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ЕЖЕМЕСЯЧНЫЙ НАУЧНЫЙ ЖУРНАЛ

Медицинские новости Грузии
საქართველოს სამედიცინო სიახლენი

GEORGIAN MEDICAL NEWS

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GMN: Georgian Medical News is peer-reviewed, published monthly journal committed to promoting the science and art of medicine and the betterment of public health, published by the GMN Editorial Board since 1994. GMN carries original scientific articles on medicine, biology and pharmacy, which are of experimental, theoretical and practical character; publishes original research, reviews, commentaries, editorials, essays, medical news, and correspondence in English and Russian.
GMN is indexed in MEDLINE, SCOPUS, PubMed and VINITI Russian Academy of Sciences. The full text content is available through EBSCO databases.

GMN: Медицинские новости Грузии - ежемесячный рецензируемый научный журнал, издаётся Редакционной коллегией с 1994 года на русском и английском языках в целях поддержки медицинской науки и улучшения здравоохранения. В журнале публикуются оригинальные научные статьи в области медицины, биологии и фармации, статьи обзорного характера, научные сообщения, новости медицины и здравоохранения. Журнал индексируется в MEDLINE, отражён в базе данных SCOPUS, PubMed и ВИНИТИ РАН. Полнотекстовые статьи журнала доступны через БД EBSCO.

GMN: Georgian Medical News – საქართველოს სამედიცინო სიახლენი – არის ყოველთვიური სამეცნიერო სამედიცინო რეცენზირებადი ჟურნალი, გამოიცემა 1994 წლიდან, წარმოადგენს სარედაქციო კოლეგიისა და აშშ-ის მეცნიერების, განათლების, ინდუსტრიის, ხელოვნებისა და ბუნებისმეტყველების საერთაშორისო აკადემიის ერთობლივ გამოცემას. GMN-ში რუსულ და ინგლისურ ენებზე ქვეყნდება ექსპერიმენტული, თეორიული და პრაქტიკული ხასიათის ორიგინალური სამეცნიერო სტატიები მედიცინის, ბიოლოგიისა და ფარმაციის სფეროში, მიმოხილვითი ხასიათის სტატიები.
ჟურნალი ინდექსირებულია MEDLINE-ის საერთაშორისო სისტემაში, ასახულია SCOPUS-ის, PubMed-ის და ВИНИТИ РАН-ის მონაცემთა ბაზებში. სტატიების სრული ტექსტი ხელმისაწვდომია EBSCO-ს მონაცემთა ბაზებიდან.

WEBSITE

www.geomednews.com

К СВЕДЕНИЮ АВТОРОВ!

При направлении статьи в редакцию необходимо соблюдать следующие правила:

1. Статья должна быть представлена в двух экземплярах, на русском или английском языках, напечатанная через **полтора интервала на одной стороне стандартного листа с шириной левого поля в три сантиметра**. Используемый компьютерный шрифт для текста на русском и английском языках - **Times New Roman** (**Кириллица**), для текста на грузинском языке следует использовать **AcadNusx.** Размер шрифта - **12**. К рукописи, напечатанной на компьютере, должен быть приложен CD со статьей.

2. Размер статьи должен быть не менее десяти и не более двадцати страниц машинописи, включая указатель литературы и резюме на английском, русском и грузинском языках.

3. В статье должны быть освещены актуальность данного материала, методы и результаты исследования и их обсуждение.

При представлении в печать научных экспериментальных работ авторы должны указывать вид и количество экспериментальных животных, применявшиеся методы обезболивания и усыпления (в ходе острых опытов).

4. К статье должны быть приложены краткое (на полстраницы) резюме на английском, русском и грузинском языках (включающее следующие разделы: цель исследования, материал и методы, результаты и заключение) и список ключевых слов (key words).

5. Таблицы необходимо представлять в печатной форме. Фотокопии не принимаются. **Все цифровые, итоговые и процентные данные в таблицах должны соответствовать таковым в тексте статьи**. Таблицы и графики должны быть озаглавлены.

6. Фотографии должны быть контрастными, фотокопии с рентгенограмм - в позитивном изображении. Рисунки, чертежи и диаграммы следует озаглавить, пронумеровать и вставить в соответствующее место текста **в tiff формате**.

В подписях к микрофотографиям следует указывать степень увеличения через окуляр или объектив и метод окраски или импрегнации срезов.

7. Фамилии отечественных авторов приводятся в оригинальной транскрипции.

8. При оформлении и направлении статей в журнал МНГ просим авторов соблюдать правила, изложенные в «Единых требованиях к рукописям, представляемым в биомедицинские журналы», принятых Международным комитетом редакторов медицинских журналов - http://www.spinesurgery.ru/files/publish.pdf и http://www.nlm.nih.gov/bsd/uniform_requirements.html
В конце каждой оригинальной статьи приводится библиографический список. В список литературы включаются все материалы, на которые имеются ссылки в тексте. Список составляется в алфавитном порядке и нумеруется. Литературный источник приводится на языке оригинала. В списке литературы сначала приводятся работы, написанные знаками грузинского алфавита, затем кириллицей и латиницей. Ссылки на цитируемые работы в тексте статьи даются в квадратных скобках в виде номера, соответствующего номеру данной работы в списке литературы. Большинство цитированных источников должны быть за последние 5-7 лет.

9. Для получения права на публикацию статья должна иметь от руководителя работы или учреждения визу и сопроводительное отношение, написанные или напечатанные на бланке и заверенные подписью и печатью.

10. В конце статьи должны быть подписи всех авторов, полностью приведены их фамилии, имена и отчества, указаны служебный и домашний номера телефонов и адреса или иные координаты. Количество авторов (соавторов) не должно превышать пяти человек.

11. Редакция оставляет за собой право сокращать и исправлять статьи. Корректура авторам не высылается, вся работа и сверка проводится по авторскому оригиналу.

12. Недопустимо направление в редакцию работ, представленных к печати в иных издательствах или опубликованных в других изданиях.

При нарушении указанных правил статьи не рассматриваются.

REQUIREMENTS

Please note, materials submitted to the Editorial Office Staff are supposed to meet the following requirements:

1. Articles must be provided with a double copy, in English or Russian languages and typed or compu-ter-printed on a single side of standard typing paper, with the left margin of **3** centimeters width, and **1.5** spacing between the lines, typeface - **Times New Roman** (**Cyrillic**), print size - **12** (referring to Georgian and Russian materials). With computer-printed texts please enclose a CD carrying the same file titled with Latin symbols.

2. Size of the article, including index and resume in English, Russian and Georgian languages must be at least 10 pages and not exceed the limit of 20 pages of typed or computer-printed text.

3. Submitted material must include a coverage of a topical subject, research methods, results, and review.

Authors of the scientific-research works must indicate the number of experimental biological species drawn in, list the employed methods of anesthetization and soporific means used during acute tests.

4. Articles must have a short (half page) abstract in English, Russian and Georgian (including the following sections: aim of study, material and methods, results and conclusions) and a list of key words.

5. Tables must be presented in an original typed or computer-printed form, instead of a photocopied version. **Numbers, totals, percentile data on the tables must coincide with those in the texts of the articles.** Tables and graphs must be headed.

6. Photographs are required to be contrasted and must be submitted with doubles. Please number each photograph with a pencil on its back, indicate author's name, title of the article (short version), and mark out its top and bottom parts. Drawings must be accurate, drafts and diagrams drawn in Indian ink (or black ink). Photocopies of the X-ray photographs must be presented in a positive image in **tiff format**.

Accurately numbered subtitles for each illustration must be listed on a separate sheet of paper. In the subtitles for the microphotographs please indicate the ocular and objective lens magnification power, method of coloring or impregnation of the microscopic sections (preparations).

7. Please indicate last names, first and middle initials of the native authors, present names and initials of the foreign authors in the transcription of the original language, enclose in parenthesis corresponding number under which the author is listed in the reference materials.

8. Please follow guidance offered to authors by The International Committee of Medical Journal Editors guidance in its Uniform Requirements for Manuscripts Submitted to Biomedical Journals publication available online at: http://www.nlm.nih.gov/bsd/uniform_requirements.html
http://www.icmje.org/urm_full.pdf
In GMN style for each work cited in the text, a bibliographic reference is given, and this is located at the end of the article under the title "References". All references cited in the text must be listed. The list of references should be arranged alphabetically and then numbered. References are numbered in the text [numbers in square brackets] and in the reference list and numbers are repeated throughout the text as needed. The bibliographic description is given in the language of publication (citations in Georgian script are followed by Cyrillic and Latin).

9. To obtain the rights of publication articles must be accompanied by a visa from the project instructor or the establishment, where the work has been performed, and a reference letter, both written or typed on a special signed form, certified by a stamp or a seal.

10. Articles must be signed by all of the authors at the end, and they must be provided with a list of full names, office and home phone numbers and addresses or other non-office locations where the authors could be reached. The number of the authors (co-authors) must not exceed the limit of 5 people.

11. Editorial Staff reserves the rights to cut down in size and correct the articles. Proof-sheets are not sent out to the authors. The entire editorial and collation work is performed according to the author's original text.

12. Sending in the works that have already been assigned to the press by other Editorial Staffs or have been printed by other publishers is not permissible.

Articles that Fail to Meet the Aforementioned
Requirements are not Assigned to be Reviewed.

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რედაქციაში სტატიის წარმოდგენისას საჭიროა დავიცვათ შემდეგი წესები:

1. სტატია უნდა წარმოადგინოთ 2 ცალად, რუსულ ან ინგლისურ ენებზე,დაბეჭდილი სტანდარტული ფურცლის 1 გვერდზე, 3 სმ სიგანის მარცხენა ველისა და სტრიქონებს შორის 1,5 ინტერვალის დაცვით. გამოყენებული კომპიუტერული შრიფტი რუსულ და ინგლისურენოვან ტექსტებში - **Times New Roman** (**Кириллица**),ხოლო ქართულენოვან ტექსტში საჭიროა გამოვიყენოთ **AcadNusx.** შრიფტის ზომა – 12. სტატიას თან უნდა ახლდეს CD სტატიით.

2. სტატიის მოცულობა არ უნდა შეადგენდეს 10 გვერდზე ნაკლებს და 20 გვერდზე მეტს ლიტერატურის სიის და რეზიუმეების (ინგლისურ,რუსულ და ქართულ ენებზე) ჩათვლით.

3. სტატიაში საჭიროა გაშუქდეს: საკითხის აქტუალობა; კვლევის მიზანი; საკვლევი მასალა და გამოყენებული მეთოდები; მიღებული შედეგები და მათი განსჯა. ექსპერიმენტული ხასიათის სტატიების წარმოდგენისას ავტორებმა უნდა მიუთითონ საექსპერიმენტო ცხოველების სახეობა და რაოდენობა; გაუტკივარებისა და დაძინების მეთოდები (მწვავე ცდების პირობებში).

4. სტატიას თან უნდა ახლდეს რეზიუმე ინგლისურ,რუსულ და ქართულ ენებზე არანაკლებ ნახევარი გვერდის მოცულობისა (სათაურის, ავტორების, დაწესებულების მითითებით და უნდა შეიცავდეს შემდეგ განყოფილებებს: მიზანი,მასალა და მეთოდები, შედეგები და დასკვნები; ტექსტუალური ნაწილი არ უნდა იყოს 15 სტრიქონზე ნაკლები) და საკვანძო სიტყვების ჩამონათვალი (key words).

5. ცხრილები საჭიროა წარმოადგინოთ ნაბეჭდი სახით. ყველა ციფრული, შემაჯამებელი და პროცენტული მონაცემები უნდა შეესაბამებოდეს ტექსტში მოყვანილს.

6. ფოტოსურათები უნდა იყოს კონტრასტული; სურათები, ნახაზები, დიაგრამები - დასათაურებული,დანომრილი და სათანადო ადგილას ჩასმული. რენტგენოგრამების ფოტოასლები წარმოადგინეთ პოზიტიური გამოსახულებით **tiff** ფორმატში. მიკროფოტოსურათების წარწერებში საჭიროა მიუთითოთ ოკულარის ან ობიექტივის საშუალებით გადიდების ხარისხი,ანათალების შეღებვის ან იმპრეგნაციის მეთოდი და აღნიშნოთ სურათის ზედა და ქვედა ნაწილები.

7. სამამულო ავტორების გვარები სტატიაში აღინიშნება ინიციალების თანდართვით, უცხოურისა – უცხოური ტრანსკრიპციით.

8. სტატიას თან უნდა ახლდეს ავტორის მიერ გამოყენებული სამამულო და უცხოური შრომების ბიბლიოგრაფიული სია (ბოლო 5-8 წლის სიღრმით). ანბანური წყობით წარმოდგენილ ბიბლიოგრაფიულ სიაში მიუთითეთ ჯერ სამამულო,შემდეგ უცხოელი ავტორები (გვარი, ინიციალები, სტატიის სათაური, ჟურნალის დასახელება, გამოცემის ადგილი,წელი,ჟურნალის №,პირველი და ბოლო გვერდები). მონოგრაფიის შემთხვევაში მიუთითეთ გამოცემის წელი, ადგილი და გვერდების საერთო რაოდენობა. ტექსტში კვადრატულ ფჩხილებში უნდა მიუთითოთ ავტორის შესაბამისი N ლიტერატურის სიის მიხედვით. მიზანშეწონილია,რომ ციტირებული წყაროების უმეტესი ნაწილი იყოს 5-6 წლის სიღრმის.

9. სტატიას თან უნდა ახლდეს: ა) დაწესებულების ან სამეცნიერო ხელმძღვანელის წარდგინება, დამოწმებული ხელმოწერითა და ბეჭდით; ბ) დარგის სპეციალისტის დამოწმებული რეცენზია, რომელშიც მითითებული იქნება საკითხის აქტუალობა, მასალის საკმაობა,მეთოდის სანდოობა,შედეგების სამეცნიერო-პრაქტიკული მნიშვნელობა.

10. სტატიის ბოლოს საჭიროა ყველა ავტორის ხელმოწერა,რომელთა რაოდენობა არ უნდა აღემატებოდეს 5-ს.

11. რედაქცია იტოვებს უფლებას შეასწოროს სტატია. ტექსტზე მუშაობა და შეჯერება ხდება საავტორო ორიგინალის მიხედვით.

12. დაუშვებელია რედაქციაში ისეთი სტატიის წარდგენა,რომელიც დასაბეჭდად წარდგენილი იყო სხვა რედაქციაში ან გამოქვეყნებული იყო სხვა გამოცემებში.

აღნიშნული წესების დარღვევის შემთხვევაში სტატიები არ განიხილება.

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BIOMECHANICAL COMPARISON OF THREE POSTERIOR MALLEOLUS FRACTURE FIXATION METHODS IN RELATION TO DIFFERENT FRACTURE MORPHOLOGY: A FINITE ELEMENT ANALYSIS

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Abstract.

Purpose: The objective of this study was to compare the biomechanical behavior of three fixation methods for posterior malleolar fracture (PMF) in relation to different fracture morphology and to evaluate the corresponding changes of the stress distribution on the articular surface of the tibia plafond by finite element analysis (FEA).

Methods: Three internal fixation techniques: two lag screws in antero-posterior direction (AP lag screws), two lag screws in postero-anterior direction (PA lag screws) and posterior plate (PP) were analyzed for posteromedial (PM) and posterolateral (PL) fragment of PMF using the FEA. The values of relative deformations, total displacements, and von Mises stress (VMS) in the model elements were estimated under vertical loading 700 N.

Results: PP showed the highest level of VMS in the elements of the metal implants (from 97.1 to 106.15 MPa), than PA (44.77 MPa and 39.2 MPa) and AP (23.99 MPa and 25.53 MPa) lag screws group, regardless morphology of PMF. The presence of the PM and PL fragment of PMF causes displacement contact stress distribution to the anterior part of the tibia plafond surface.

Conclusion: PP is biomechanically the most efficient technique for the fixation of PMF regardless of the fragment morphology. The distribution of loads on the articular surface of the tibia plateau depends on the morphology of the injury and the type of osteosynthesis of the PMF.

Key words. Posterior malleolus fracture, finite element analysis, morphology, biomechanics.

Introduction.

The problem of treating posterior malleolus fracture (PMF) remains a relevant subject of discussion in the surgery of ankle joint (AJ) for a long time. According to modern literature sources, PMF occurs in 50% of cases of ankle fractures [1] which significantly increases the risk of post-traumatic osteoarthritis of AJ [2,3] and worsens long-term treatment results [1]. Classic recommendations for osteosynthesis of PMF, which determine indications for surgical treatment based on the size and displacement of the fragment of posterior malleolus, are gradually losing their clinical significance, although they are still used by many orthopedic surgeons in practice. The lack of a unified view on the treatment of these injuries is explained by controversial results of a number of experimental and clinical studies[2-4], and the preferred choice of surgical strategy depending on the experience and opinions of the surgeon [3]. Taking into account that PMFs are three-dimensional structures, and their characteristics on neutral axes can be different [5], by a series of recent publications the attention has been focused on evaluating the morphology of the PMF as an important prognostic parameter of the functional outcomes [6,7]. The morphological approach to osteosynthesis of the posterior malleolus has changed modern views on the fixation of PMF, but even now most studies are focused on the study of the "classic" posterolateral fragment of the posterior malleolus (Volkmann's triangle). At the same time, posterior part of the tibia plafond damage involving the medial tibial plateau [8,9] are insufficiently studied, in despite of its prevalence and worse outcomes. Computer modeling by Finite Element Analysis (FEA) makes it possible to reproduce the behavior of biomechanical systems with high accuracy and brings the experiment closer to the most realistic conditions, which makes it possible to study the biomechanical behavior of fixation systems of the posterior malleolus under various morphological types of damage. Objective: to conduct a comparative biomechanical analysis of posterolateral and posteromedial morphological types of PMF using three methods of osteosynthesis and to evaluate the corresponding changes in the distribution of peak contact pressure on the articular surface of the distal tibia using computer simulative modeling by FEA.

Materials and methods.

Fixation techniques and grouping:

PMF models were divided into groups depending on the morphology of the injury (types 3 and 4 according to the Bartoníček and Rammelt classification) [13]: posteromedial fragment (Group A) and posterolateral fragment (Group B) of posterior malleolus. For each group, three methods of osteosynthesis were used: 1) screws in the "anterior-to-posterior" direction (AP lag screws); 2) screws in the "posterior-to-anterior" direction (PA lag screws) and 3) osteosynthesis with buttress plate according to the recommendations of AO. The view of models of PMF is shown in Figure 1.

Three dimensional (3D) models:

The study was conducted in accordance with the Declaration of Helsinki and approved by the Academic Council of the ITO NAMS of Ukraine. Three-dimensional (3D) model of the right AJ in the no-load position was performed on the basis of spiral CT scans of a healthy 30-year-old volunteer obtained on a 64-section CT Toshiba Asteion Super 4 (Japan). There was no past history of trauma and no anatomical abnormality was observed by X-ray examination. The participant gave informed consent for X-ray examination and CT. CT images of the ankle joint were taken at 0.625 mm intervals. CT data consisting of 680 DICOM images were then imported into Mimics 10.1 software (Materialise, Leuven, Belgium), where the spatial geometry of the tibia, fibula, talus, and calcaneus was reproduced in automatic and semi-automatic modes. The structure of each bone was exported to IGS file format, and the data was transferred to Geomagics Studio 11.0 software (Raindrop Company, USA), bone models were obtained, and exported as STP files for SolidWorks 2018 (DS SolidWorks Corp., USA), where, with the help of using appropriate tools, imitative geometric 3-D

Figure 1. *Two morphological types of posterior malleolus fracture involvement 25% articular surface. Construction of fixation methods for posterior malleolus fracture: (A): posteromedial PMF with buttress plate, (B): posteromedial PMF with two lag screws in the «posterior-to-anterior» direction, (C): posteromedial PMF with two lag screws in the «anterior-to-posterior» direction, (D) posterolateral PMF with buttress plate, (E):posterolateral PMF with two lag screws in the «posterior-to-anterior» direction, (F):posterolateral PMF with two lag screws in the «anterior-to-posterior» direction.*

models of AJ were created with modeling of posterolateral and posteromedial fragments of the PMF. Geometric parameters for reproducing morphological models of PMF were determined by separating the articular surface of the tibial plateau with an intermalleolar line connecting the medial and lateral malleoli and a line, perpendicular to the previous one in the direction of the posterior surface of the tibial plateau. According to the specified parameters, posterolateral and posteromedial fragments of PMF were formed, which accounted for 25% of the area of the articular plateau of the tibia, respectively. To illustrate the precise, reposition of the fracture zone, the parameters of the absence of a gap between the fracture fragments and the Poisson's ratio of 0.3 were set [10]. The coordinate axes of the model were defined as: the Y-axis is directed in the sagittal plane (toes to heel), the Z-axis in the vertical plane (knee joint to heel), and the X-axis in the frontal plane (medial to lateral bones). Special functions of the software were used to make the interaction between different parts of the models.

Finite element analysis:

The reconstructed 3D-models of bones in STEP AP214 files (* .step) were imported into the ANSYS 19.2 finite element analysis software package (Ansys Inc., Canonsburg, Pennsylvania, United States), where finite element (FE) discretization of models of "fixator-bone" biomechanical systems was performed in semi-automatic mode using tetrahedral and hexagonal finite elements. In the most important transition sections of the model with different mechanical properties, the FE grid was condensed to improve the accuracy of calculations. The generated FE models of biomechanical systems had a common sampling order with a maximum FE size of no more than 1 mm, a total number of nodes of 422,480, and consisted of 240,409 elements, which is optimal for ensuring the required accuracy of calculations. Models of biomechanical systems are presented as isotropic, linear elastic. All model materials were given the corresponding mechanical properties (Young's elastic modulus (E) and Poisson's coefficient (v). The computational process used the physical properties of bone and cartilage tissues obtained from literature sources [15,16], an elastic isotropic model of titanium alloy BT16 was chosen for the fixator elements, and the characteristics of artificial materials were selected according to the technical literature [17] (Table 1).

Table 1. *Properties of materials (cortical bone, cancellous bone, and titanium alloy).*

Material	**Elastic (Young's) мodulus, E (MPa)**	**Poisson's ratio (v)**	**Strength limit, MPa**
Cortical bone	17600	0,3	93,4
Trabecular bone	500	0,2	17,5
Cartilage	50	0,45	16,7
Titanium alloy BT16	112000	0,32	590

Boundary conditions and evaluation criteria:

To carry out the load, the models had a rigid fixation in all degrees of freedom at the level of the hindfoot in order to minimize errors in calculations. Vertical axial load on the proximal end of the tibia was performed with a force of 700H, which corresponds to the simulation of the one leg stand load on the AJ (Figure 2). In each case of load, single forces and a moment were applied to the system. The values of the maximum stress and the values of relative deformations in the model elements were studied. Von Mises stress analysis and total deformation (TD) were performed for the model as a whole, as well as separately for the model elements relative to each other, wherefore additional coordinate axes were set, regarding which the displacements in each plane were determined.

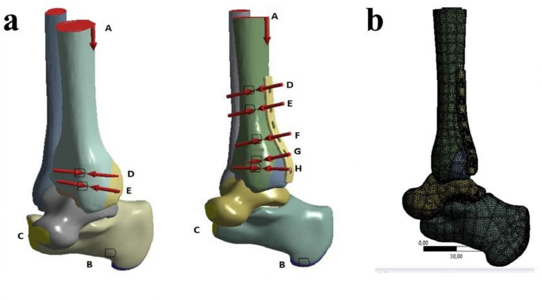

Figure 2*. a. Calculation model of the AJ with fixing and loading conditions: A - load 700 H (70 kg); B – rigid fixation at the level of the calcaneus was introduced; C - restriction of movement at the level of the bones of the middle part of the foot (continuation of the model); D-H - compression zone.*
b. FE calculation grid model with simulated posteromedial type PMF and buttress plate.

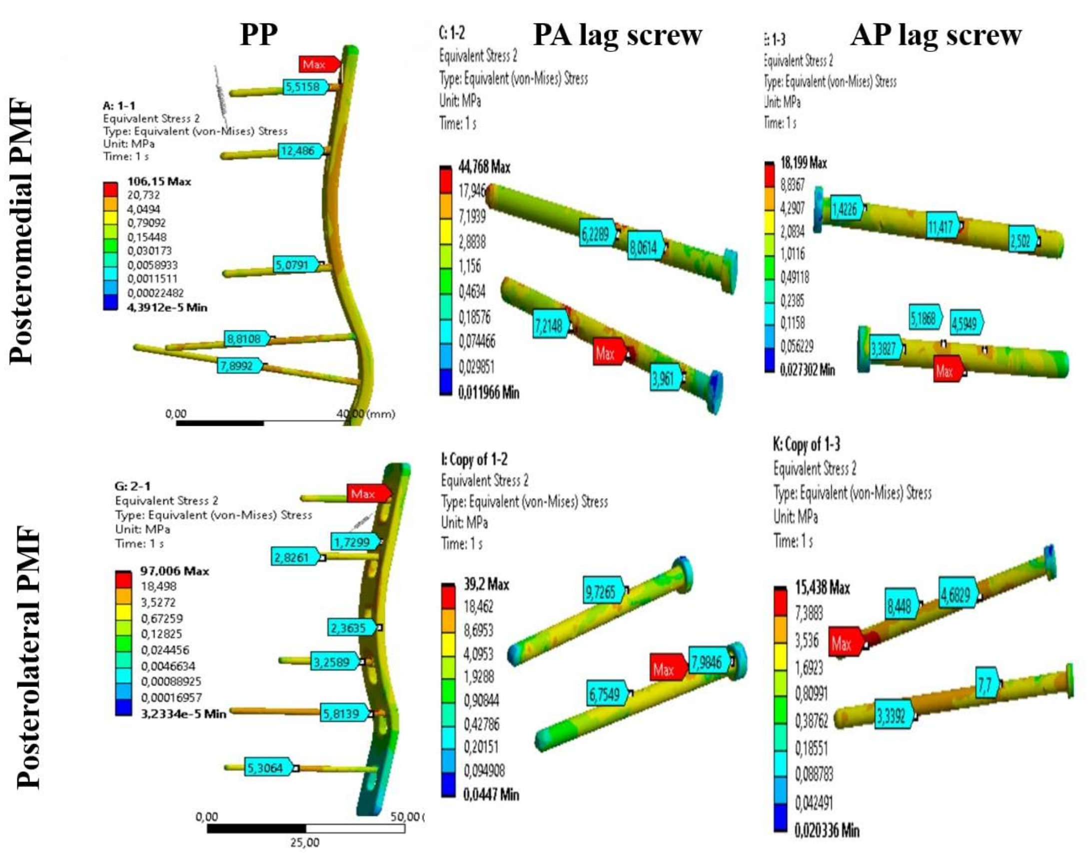

Figure 3. *Distribution of VMS in different fixation implants. PMF – posterior malleolus fracture; PA lag screw – two lag screws in the «posterior-to-anterior» direction; AP lag screw – two lag screws in the «anterior-to-posterior» direction, PP – buttress plate.*

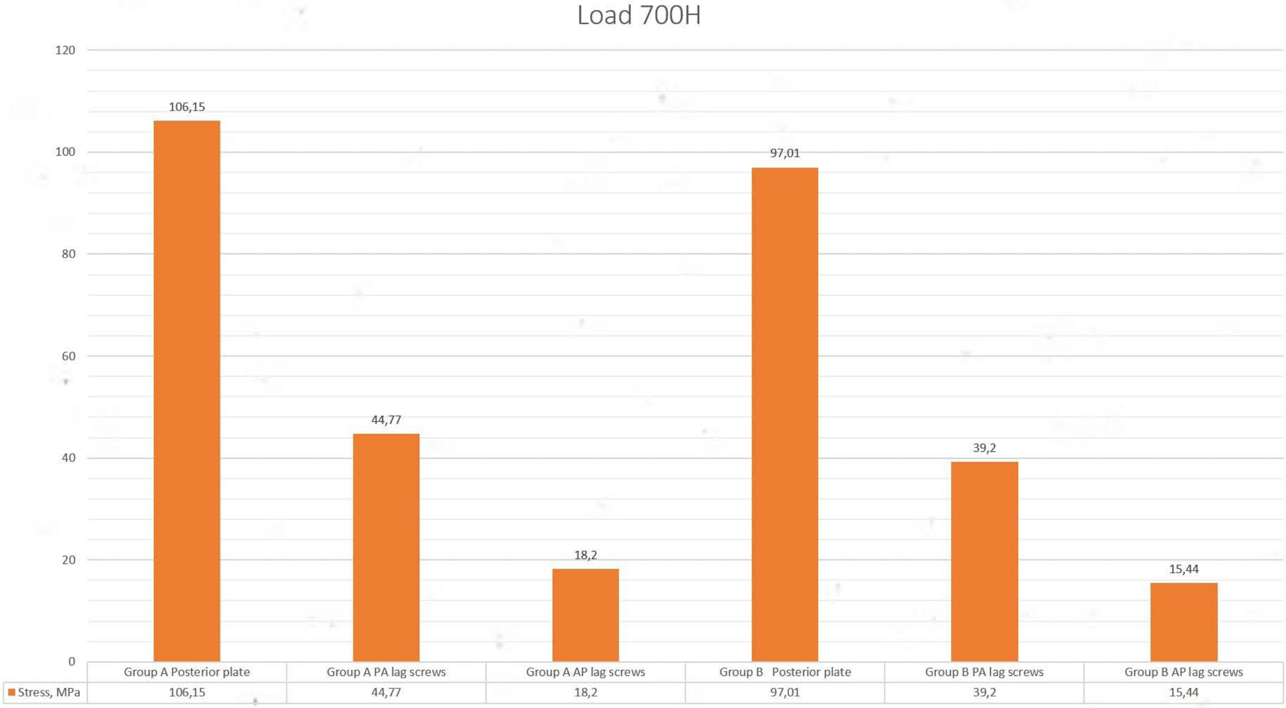

Figure 4. *Comparative analysis of Von Mises peak stress values in fixation implants.*

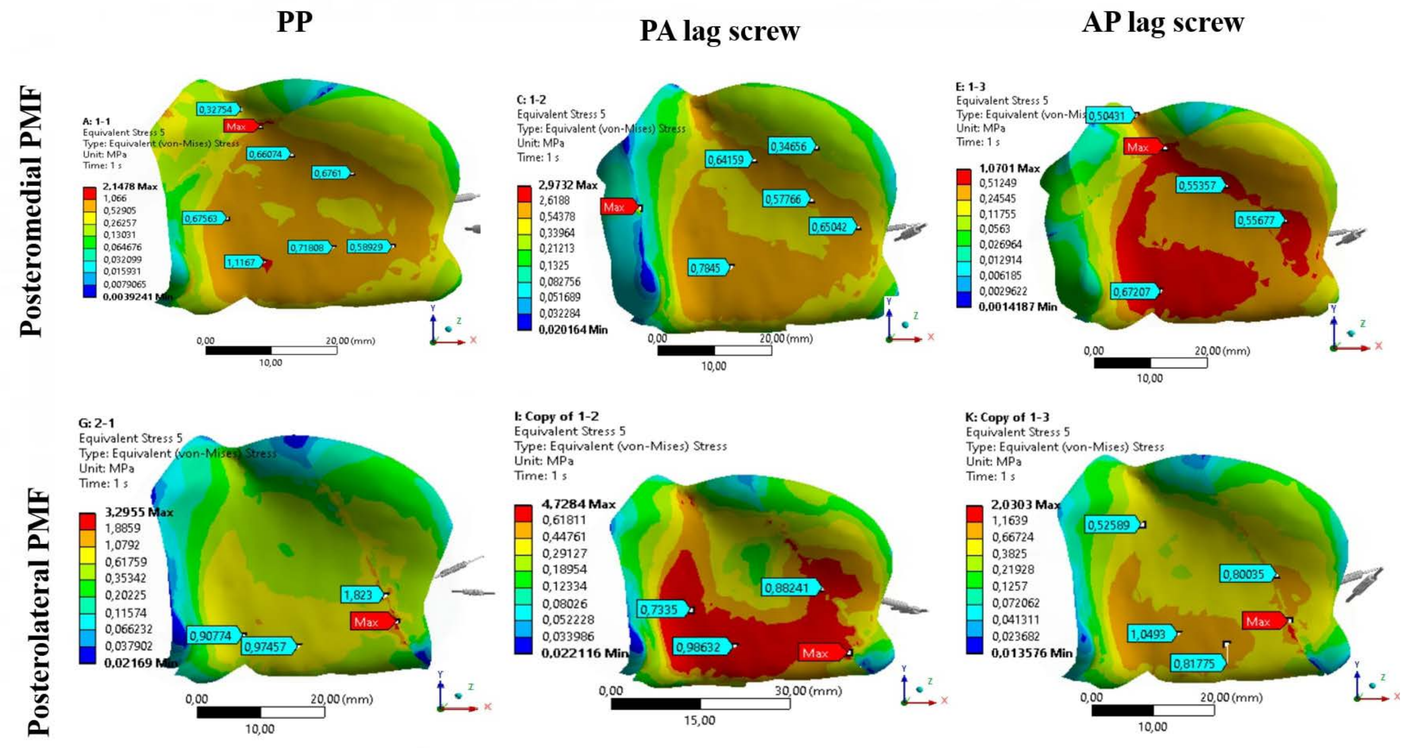

Figure 5. *Contact von Mises stress and pressure distribution on the articular surface of the tibia in models with different fixation constructs and morphological types of PMF.*

Table 2*. Von Mises peak stress values of the implants (MPa) in two groups.*

Physiological conditions	**Fixation**	**Group A (posteromedial PMF)**		**Group B (posterolateral PMF)**		**[σ]** [c]
		σ_{max} [a]	n[b]	σ_{max} [a]	n[b]	
Load 700H	Buttress plate	106.15	2.22	97.01	2.43	236
	PA lag screws	44.77	5.07	39.2	5.80	227.2
	AP lag screws	18.2	12.48	15.44	14.72	

σ_{max} [a] - *maximum stresses on the Model elements*

[c] *[σ]- maximum allowable stress values*

[b] *n-safety margin.*

Table 3*. The displacement values of the fracture (mm) in two subgroups (total and localized displacement).*

Fixation strategy	**Posteromedial PMF**				**Posterolateral PMF**			
	Axis				**Axis**			
	Localized displacement			**Total displacement**	**Localized displacement**			**Total displacement**
	X	**Y**	**Z**		**X**	**Y**	**Z**	
Buttress plate	0,2	0,11	0,17	0,28460	0,05	0,24	0,09	0,26115
PA lag screw	0,19	0,11	0,17	0,27767	0,06	0,24	0,09	0,26325
AP lag screw	0,15	0,08	0,14	0,22023	0,05	0,24	0,09	0,26115

Results.

Von Mises Stress (VMS) distribution in different fixation implants:

At the first stage of the research, the stress-deformed state of the model elements was analyzed under conditions of a load of 700H for various morphological types of PMF. The distribution of von Mises-equivalent stress fields in fixation implants of biomechanical system when modeling osteosynthesis of posterolateral and posteromedial PMF is given in Figure 3 and Figure 4.

The peak stress value in implants at a load of 700H was the highest in the subgroup of plate osteosynthesis (posteromedial PMF- 106.15 MPa, posterolateral PMF-97.01 MPa) and did not reach the strength limit of the fixators (σMax = 236 MPA). The lowest stress values were observed in the subgroup of AP screws - 23.99 MPa and 25.53 MPa, and almost 1.5 times less than similar indicators in the subgroup of PA screws (44.77 MPa and 39.2 MPa), respectively (Table 2). Stress indicators were concentrated mainly in the central 1/3 of the screws in both subgroups of AP and PA screws, which can be explained by the reflection of the transfer of body weight to the fixators in these sections and the maximum proximity to the fracture line, while the upper part of the plate was the most loaded element during osteosynthesis by the plate. Analysis of the stress and deformations distribution in the case of using various fixation devices under the influence of a load of 700H showed an advantage in the aspect of rigidity and stability of fixation when using osteosynthesis by the plate.

Von Mises stress distribution in the different PMF models:

Analysis of the stress-deformed state of the models showed that at a load of 700H, the highest stress concentrations on the fragment of posterior malleolus for all the considered types of osteosynthesis occurred when the posterolateral fragment PMF was fixed with a plate, and in the case of posteromedial fragment PMF - with PA screws, which on average did not exceed 18 MPa, and did not reach the maximum limit stress value for bone tissue (37.36 MPA). An increase in VMS values on elements of the PMF model in these methods of osteosynthesis and the presence of a corresponding PMF fragment can lead to an increase in local destruction of the bone structure in the PMF fragment and increase the probability of loss of reposition and fixation.

The relationship between morphology PMF, fixation method, total and localized displacement (TD):

When analyzing micro-movements of the fragment of posterior malleolus at a load of 700H, all fixation implants show satisfactory results of posterior malleolus stabilization with the maximum displacement of the fragment not exceeding 0.3 mm. The smallest displacement of the posteromedial fragment of PMF was recorded with AP screws. In the posterolateral PMF group, the greatest displacement of the fragment was observed with PA screws. Evaluation of fragment displacements according to the established coordinates demonstrates that in osteosynthesis of the posteromedial PMF, the greatest displacement occurs along the X-axis (lateral displacement of the fragment) and Z-axis (vertical displacement); osteosynthesis of the posterolateral PMF shows the greatest displacement along the Y-axis (displacement to the back), regardless the type of osteosynthesis. Total and localized displacement of the different PMF types with three fixation methods are shown in Table 3.

The relationship between morphology PMF, fixation method and maximum contact stress (MCS):

The next stage of the research was to assess the stress-deformed state and the distribution of peak contact pressure on the articular surface of the distal tibia. As a result of the study, it was determined that for different model scenarios, changes in the distribution of load zones on the articular surface of the tibial plateau are observed, depending on the morphotype and type of osteosynthesis of the fragment of posterior malleolus. The highest contact pressure values were recorded when using AP screws for the posteromedial PMF and PA screws for the posterolateral PMF. It should be noted that when modeling the posterolateral and posteromedial morphological types of PMF, the load zones move on the anterior parts of the articular surface of the tibia plateau (Figure 5).

Discussion.

As a result of the experiment, the obtained indicators of peak contact pressure on the articular plateau of the tibia, maximum contact stress and stress distribution on metal structures in the "fixator-bone" system were similar to other results of biomechanical studies[11-13], which proves the reliability and efficiency of the model we created.

Recent reviews of the literature on the results of treatment of PMF indicate that it is the assessment of the morphology of the fragment of posterior malleolus, rather than its size, that remains an important condition for successful treatment of these injuries [14,15]. Awareness of the importance of evaluating this parameter is taken as the basis of corresponding classifications that allowed not only to create an appropriate algorithm for the treatment of PMF in lower leg fractures of bones, but also help to predict long-term outcomes and expected treatment results [16-20].

PMF with significant involvement of the posteromedial parts of the tibial plateau (Bartonicek type 3/Haraguchi type 2) are considered as a special variant of "pylon injury" [21], which requires an individual approach in each specific case, depending on the nature of the damage [22]. A number of studies demonstrate that these injuries constitute a separate damage pattern [23], which is characterized by a more complex mechanism of occurrence and worse results of surgical treatment. Meta-analysis performed by Patel et al. [8] that is devoted to the study of the influence of the morphology of posterior malleolus on the outcomes of trimalleolar fractures, showed that fractures of Type 2 (medial extension type) according to the Haraguchi classification, have worse functional results of treatment compared to injuries of Type 2 and 1 (posterolateral-oblique type). The study that was conducted by Vosoughi et al. [24], demonstrates that the avulsion type of fractures of the posteromedial fragment of posterior malleolus, which is an outcome of the pronation mechanism of damage more often, does not require obligatory surgical treatment, since it serves only as an additional factor in stabilizing syndesmosis, while the pilon type, which is an outcome of supination and axial load, violates the congruence of AJ, has to be surgically treated. This point of view is also supported by the research of Wang at al. [25], that recommend anatomical reposition and fixation for pylon-type PMF, while avulsive fractures may only require conservative treatment.

In our opinion, the probable cause that may affect the unsatisfactory results of treatment of PMF may be an underestimation of morphology and unjustified use by surgeons of suboptimal osteosynthesis methods for specific types of PMF. Wide morphological diversity of PMF [26,27], is the main reason for both underestimation and overestimation in terms of the need for osteosynthesis. The trends of routine osteosynthesis of PMF with a plate that have developed in recent years are criticized in the modern scientific literature, which is due to satisfactory results and a lower level of complications with less invasive treatment methods [28,29]. White T.O. [34] believes that an inevitable consequence of an increase in the volume of surgical intervention is an increase in the frequency of complications with excessive use of expensive medical resources. The optimal choice of the PMF osteosynthesis method still needs further development and improvement.

Osteosynthesis of the PMF using a buttress plate has several advantages, including the ability to visualize and reduce intraarticular impacted tibial plateau fragments, better restoration of the anatomical position of the lateral malleolus in the fibula notch due to tension of the posterior tibiofibular ligament[30] and provides greater syndesmotic stability compared to conservative treatment and screw fixation [31]. The use of a buttress plate demonstrates better clinical outcomes [32,33]. The disadvantages are the complexity of fixation of the medial malleolus due to the positioning of the patient during surgery; increased risk of damage to the neurovascular structures and the tendon of the flexor hallucis longus [34]; devascularization of fragments of the PMF and the possibility of intra-articular screw placement [35], increased risk of infectious wound complications associated with the presence of metal implants and the frequency of reoperation [36].

AP and PA lag screws have similar functional and radiological results, so the use of a particular option should be based mainly on the surgeon's experience [37]. The advantages of AP and PA lag screws are the relative simplicity of the procedure, reduced surgical time, and a lower rate of local infectious complications. At the same time, these methods of fixation have a number of significant disadvantages, including an increase in the frequency of syndesmotic fixation, the inability to perform precise reduction and fixation of PMF fragments, increased risk of screw positioning in the distal tibiofibular syndesmosis area and damage to extensor tendons and neurovascular structures [38,39].

A biomechanical study by Benett et al. [40] shows that buttress plate provides greater biomechanical stability with a lower degree of axial displacement PMF under cyclic loading compared to the use of screws, which is consistent with the results of our study. At the same time, a study Wang X et al. [41] found no specific advantages in the fixation of PMF with a buttress plate compared to the screws. The presence of contradictory results of biomechanical studies is explained by the methodological diversity of studies and the variability of the characteristics of the PMF fragment, which makes it difficult to compare these studies and make decisions about the need for surgery and the method of fixation [42].

One of the most common theories of the development of post-traumatic osteoarthritis of the AJ due to trimalleolar fractures is a decrease in the contact area and residual discongruence of the AJ, which causes excessive stress on the articular surfaces [2]. This is confirmed by biomechanical studies that indicate the duration of loads and characteristic changes in the distribution of peak contact pressure on the articular surfaces of AJ, as the main factors of osteoarthritis of AJ [43,44]. Our study shows typical changes in the load in the areas of pressure on articular cartilage of the tibia, which are normally subjected to lower loads, which complies with the results of previous studies. The research of Xie et al. [45] is interesting as it shows that the contact pressure on the tibial plateau in PMF with the presence of intra-articular impacted fragments (IAIFs) varies depending on the characteristic location of the injury.

Our research has some limitations. First, the results were not confirmed by clinical experiments. Second, our model used static modeling. Further studies are needed to research the behavior of the biomechanical system "fixator-bone" under cyclic loading conditions. The created biomechanical model did not take into account the influence of soft tissue structures of AJ (capsule and ligaments), bone quality, and the application of supraphysiological loads on AJ, which can serve as a basis for further research in this direction.

The aim of the study is to emphasize the importance of morphological assessment of the PMF and, accordingly, the choice of the optimal method of osteosynthesis depending on the morphology of posterior malleolus. Improving indications for surgical treatment, creating a differentiated approach to the treatment of PMF, along with restoring injuries of other anatomical structures of the AJ should remain the main goals of successful treatment of ankle fractures.

Conclusion.

Maximum biomechanical stability of PMF fixation can be achieved by osteosynthesis with a buttress plate, regardless of the morphology of the injury. The distribution of loads on the articular surface of the tibia plateau depends on the morphology of the injury and the type of osteosynthesis of the PMF. The defined changes in the distribution of contact pressure on the articular surface of the AJ may be probable factors of post-traumatic osteoarthritis in patients with ankle fractures and the presence of PMF.

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РЕЗЮМЕ

БИОМЕХАНИЧЕСКОЕ СРАВНЕНИЕ ТРЕХ МЕТОДОВ ФИКСАЦИИ ПЕРЕЛОМА ЗАДНЕГО КРАЯ БОЛЬШЕБЕРЦОВОЙ КОСТИ В ЗАВИСИМОСТИ ОТ РАЗЛИЧНОЙ МОРФОЛОГИИ ПЕРЕЛОМА: АНАЛИЗ МЕТОДОМ КОНЕЧНЫХ ЕЛЕМЕНТОВ

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Цель исследования. Сравнить биомеханическое поведение трех методов фиксации перелома заднего края большеберцовой кости (ЗКББК) в зависимости от различной морфологии перелома и оценить соответствующие изменения распределения напряжений на суставной поверхности плато большеберцовой кости с помощью анализа методом конечных элементов (FEA).

Методы. Три метода внутренней фиксации: два винта в передне-заднем направлении (AP lag screws), два винта в задне-переднем направлении (PA lag screws) и остеосинтез пластиной (PP) были проанализированы для заднемедиального (PM) и заднелатерального (PL) фрагментов ЗКББК с помощью FEA. Значения относительных деформаций, общих смещений и напряжения фон Мизеса (VMS) в элементах модели были оценены при вертикальной нагрузке 700 Н.

Результаты. PP показал самый высокий уровень VMS в элементах металлических имплантатов (от 97,1 до 106,15 МПа), в сравненини с PA (44,77 МПа и 39,2 МПа) и AP (23,99 МПа и 25,53 МПа) группами винтов, независимо от морфологии ЗКББК. Наличие PM и PL фрагментов ЗКББК вызывает смещение распределения контактного напряжения на переднюю часть поверхности плато большеберцовой кости.

Выводы. Остеосинтез пластиной является биомеханически наиболее эффективной техникой фиксации ЗКББК независимо от морфологии фрагмента. Распределение нагрузок на суставную поверхность плато большеберцовой кости зависит от морфологии повреждения и типа остеосинтеза ЗКББК.

Ключевые слова: биомеханика; перелом заднего края большеберцовой кости; морфология; конечно-элементный анализ.