

Original article

Reprint

Topographic and anatomical substantiation of a novel surgical technique for treating impression fractures and deformities of the proximal tibial epiphysis

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Abstract:

Objective: to substantiate the feasibility and safety of a new surgical treatment method for patients with impression fractures and deformities of the posterolateral proximal tibial epiphysis from a topographic and anatomical standpoint.

Materials and Methods. The study was conducted on 11 unfixed lower limb specimens obtained from six deceased individuals aged 52 to 64 years. The experiment was performed in two series. In the first series, the proposed surgery was simulated on three specimens, followed by dissection to assess the risk of damage to anatomical structures. In the second series, horizontal cuts with epoxy plastination (according to the method by D.A. Starchik) were made on eight specimens after the operation, and morphometry was performed.

Results. In the first series of experiments, the technique of the proposed treatment method was tested, and nonexistent risk of damage to important neurovascular structures was confirmed. In the second series, the shortest distances from the fixation screw to the neurovascular structures were determined. The popliteal vein, popliteal artery, tibial nerve, and common peroneal nerve were located at a distance of 20.1–24.8 mm, 16.2–23.2 mm, 17.8–24.5 mm, and 13.2–24.1 mm, correspondingly.

Conclusion. The effective technique of the proposed method was experimentally developed. The anatomical safety of the intervention was confirmed: the tibial nerve and popliteal vessels were located outside the risk area. The identified risk of injury to the common peroneal nerve during fibular head mobilization is minimized by correct execution of the technique.

Keywords: proximal tibial epiphysis, fibular head, impression fractures and deformities of the tibial lateral condyle

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Introduction

Impression fractures and deformities of the lateral tibial condyle represent a complex and demanding issue in contemporary traumatology and orthopedics [1–3]. Fractures localized in this region are observed in 55–70% of cases, and the proportion of isolated injuries to the posterolateral condyle accounts for 8% of all intra-articular tibial fractures [3–5].

It is acknowledged that this type of fracture most often occurs with complex high-energy injuries, such as falls while skiing or falls from a height with valgization of the knee joint, which is often combined with damage to its ligamentous apparatus [5, 6]. Additionally, the topographic and anatomical features of the fracture area in question, including the close location of the common peroneal nerve and its branches, the popliteal vascular bundle, as well as the complex topography of the articular surfaces in the knee joint, create significant difficulties in surgical treatment [6].

Inadequate repositioning and improper fixation of bone fragments in fractures of the posterolateral tibial plateau result in severe undesirable consequences: knee joint instability, post-traumatic osteoarthritis, chronic pain

syndrome, and ultimately, a significant deterioration in the function of the affected lower limb [3, 7, 8]. Available surgical approaches and osteosynthesis techniques (the use of lateral or posterior plates with screws, as well as individual screws) often do not provide reliable fixation of fragments due to limited visibility of the surgical field, the risk of damage to large vessels and nerves, and inadequate mechanical support of the impacted fragment of the joint [2, 7–10]. Hence, the search for new, more effective and safe methods of stable osteosynthesis for impression fractures in the posterolateral tibial plateau, taking into account the topographic and anatomical features of the injury site, remains relevant.

To date, conventional and modified surgical approaches to the posterolateral tibial plateau (according to D.A. Carlson [11] and K.H. Frosch et al. [9]) has been described in detail in the specialized scientific literature. Some studies were devoted to the analysis of the results of using various metal structures for osteosynthesis [1, 5–7, 10]. Yet, issues related to the optimization of fixation points in the lateral tibial condyle, taking into account the individual anatomical variability of bones, and neurovascular structures, have not been sufficiently addressed. Furthermore, there is no consensus among specialists regarding the choice of a

fixation method for bone fragments that reduces the risk of damage to these important anatomical structures.

At the Vreden National Medical Research Center for Traumatology and Orthopedics of the Russian Federation Ministry of Healthcare, researchers have developed a surgical technique for the treatment of patients with impression fractures and post-traumatic deformities in the posterolateral region of the proximal tibial epiphysis using a posterolateral approach and subchondral osteotomy with separation of the tibiofibular joint from the lateral tibial condyle. This technique ensures complete visual access to the surgical field and bone grafting with reliable fixation [12, 13]. In this case, the bone autograft provides main support, while the fibula acts as a congruent supporting structure, which is fixed with a single screw inserted through the fibular head into the lateral tibial condyle.

We conducted this applied topographic anatomy study to experimentally validate the safety of the proposed new technique.

Objective: To substantiate the feasibility and safety of a new surgical treatment method for patients with impression fractures and deformities of the posterolateral proximal tibial epiphysis from a topographic and anatomical standpoint.

Materials and Methods

This applied topographic anatomy study was conducted at the Department of Human Morphology of the North-Western State Medical University, St. Petersburg, Russia, using 11 unfixed lower limb specimens obtained from 6 cadavers (the deceased patients ranged in age from 52 to 64 years).

The anatomical material in this study was obtained and used in accordance with the requirements of Federal Law No. 8-FZ of January 12, 1996, "On Burial and Funeral Services," and Russian Government Resolution No. 750 of July 21, 2012, "On Approval of the Rules for the Transfer of the Unclaimed Body, Organs, and Tissues of a Deceased Person for Medical, Scientific, and Educational Purposes, as well as the Use of the Unclaimed Body, Organs, and Tissues of a Deceased Person for the Said Purposes." The study received an approval from the Ethics Committee of the Vreden National Medical Research Center of Traumatology and Orthopedics of the Russian Ministry of Healthcare of the Vreden National Medical Research Center for Traumatology and Orthopedics of the Russian Federation Ministry of Healthcare (Protocol No. 3 of November 21, 2023).

The study included two sequential series of experiments using different methods. Inclusion criteria were as follows: a mesomorphic (sthenic) type of body habitus and no history of trauma or surgery on the lower limb joints.

In the first series, a simulation of the proposed method of bone autografting of the posterolateral portion of the lateral tibial condyle was performed on three specimens, thereby practicing a relevant surgical technique. The projection of the bony landmarks, determined by palpation, is shown in *Figure 1*. The diagrams for positioning the bone autograft and fixation screw are shown in *Figure 2*.

We proposed the method of surgical treatment, for which the following Russian Federation patents were issued: Invention No. 2830403 [12] and Utility Model No. 220201 [13]. This method was employed when performing the procedure on the lateral surface of the knee joint with the

anatomical specimen positioned with its medial surface facing the operating table. First, the skin of the specimen was labeled with a marker, indicating important anatomical landmarks and the surgical approach projection (*Figure 1*). Next, we made a 10–12 cm long skin incision in the projection of the fibular head, followed by a layer-by-layer dissection of the soft tissues, carefully isolating and mobilizing the common peroneal nerve, after which it was secured with rubber holders. A Kirschner wire was used to determine the line of the proximal tibiofibular joint. Then, we performed a subchondral osteotomy of the tibiofibular joint with a wide, thin osteotome, thereby creating an osteotomy plane parallel to the articular surface of the tibiofibular joint and separating an osteochondral fragment (3–4 mm thick).

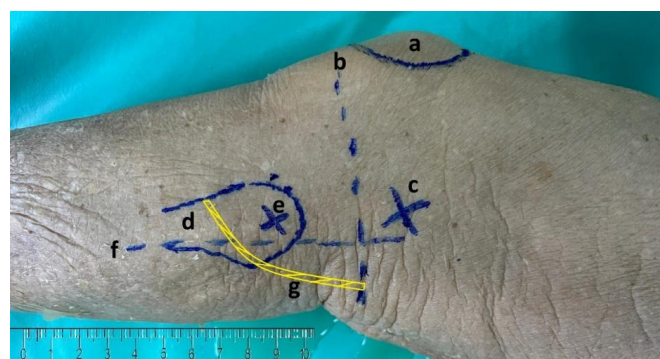


Figure 1. Anatomical structures of a specimen of the left knee joint, external view: a – patella; b – projection line of the tibial articular surface; c – lateral condyle of the femur (X); d, e – neck and head (X) of the fibula; f – projection of the skin incision for performing the surgical approach; g – projection of the common peroneal nerve onto the skin

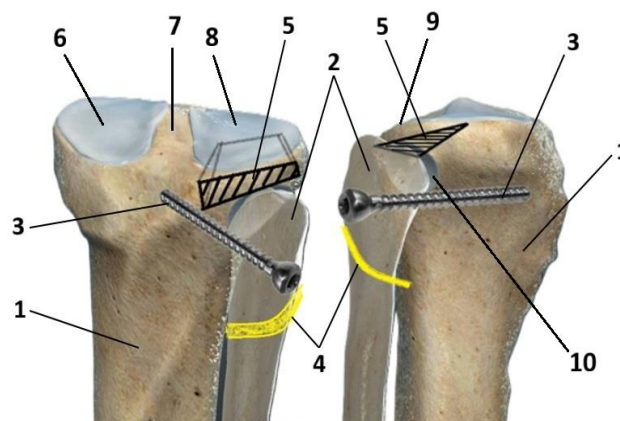


Figure 2. Diagram of the bone autograft and fixation screw positioning when performing the proposed way of the posterolateral tibial plateau fixation in impression fractures, anterior view (left) and posterior view (right):

1 – tibia; 2 – head of the fibula; 3 – fixation screw for the proximal tibiofibular joint; 4 – common peroneal nerve; 5 – bone autograft from the iliac crest; 6 – medial condyle; 7 – intercondylar eminence; 8 – lateral condyle; 9 – posterolateral part of the tibial condyle; 10 – proximal tibiofibular joint

It should be noted that the tibiofibular joint was separated from the tibia jointly with its complex of the capsule and ligaments, which ensured mobilization of the proximal fibula. The latter was retracted posteromedially with a Hohmann retractor, while the interosseous membrane remained intact. Then, using a special retractor that we proposed for the posterior tibia [13], the damaged lateral condyle of this bone was elevated, ensuring sufficient visibility from the posterior to the anterior edge of the assumed impacted fragment of the lateral tibial condyle. Next, we moved the repositioning osteotome parallel to the plane of the articular surface of the dented (impacted) lateral tibial condyle fragment, mobilized it with this osteotome and, using osteotome as a lever, raised the posterior edge of this fragment to the level of eliminating the articular surface deformation of the tibia, with a subsequent fixation with a Kirschner wire.

Next, we measured the height, width, and depth of the resulting bone defect of a triangular/trapezoid shape. Cancellous bone from the iliac wing of cadavers was used as a bone graft in the anatomical experiments, modeled to match the dimensions of the bone defect. We then placed this bone graft by impaction under the repositioned impacted bone fragment, after which we removed the previously inserted pin. The tibiofibular joint was subjected to repositioning and fixation with a single 4.5 mm cortical screw through the fibular head at a safe distance from the common peroneal nerve. The stages of this procedure are presented in *Figure 3*.

Following the simulated surgical procedure, we performed a layer-by-layer soft tissue preparation to visually assess the proximity of important anatomical structures to the surgical site and the risk of their injury in the course of the surgery. Particular attention was paid to accurately defining the spatial topographic and anatomical relationships of the inserted fixation screw with adjacent important anatomical structures. These included the popliteal artery and vein, along with the tibial and common peroneal nerves. The various stages of preparation were photographed and documented. The result of the preparation performed on a specimen of the left lower limb is shown *Figure 4*.

The second series of anatomical experiments on eight specimens was conducted after performing the proposed surgery using the original method described above. During this series, fragments of unfixed anatomical specimens, on which the surgery was simulated using the method by D.A. Starchik, were sawed and plastinated [14]. Specifically, for a detailed analysis of the spatial relationships between the bone graft and orthopedic screw with the surrounding tissues, D.A. Starchik's epoxy plastination method was employed, followed by the preparation of transparent histotopograms [14–17].

After the simulated surgical intervention, the biological specimen was subjected to rapid cryofixation in liquid nitrogen vapor. Using a diamond-coated band saw, we then segmented the knee joint into three anatomical blocks corresponding to the apex, caput, and collum of the fibular head. Next, the resulting blocks were sequentially dehydrated and degreased in acetone, then subjected by forced vacuum impregnation with an epoxy resin (ED-20:YD-128=5:1) with a gradual decrease in pressure from 300 to 3 mmHg over 20–24 hours, followed by resin curing (three days at room temperature with a subsequent incubation in a thermostat at 45–48 °C for 12–14 days).

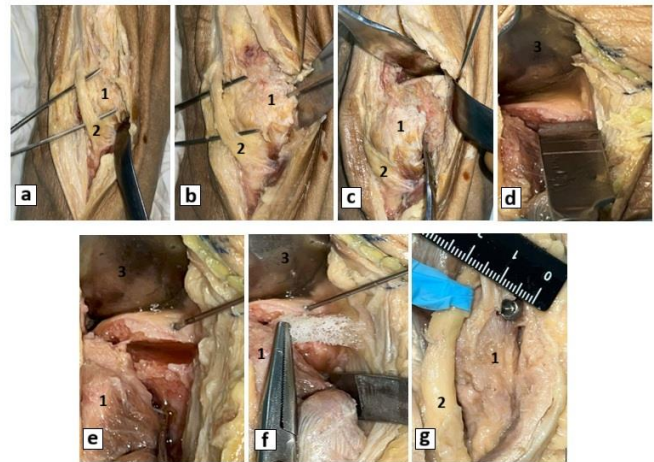


Figure 3. Implementation stages of the proposed technique on unfixed anatomical specimen:

1 – head of the fibula; 2 – common peroneal nerve; 3 – retractor for the posterior tibial condyle [13]; a – approach, isolation and mobilization of the common peroneal nerve; b – osteotomy in the area of the proximal tibiofibular joint parallel to its articular surface; c – using a Hohmann retractor for posterior retraction of the separated proximal fibula with a part of the osteochondral fragment of the posterolateral tibial plateau; d – osteotomy and elevation of the impacted osteochondral fragment of the tibial plateau; e – formed triangular/trapezoid bone defect after elevation of the impacted osteochondral fragment; f – plastic surgery with a modeled bone graft; g – fixation of the proximal fibula with a screw

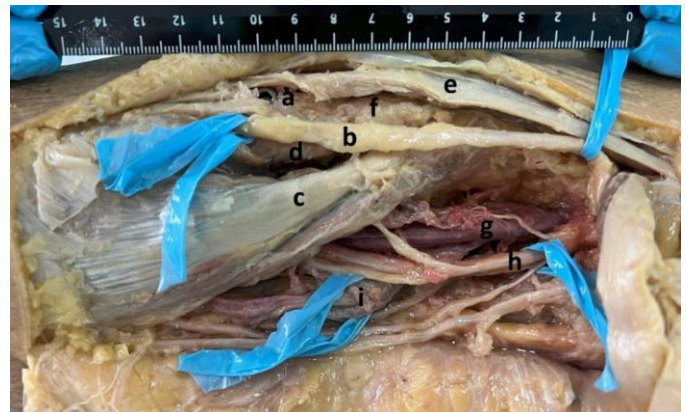


Figure 4. Result of unfixed specimen preparation of the left lower limb after simulating the proposed surgical treatment method for impression deformity of the posterolateral tibial plateau: a – fibular head fixated with a screw after osteotomy in the proximal tibiofibular joint area; b – common peroneal nerve. c – lateral head of the gastrocnemius muscle; d – soleus muscle; e – iliotibial tract; f – fibular collateral ligament; g – popliteal artery; h – tibial nerve and its branches; i – popliteal vein

Further on, the laminated blocks underwent multiple transverse cutting with a diamond-coated band saw, yielding 8–10 topographic cuts (histotopograms) 3–4 mm thick, which included the metal implant (fixation screw). The sections were washed, reimpregnated, and cured in flat polymethylacrylate chambers for their stabilization. The resulting histotopograms were digitized on a high-resolution

flatbed scanner, and measurements were taken in Adobe Photoshop CC 2018 with an accuracy of 0.1 mm [14, 15].

Subsequent mesoscopic examination (at magnification up to 20×) in transmitted light provided highly detailed visualization and differentiation of all anatomical structures of interest, including vascular networks and smaller nerve trunks, thereby exceeding the resolution of conventional anatomical dissection methods. Besides that, we performed targeted spatial relationship analysis on the prepared specimens, measuring the shortest distances between the inserted fixation screw and the important anatomical structures under study, such as the popliteal artery and vein, and the tibial and common peroneal nerves.

We subjected the measurement results to statistical processing yielding mean values (M) and their errors (m), which were entered into the relevant spreadsheet.

Results

Based on the results of our applied topographic anatomy study conducted in the first series of experiments on three anatomical specimens, we refined a feasible technique for the proposed surgical procedure. When used correctly, this method eliminates the risk of damage to the most important anatomical structures in the surgical area: the popliteal artery and vein, along with the tibial and common peroneal nerves. We confirmed that, when correctly performed, the proposed method eliminates the risk of direct contact and, consequently, iatrogenic damage to these anatomical structures. Layer-by-layer dissection revealed that the fixation screw, which ensures stability of the osteotomized osteochondral fragment (including the tibiofibular joint), after its repositioning, was located within the lateral tibial condyle and did not extend beyond it. This ensured the preservation of adjacent large neurovascular structures, as well as the complex of tendons and ligaments in the knee joint.

During the second series of anatomical experiments, conducted on eight unfixed lower limb specimens, the shortest distances from the fixation screw elements to major blood vessels and nerves were determined using plastinated sections at three levels of the knee joint: the apex, the midhead, and the neck of the fibula. Specifically, using plastinated horizontal sections at the apex of the fibular head, we assessed the position of the proximal portion of the screw relative to the popliteal artery, popliteal vein, tibial nerve, and common peroneal nerve passing through the area. The photograph of one of these sections (*Figure 5*) shows that all of these structures are located at fairly large distances from the fixation screw. Further measurements on the resulting histotopograms (*Table*) revealed that, on average, the popliteal vein is located at 24.8 ± 3.3 mm from the proximal portion of the fixation screw. The distances for the popliteal artery, common peroneal nerve, and tibial nerve were of 22.5 ± 3.7 mm, 13.2 ± 2.7 mm, and 23.2 ± 2.9 mm, respectively.

We assessed the position of the middle portion of the fixation screw on plastinated horizontal sections at the level of the fibular midhead in relation to four major neurovascular structures passing through this area: the popliteal artery, popliteal vein, tibial nerve, and common peroneal nerve. The presented photograph of one of these cuts (*Figure 6*) confirms the conducted measurements, which allowed us to establish that the popliteal vein is located at a mean distance

of 20.1 ± 2.4 mm, the popliteal artery at 16.2 ± 4.4 mm, the common peroneal nerve at 17.9 ± 2.2 mm, and the tibial nerve at the mean shortest distance of 17.8 ± 4.2 mm from the middle portion of the fixation screw.

We also assessed the location and measured the shortest distances from the distal portion of the fixation screw to the popliteal artery and vein, as well as the tibial and common peroneal nerves, passing at this level, on plastinated horizontal sections (histotopograms) taken at the level of the fibular neck. The presented histotopogram photograph of the left knee joint at this level confirms our measurements (*Table*). Specifically, we established the following mean distances for important anatomical structures from the distal portion of the fixation screw: 21.2 ± 3.7 mm for the popliteal vein, 23.2 ± 3.6 mm for the popliteal artery, 24.1 ± 4.2 mm for the common peroneal nerve, and 24.5 ± 2.2 mm for the tibial nerve. It should be noted that, if performed correctly, the proposed treatment method for patients with the studied injury ensures the preservation of important anatomical structures in the surgical area, specifically the common peroneal and tibial nerves, popliteal vessels, and knee ligaments.

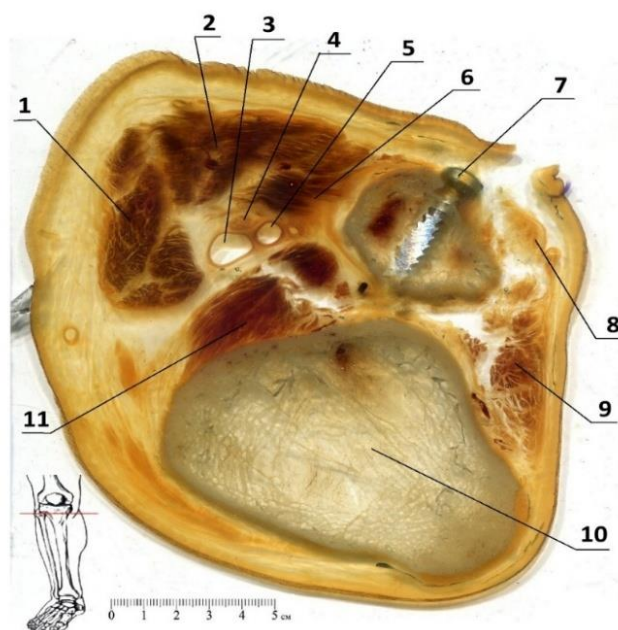


Figure 5. Plastinated horizontal section of the left knee joint at the level of the fibular head apex after the experimental implementation of the proposed surgery: 1 – medial head of the gastrocnemius muscle; 2 – lateral head of the gastrocnemius muscle; 3 – popliteal vein; 4 – tibial nerve; 5 – popliteal artery; 6 – soleus muscle; 7 – proximal part of the fixation screw (measurement point); 8 – common peroneal nerve; 9 – tibialis anterior muscle; 10 – tibia; 11 – popliteal muscle

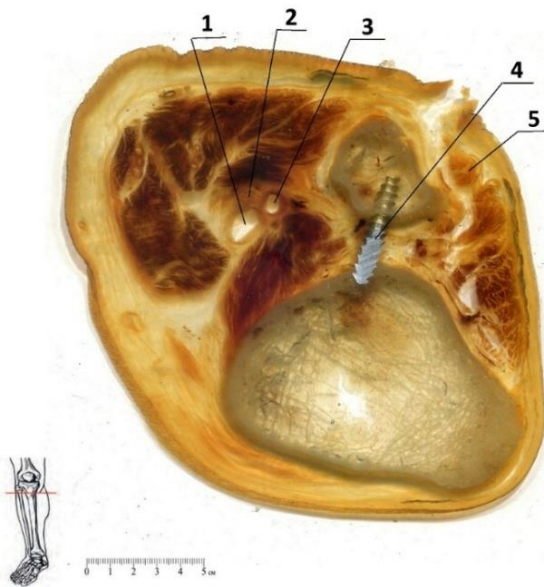


Figure 6. Plastinated horizontal section of the left knee joint at the level of the fibular midhead after the experimental implementation of the proposed surgery: 1 – popliteal vein; 2 – tibial nerve; 3 – popliteal artery; 4 – middle portion of the fixation screw (measurement point); 5 – common peroneal nerve

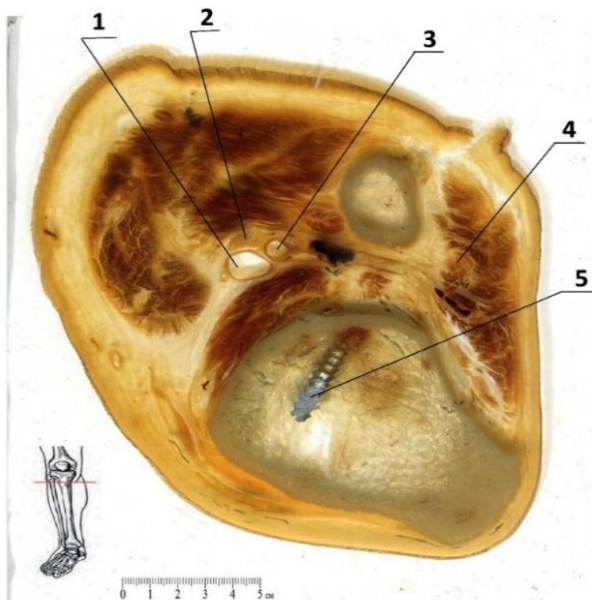


Figure 7. Plastinated horizontal section of the left knee joint at the level of the fibular neck after the experimental implementation of the proposed surgery: 1 – popliteal vein; 2 – tibial nerve; 3 – popliteal artery; 4 – common peroneal nerve; 5 – distal portion of the fixation screw (measurement point)

Table. Mean distances (mm) from various parts of the fixation screw to major blood vessels and nerves after metal osteosynthesis of the fibular head

Distance from fixation screw elements	Fixation screw elements	<i>M±m</i>
To the tibial nerve	Proximal part	23.2±2.9
	Middle part	17.8±4.2
	Distal part	24.5±2.2
To the popliteal artery	Proximal part	22.5±3.7
	Middle part	16.2±4.4
	Distal part	23.2±3.6
To the popliteal vein	Proximal part	24.8±3.3
	Middle part	20.1±2.4
	Distal part	21.2±3.7
To the common peroneal nerve	Proximal part	13.2±2.7
	Middle part	17.9±2.2
	Distal part	24.1±4.2

Discussion

Our applied topographic anatomy study developed a feasible surgical technique and substantiated the safety of our proposed reconstructive osteosynthesis procedure with bone autografting through a posterolateral surgical approach for impression fractures and deformities of the posterolateral proximal tibial epiphysis. Furthermore, experiments on unfixed anatomical specimens confirmed the practicability and ease of performing a unique surgical approach to the posterior lateral tibial condyle, achieved by separating the tibiofibular joint via osteotomy and displacing it laterally along with the proximal fibula. An original technique was also tested and refined [12, 13]. This was the technique for elevating the impacted osteochondral fragment of the articular surface of the tibial plateau, replacing the resulting bone defect with a bone autograft and subsequent fixation of autograft with the proximal portion of the fibula, through the head of which a single fixation screw was inserted.

We would like to point out that the safety of the posterolateral approach to the lateral condyle of the proximal tibial epiphysis remains controversial among traumatologists [8–10, 18–20], as it is traditionally associated with the risk of injury to the common peroneal nerve, its branches, and the anterior tibial recurrent artery, which requires high precision in soft tissue manipulation. Our topographic anatomy study demonstrated that, when the developed technique is correctly performed, the distance to important anatomical structures in the surgical area is sufficiently large, virtually eliminating the risk of injury. However, to ensure adequate safety, the common peroneal nerve requires minor mobilization at the level of the fibular neck and constant visual monitoring, which is possible due to its superficial location. This feature was noted both during traditional dissection in the first series of our experiments and in the second series of experiments involving plastinated sections made in the surgical site at three levels, at which surgeons work with specialized instruments [1, 2, 5, 7, 18, 19].

It should also be noted that the combination of traditional (analysis of the anatomical and topographic relationships between the fixation screw and anatomical structures in the surgical wound performed by dissection) and innovative (analysis of plastinated cuts of the tibia at the surgical levels)

methods significantly increased the accuracy and practical value of the results. In particular, this allowed to obtain a more comprehensive picture of the topographic and anatomical relationships between the fixator and important anatomical structures in the area of our proposed intervention and increased the accuracy of the surgeon's calculations and actions during preoperative planning and execution of the proposed procedure.

In studies devoted to osteosynthesis in tibial plateau fractures from posterolateral surgical approaches, the authors, as a rule, investigated the possibilities of positioning an extramedullary support plate within the proximal third of the tibia [1, 5–9, 18, 22]. One of the known technical solutions for visualizing the posterolateral bone fragment of the tibial plateau is a posterolateral surgical approach with osteotomy at the level of the fibular neck, described in detail by L.B. Solomon et al. [19]. However, this technique is associated with two significant potential dangers: the risk of nonunion (pseudarthrosis) of the fibular neck and the threat of iatrogenic damage to the common peroneal nerve, which runs in close proximity to the osteotomy zone. In an effort to minimize these risks, K.H. Frosch et al. [9] proposed a technique that eliminates osteotomy and utilizes two surgical windows for mobilization and repositioning of bone fragments. However, this method increases soft tissue traumatization. In the first and second cases, the authors used bone plates for fixation of posterolateral tibial plateau fractures. Our original technique solves this problem by eliminating the need for plates and instead using the patient's own proximal fibula for fixation of the repositioned bone autograft [12, 13, 20].

We would also like to emphasize that the undertaken topographic anatomy study revealed two advantages of our proposed technique. The first is that the high congruence of the two bones ensured uniform and complete contact while the fibula performed its natural supporting function, which we now use as a fixator in osteosynthesis and bone autografting for impression fractures of the posterolateral tibial plateau. The second advantage is the ability to use just one screw for fixation, which is safe for adjacent important anatomical structures.

It is also important to note that the fixation screw remains within both lower leg bones (the tibia and the fibula) and does not damage important neurovascular structures. Besides, the fixation stability is sufficient to initiate early knee joint motion for rapid restoration of its functioning. Hence, from a topographic anatomy perspective, the feasibility and safety of the proposed original surgical technique for important anatomical structures in the knee joint has been experimentally proven.

Conclusion

A detailed analysis of the relationships between bone structures, the complex of the capsule and ligaments, and the neurovascular structures in the knee joint, based on the results of two series of anatomical experiments, allowed us to substantiate the feasible technique of the proposed reconstructive osteosynthesis surgery with bone autografting. This method provides direct visualization of the posterior impression zone of the lateral articular surface in the proximal tibial epiphysis with minimal risk of iatrogenic damage to the popliteal vessels, the tibial and common

peroneal nerves, and the lateral stabilizing structures of the knee joint

The proposed surgical technique for reconstructing the posterolateral fragment of the lateral tibial condyle in cases of impression fractures and deformities takes into account the studied details of the topographic and anatomical relationships in the posterior knee joint and new possibilities for repositioning and fixation of the impacted articular surface of the tibial plateau. Also, this technique allows achieving anatomical restoration of the tibial plateau in cases of impression fractures, along with reliable fixation of the osteochondral fragment and the transplanted bone autograft. This creates the prerequisites for early initiation of restorative movement and rapid restoration of knee joint function, slowing the development of post-traumatic arthrosis. This gives us hope for improved anatomical and functional treatment outcomes in this problematic category of patients.

The new surgical treatment method for impression fractures and deformities of the posterolateral tibial condyle, presented in this article and studied in our applied topographic anatomy study, has received sufficient topographic and anatomical substantiation for its implementation in clinical practice. However, a definitive answer to the question of the viability of this technique will undoubtedly be provided only by further clinical studies.

Conflict of interest. The authors declare no obvious or potential conflicts of interest related to the publication of this article.

Author contributions. All authors contributed equally to the preparation of this publication.

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Compliance with ethical principles. The study protocol was approved by the local ethics committee. Approval and protocol implementation procedures complied with the current legislation of the Russian Federation.

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