior edge of the fibula head. The lateral knee joint capsule was exposed and incised horizontally below the joint line. The lateral meniscus was mobilized, while protecting its attachment anteriorly and sparing the lateral collateral ligament posteriorly. The lateral meniscus was retracted proximally and the developed field of view of the lateral articular surface was labeled with the electrocautery device (Fig. 3a).

Extended lateral approach (eL) [12, 26]

To increase the surgical exposure of the lateral tibia plateau, a femoral epicondylar osteotomy was performed, as previously described [12] (Fig. 3b). The lateral collateral ligament (LCL) was developed to its femoral bony insertion, the lateral femoral epicondyle, which was subsequently osteotomized with the LCL still attached (Fig. 3c). With a 1 cm osteotome, a cuboid bone block ($3 \times 4 \times 1$ cm) comprising the insertion of the LCL was carefully osteotomized, while leaving the popliteus tendon, in contrast to its original description by Bowers et al. [12], attached (Fig. 3d). With gentle manual varus force, almost the entire lateral tibial articular surface could be inspected and the visible field of view was labeled, again, with the electrocautery device (Fig. 3e).

Antero-medial approach (AM) [18, 20]

On the antero-medial side, a 12–15 cm skin incision (parallel to the patellar tendon) started from the most prominent aspect of the medial femoral condyle descending to the patellar tuberosity down to the fascia, sparing the ramus infrapatellaris of the n. saphenous. The medial patellar retinaculum was incised parallel direction to the skin incision. Subsequently, the subfascial fat pad was mobilized laterally to the superficial medial collateral ligament, exposing the knee joint capsule. Arthrotomy was performed below the joint line, which was developed by periosteal preparation to the proximal while protecting the anterior medial meniscus (Fig. 4a). Again, the visible articular surface was labeled with the electrocautery device.

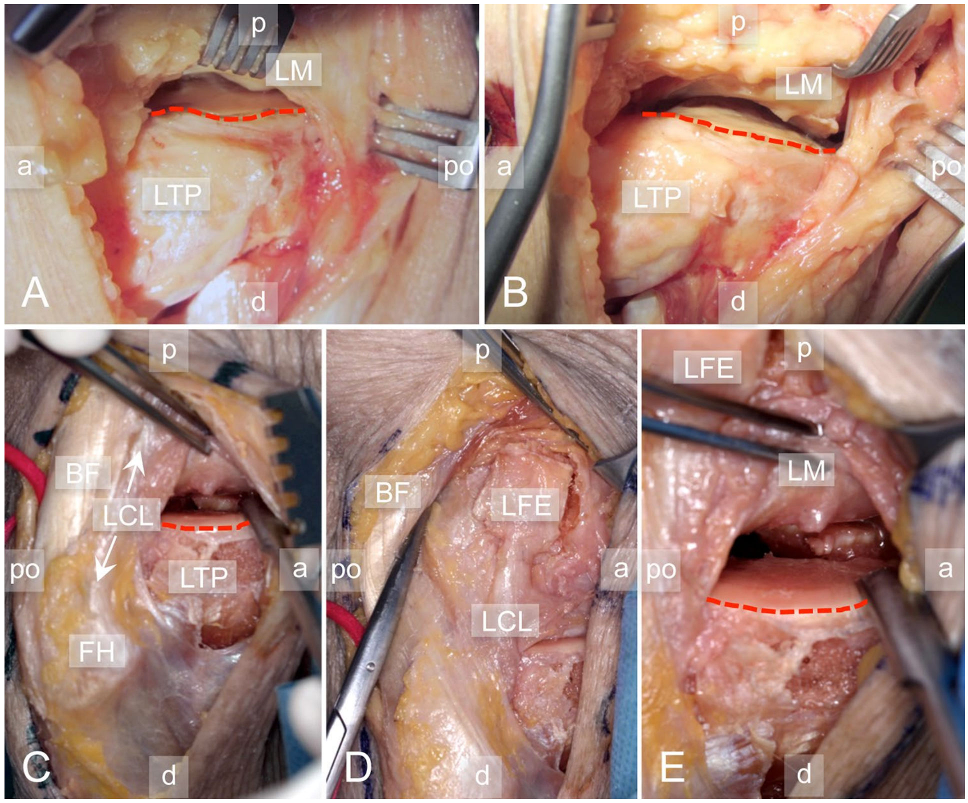

Fig. 3 **a**–**e** Antero-lateral and extended lateral approach. Standard antero-lateral approach with the labeled articular surface below the proximally retracted lateral meniscus (LM) (**a**). Extended lateral approach with exposure of the almost entire lateral tibial plateau (**b**). Visualization of a complex fracture of the lateral tibial plateau (LTP) via the postero-lateral approach in a fracture model provided by RIMASYS. Fibular head (FH), peroneal nerve (red band), m. biceps femoris (BF), the lateral collateral ligament (LCL), and the lateral meniscus (LM) (**c**). Osteotomy of the lateral femoral epicondyle (LFE) (**d**). Improved exposition of the almost entire lateral tibial plateau after osteotomy (LFE) and retraction of the lateral meniscus (LM); *a* anterior, *po* posterior, *p* proximal, *d* distal, *LTP* lateral tibial plateau, red dotted line visible articular surface (**e**)

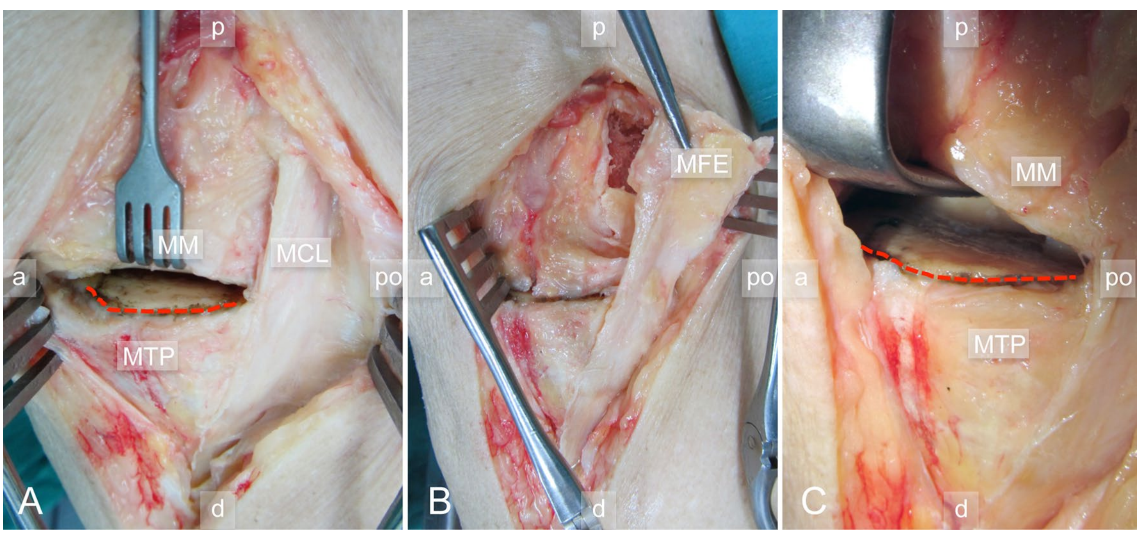

Fig. 4 **a**–**c** Antero-medial and extended medial approach. Standard antero-medial approach with submeniscal exposition of the articular surface. Medial meniscus (MM), medial collateral ligament (MCL) (**a**). Osteotomy of the medial femoral epicondyle (MFE) (**b**). Submeniscal exposition of the almost entire medial tibial plateau after epicondylar osteotomy; *a* anterior, *po* posterior, *p* proximal, *d* distal, red dotted line visible articular surface (**c**)

Extended medial approach (eM) [13]

As the surgical exposure of the medial tibial plateau was limited due to the wide medial collateral ligament (MCL), a medial epicondylar osteotomy was performed. To visualize the postero-medial sections of the articular surface, a 4 × 4 × 1 cm bone block was obtained, comprising the femoral insertions of the MCL and the posterior oblique ligament (POL, Fig. 4b) [13, 27]. Retraction of the medial meniscus proximally revealed almost the entire medial tibial articular surface, which was then labeled (Fig. 4c).

After the completion of articular surface labeling, the proximal tibia was resected in total. The articular surface was photographed and digitally stored. The labeled articular surface was analyzed with the public image analysis software ImageJ provided by the National Institute of Health [28].

Statistics

Descriptive statistics of the labeled articular surfaces are given as mean ± standard deviation. An unpaired Student's *t* test was used to compare the mean articular surface areas among the different surgical approaches. The significance level was set at a $p < 0.05$.

Results

In the lateral tibial plateau, only the dorsally convex aspect of the articular surface could be exposed via the postero-lateral approach (19.0 ± 5.8%). In addition, gentle medial retraction of the lateral gastrocnemius head revealed the tibial footprint of the posterior cruciate ligament in all cases, while the accompanying neurovascular structures were protected. Unfortunately, due to the soft tissue nature of the accessible field of view, viable labeling was not consistently possible. Using the antero-lateral standard approach, barely more than one-third of the articular surface was accessible (36.6 ± 9.4%). The lateral extension, with the additional osteotomy of the femoral epicondyle, enabled the visualization of the almost entire anterior lateral articular surface and significantly increased the exposure compared to the AL standard approach (65.6 ± 7.7%, $p < 0.001$). In the medial tibial plateau, the postero-medial approach resulted only in rather small exposure of the posterior articular surface (14.0 ± 7.3%). Mobilization and lateral retraction of the medial gastrocnemius head revealed the tibial footprint of the posterior cruciate ligament in all cases. Also, fractions of the postero-latero-central segments were visible. Unfortunately, due to the depth of surgical preparation, a valid labeling of these regions was not consistently possible. While with the antero-medial approach barely more than one-third of the articular surface could be exposed (36.9 ± 9.2%), the additional osteotomy of the femoral insertion of the MCL and POL significantly improved visualization of the medial articular surface (62.3 ± 8.6%, $p < 0.001$, Fig. 5). Also, the tibial footprint of anterior cruciate ligament could clearly be exposed.

With respect to different classifications of tibial plateau fractures based on the axial view, Fig. 6 illustrates articular exposition in different segments, columns, or quadrants of the tibial plateau. Comparing the 10-segment, the 3-column, the revisited Schatzker, and 4-quadrant classification with respect to articular exposition through different surgical approaches, each classification provides sufficient diversification depending on the necessary articular exposition.

Discussion

The nearly anatomic articular reconstruction is essential to maintain knee function after complex tibial plateau fractures [4]. The limited visualization of the tibial plateau after fragment reduction through the surgical approach is the most critical reason for articular malreduction [8–10]. Especially in the lateral tibial plateau, the comminuted articular surface can usually only be reconstructed approximately as these areas cannot entirely be accessed through the antero-lateral standard approach and even harder to reduce accurately due to its posterior convex shape [7–9]. Hence, a specific knowledge of the articular accessibility of established surgical approaches to the tibial plateau is a pre-requisite in

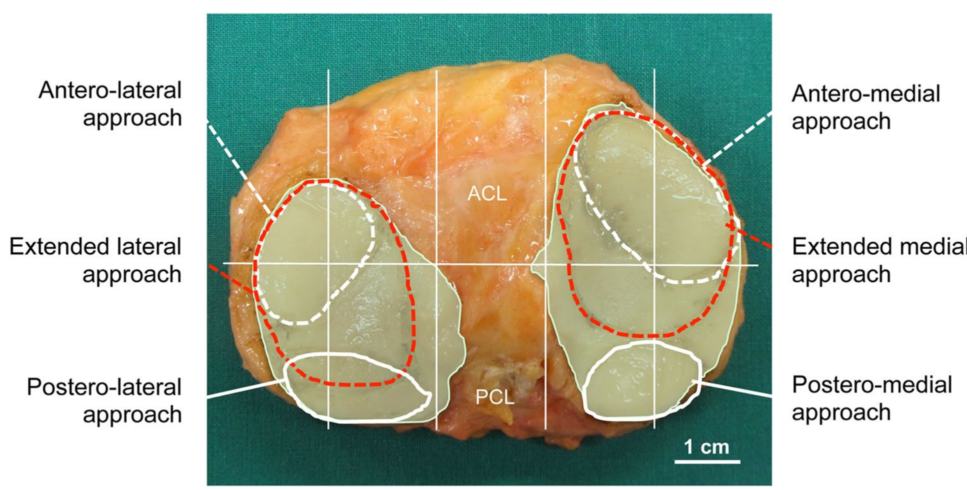

Fig. 5 Tibial plateau with labeled regions of the articular surface to be accessible with specific surgical approaches, green area: articular surface. Lines represent the 10-segment classification of the tibial plateau. The tibial footprint of the anterior cruciate ligament (ACL) could also be exposed via the antero-medial approach. The tibial footprint of the posterior cruciate ligament (PCL) could be exposed via the postero-medial and postero-lateral approach

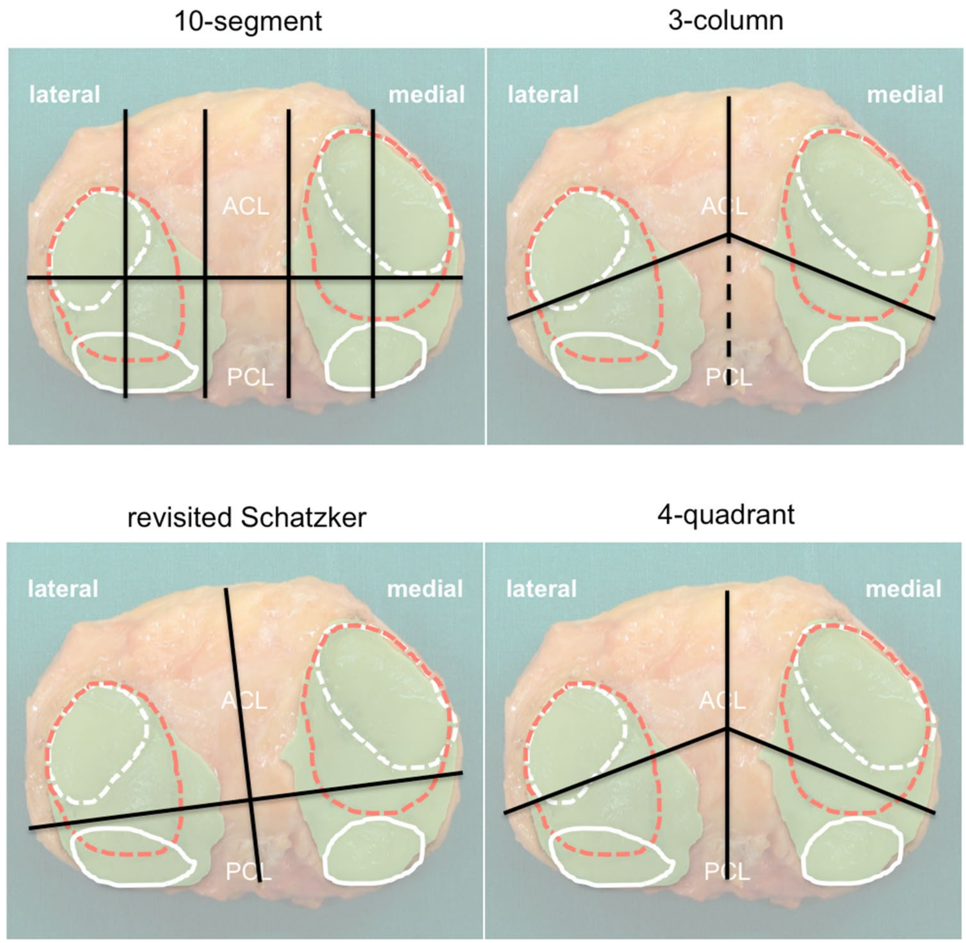

Fig. 6 Illustration of the tibial plateau in axial view with respect to the different fracture classifications depending of the articular visualization

the preoperative planning in the treatment of complex tibial plateau fractures, but specific data are not available.

In the present study, we were able to demonstrate that with the most commonly applied standard antero-lateral or posterior approaches, only one-third or less than one-fifth of the articular surface was visible, respectively. Only the osteotomy of the femoral epicondyle, either medial or lateral, resulted in significantly increased exposure of the tibial plateau compared to the established standard approaches.

Due to the emerging understanding of complex tibial plateau fractures, numerous surgical approaches have been proposed to facilitate optimal direct reduction and fixation with respect to concomitant soft tissue structures, especially around the postero-lateral corner [15, 23, 26, 29–34]. Here, the posterior convex shape of the articular surface, the ligamentous stabilizers of the arcuate complex, the peroneal nerve, and the fibular head prevent ideal articular fracture visualization. In addition, together with the frequent manifestation of comminuted lateral fragments, malreduction rates of up to 77% have been reported, if the tibial plateau was approached through an antero-lateral approach only [8, 9, 19]. Whereas direct posterior approaches allow anatomic reduction and direct fixation of meta- and epiphyseal fragments [23, 31, 34], the subsequent evaluation of the reconstruction result may be insufficient [2, 35]. Specific advanced postero-lateral approaches, on the other hand, enable an improved visibility in combination with direct fixation, in particular for postero-latero-lateral segments without an increased risk of nerve palsy [15, 32, 36]. Although the initial folding of peripheral fragments may allow anatomic reduction of the central parts of the articular surface, the final result is hard to visualize directly or with fluoroscopy once the peripheral fragments are reduced and fixed [8, 9]. The postero-lateral approach allowed visualization of the posterior 19.0 ± 5.8% of the lateral tibial plateau only, while the mean fragment size is 14.5% of the total articular surface [37]. However, anatomic articular reconstruction should be the objective, also in the lateral compartment, as it is significantly associated with functional outcome as well [2, 38]. To improve visual access, additional techniques such as a distractor or 3D imaging have been described [9]. The subsidiary insertion of an endoscopic optic (fracturoscopy) has been shown to be an excellent aid to intraoperatively detect residual articular steps and correct them in the same surgical session, even in complex tibial plateau fractures [7, 8]. However, fracturoscopy is a demanding technique, which requires some surgical familiarity. Although the surgical exposure of the articular surface in terms of width and depth has to be balanced with respect to the additional soft tissue trauma, an extended surgical approach may be justified in cases with severely depressed postero-lateral fragments. The postero-medial L-shaped approach has proven useful in some cases of complex tibial plateau fractures to expose postero-latero-central segments by lateral retraction of the medial gastrocnemius head [30, 31, 33]. However, extensive lateralization for an entire postero-lateral visualization, not to mention fracture reduction or even fixation is frequently challenging due to an impaired soft tissue envelope or a strong muscle tone. In these cases, a femoral epicondyle osteotomy with a slight varus stress can expose the lateral hemijoint and improve visualization by an average of 65.6% [12, 21]. The osteotomy and mobilization of the femoral insertion of the lateral collateral ligament, originally including the popliteus tendon and popliteo-fibular fibers [29, 26], has been used successfully before [21]. However, although almost two-thirds of the lateral plateau were visible, its posterior slope was not sufficiently exposed, which has to be acknowledged prior to surgery. The additional femoral osteotomy of the popliteus tendon or, alternatively, the transfibular approach has also been described to increase articular visualization [26, 32, 12]. However, specific data comparing the extent of postero-lateral articular exposure are not available. Hence, the combination of surgical approaches, such as antero-lateral, postero-medial L-shaped, or postero-lateral, may be required to also directly fix the anatomically reduced comminuted lateral plateau fracture. Solomon et al. were only able to achieve anatomic articular reconstruction using a combination of the antero-lateral and the postero-lateral approach compared to using antero-lateral arthrotomy alone [19].

Compared to the frequent lateral fragment comminution, the medial tibial plateau typically presents with a coronal postero-medial split fracture, although complex fracture patterns have also been described [39–41]. In shear fractures, anatomic reduction and fixation of the distal cortical fragment wedge extension usually results in a congruent articular reconstruction. However, the articular visibility with the postero-medial approach is rather small (14.0%) and does not necessarily allow exposure of the entire postero-medial fragment, which typically comprises about 25% of the total joint surface [39]. Nonetheless, and most importantly, next to addressing bony PCL avulsions, this approach allows for biomechanically advantageous direct fixation of postero-medial shear fragments [7, 14, 31, 40, 42]. If needed, visual reduction control can be achieved via fracturoscopy, the antero-medial approach or the extension via the medial femoral epicondyle osteotomy [8, 9]. Usually, the medial femoral epicondyle osteotomy is used in total knee arthroplasty or meniscus transplantation to increase articular exposure [13]. Yet, in the case of fragment comminution of the medial plateau, the medial epicondyle osteotomy can also provide improved articular exposition.

Comparing different fracture classifications respecting the axial view of the tibial plateau, the 10-segment, 3-column, 4-quadrant, and the revisited Schatzker classification each provided a differentiated visualization of the articular surface with respect to the intra-articular fracture course [30, 41, 43, 44]. From our point of view, the lack of visual control of the articular surface after “successful” fragment reduction is the most important risk factor for articular malreduction [8, 9]. Hence, our present findings emphasize the use of an axial view-based fracture classification in the case of focussing on articular reconstruction, which adds important information to the decision making about the correct surgical approach. However, articular exposition is an important but not the only aspect for the choice of the surgical approach. Also, with respect to the extra-articular fracture configuration and to provide long-term stability of the knee, the possible placement of the osteosynthesis as well as concomitant soft tissue injuries should be considered [3].

Study limitations include the labeling of the articular surface in patients without a tibial plateau fracture and the preclinical study design in cadavers. In the clinical setting, visualization and reduction of central fragments may be achieved by folding peripheral fragments of the fractured tibial plateau apart. However, from our own experience, subsequent reduction of these peripheral segments precludes optimal visual control of an anatomic reconstruction afterwards in complex tibial plateau fractures resulting in high rates of malreduction. Especially in the postero-latero-central segments, no congruent articular reconstruction could be achieved in 89% of the cases [8]. Therefore, from our point of view, the present study resembles the intraoperative visualization capability in the clinical setting after final reduction and fixation quite realistically. The potential rigor mortis of the patients may have impaired the exposure of the prepared articular surface while applying varus or valgus force. However, prior to surgical preparation all lower extremities were mobilized within their full range of motion without an assessable impaired visualization. In addition, with respect to the large number of various surgical approaches to the tibial plateau and given the limited number of cases only a selection of surgical approaches was analyzed. The chosen approaches do not claim completeness, but represent a fundamental selection from our point of view. Specifically, we did not perform the transfibular approach or an elevation of the popliteus tendon to increase postero-lateral articular visualization compared to the lateral femoral epicondyle osteotomy solely including the lateral collateral ligament, as originally described by Bowers et al. [12] or recently Kfuri and coworkers [26]. We also did not include extensive postero-medial approaches like the postero-medial approach described by Lobenhoffer or the reversed posterior L-shaped approach [32, 33]. With respect to the correlation of the present findings to different fracture classifications, the updated and widely used OTA/AO classification has not been considered as it defines specific fracture types rather than quadrant, columns, or quadrants to correlate with.

In conclusion, the present findings illustrate which articular regions of interest of the tibial plateau can be visualized through which surgical approach. These results are of great clinical significance as they help to strategically choose the correct surgical approach with respect to the individual fracture pattern in complex tibial plateau fractures to treat as minimal invasive as possible. Extension by osteotomy of the medial or lateral femoral epicondyle may be considered a salvage procedure but led to a significant improvement in articular exposure without, however, obtaining sufficient visibility of the posterior joint segments, which should also be included in the preoperative strategy. The extension of the lateral or lateral approach via osteotomy may, therefore, prove to be advantageous in patients with comminuted tibial plateau fractures with a deep central fragment depression to realize anatomic reconstruction of the articular surface. We were able to produce a map of accessibility of the tibial plateau for different surgical approaches, which constitutes an important instrument, along with many others, in the toolbox of an experienced surgeon to treat complex tibial plateau fractures at the highest level.

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Compliance with ethical standards

Conflict of interest MK has received research Grants from AO Trauma, Germany e.V. SK, GM, KP, and KHF declare that they have no conflict of interest.

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