

DOI: <https://doi.org/10.34921/amj.2025.4.018>**DABAN SÜMÜYÜNÜN QIDA DƏLİYİNİN ANATOMİK-TOPOQRAFİK
XÜSUSİYYƏTLƏRİ: CƏRRAHİ YOLUN SEÇİMİ VƏ FİKSASIYA ÜÇÜN ƏHƏMİYYƏTİ****H.N.Hoduadze, O.V.Pelipenko**

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Xülasə. Məqalədə insanın daban sümüyünün müxtəlif səthlərində olan qida dəliklərinin anatomik-topoqrafik xüsusiyyətlərini öyrənmək və onların müxtəlif osteosintez konstruksiyalarına uyğunluğunu qiymətləndirmək məqsədilə aparılmış tədqiqat işi haqqında məlumat verilmişdir. Tədqiqat materialı olaraq daban sümüyünün makropreparatlarından və sxematik 3-D modelləşdirilmədən istifadə edilmişdir.

Tədqiqat göstərmişdir ki, sümüklərin lateral səthlərində qida dəliklərinin sayı daha çoxdur (ümumi saydan 44,40%-ə qədər); müxtəlif ölçülü dəliklərin say nisbəti mütənasib olmuşdur: iri ölçülü dəliklər – $18,14 \pm 0,93\%$, orta ölçülülər – $19,7 \pm 1,36\%$, xırda ölçülər $15,36 \pm 0,96\%$.

Müxtəlif osteosintez konstruksiyalarının, o cümlədən klassik lateral daban lövhələrinin, modelləşdirilmiş mini-plastinlərin və sümükdaxili ştiftlərin müqayisəsi aparılmış, onların damar mənfəsinə potensial təsiri, həmçinin yumşaq toxumaları və sümükləri zədələmə potensialı araşdırılmışdır. Alınmış nəticələr daban sümüklərinə operativ müdaxilə zamanı angiosomal prinsipə riayət etməklə azinvaziv cərrahi yol seçilməsinin məqsədəuyğun olduğunu göstərir; bu, yaraların sağlması prosesində ağırlaşma risklərinin azaldılmasına və sınıqların bitişməsinin sürətlənməsinə şərait yarada bilər. Müəlliflərin fikrincə, tədqiqatdan alınmış nəticələr daban sümüklərinin sınıqlarının müalicəsi zamanı operativ müalicə üçün cərrahi yolun daha səmərəli seçilməsinə kömək etdiyinə görə praktik əhəmiyyətə malikdir.

Açar sözlər: daban sümüyü, qida dəlikləri, angiosomlar, sınıqlar, sümükdaxili arteriyalar, azinvaziv cərrahiyyə

Ключевые слова: пяточная кость, питательные отверстия, ангиосомы, переломы, внутрикостные артерии, малоинвазивная хирургия

Keywords: calcaneus, nutrient foramina, angiosomes, fractures, intramedullary arteries, minimally invasive surgery

**ANATOMICAL AND TOPOGRAPHICAL CHARACTERISTICS OF
NUTRIENT FORAMINA IN THE CALCANEUS: IMPLICATIONS FOR
SURGICAL APPROACH AND FIXATION****H.N.Hoduadze, O.V.Pelypenko**

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The article presents a study aimed at performing an anatomical-topographical analysis of nutrient foramina on various surfaces of the human calcaneus and assessing their relationship with different osteosynthesis constructs. The materials included human calcaneal macroscopic specimens and schematic 3D modeling. The lateral surface demonstrated the highest concentration of foramina, accounting for 44.40% of the total. Among them, a relatively even size distribution was observed: large — 18.14 ± 0.93 , medium — 19.07 ± 1.36 , and small — 15.36 ± 0.96 . A comparative evaluation of different osteosynthesis constructs — including conventional lateral plates, pre-contoured mini-plates, and intramedullary nails — was conducted to assess their impact on local vascular integrity and the potential trauma to both bone and soft tissue structures. The findings support the use of minimally invasive surgical approaches aligned with angiosomal principles, contributing to reduced risk of wound healing complications and improved fracture consolidation. These results offer practical guidance for optimizing surgical access and fixation strategies in the treatment of calcaneal fractures.

Introduction

The calcaneus is a key component of the musculoskeletal system, as it participates in load distribution, provides foot stability, and contributes to the formation of the foot arch. The morphological variability of its articular surfaces, ossification features, and pathological changes significantly affect both static and dynamic aspects of movement. Studying the anatomical characteristics of the calcaneus is important not only for fundamental morphology but also for clinical practice, particularly in orthopedics, traumatology, and podiatry [1-3].

Calcaneal fractures are relatively common among hindfoot injuries, accounting for up to 60% of such injuries and approximately 2% of all fractures in the musculoskeletal system. These injuries have a notable socio-economic impact, as nearly 90% of the affected individuals are of working age [4,5].

Depending on the involvement of the subtalar articular surfaces, calcaneal fractures are classified as intra-articular or extra-articular. Intra-articular fractures constitute more than 75% of all calcaneal fractures and are thus associated with a high risk of complications [6,7].

The primary treatment method for displaced intra-articular fractures is open reduction with internal fixation. Common postoperative complications include marginal skin necrosis at the surgical approach site, prolonged wound healing with superficial or deep infection, delayed union or non-union with pseudoarthrosis formation.

The vascular supply of the calcaneus must be taken into account when planning surgical approaches to minimize vascular injury and reduce the risk of impaired wound healing and bone fragment consolidation. Considering the anatomical and topographical features of the nutrient foramina on the surface of the calcaneus during preoperative planning may improve treatment outcomes and accelerate functional recovery of the injured segment.

Currently, there is a lack of practical recommendations that consider the vascular anatomy of the foot and the topography of nutrient foramina on the surface of the calcaneus in the context of selecting fixation methods and planning surgical approaches.

The aim of this study is to analyze the

nutrient vascular foramina on the surfaces of the calcaneus, taking into account their topographic and anatomical location, number, and size, with the subsequent development of practical recommendations for planning surgical approaches and methods of bone fragment fixation.

Materials and Methods

To analyze the nutrient vascular foramina on the surface of the human calcaneus, 18 anatomical specimens of human calcanei were selected from the anatomical museum of Poltava State Medical University. Four specimens were excluded from the study due to pronounced pathological changes or mechanical damage. The final sample included 14 calcanei (8 right and 6 left). The anatomical specimens consisted of both isolated bones ($n = 10$) and bones integrated within anatomical models of the foot ($n = 4$). The age and sex of the individuals were unknown.

To identify the nutrient vascular foramina on the surfaces of the calcanei, all bone surfaces were preliminarily cleaned of debris and calcium deposits using standard injection needles of various sizes.

Considering the small size of the areas of interest, a Schweizer Tech-Line 4X desktop magnifying glass with a glass lens was used for adequate visualization and assessment. A digital camera integrated into a mobile device in zoom mode was employed for photographic and video documentation. Upon locating the nutrient foramina on the surface of the calcaneus, photographs were taken (Fig. 1). To assess bone dimensions, a calibrated digital caliper with 0.01 mm accuracy (length 150 mm) was used. All measurements were conducted by the same examiner. The size of the nutrient foramina was evaluated using standard millimeter graph paper.

The foramina were classified into three size categories. Large foramina were those clearly visible to the naked eye and occupied at least one square of the millimeter grid (approximately 1 mm² or larger). Medium-sized foramina were those discernible at close range or upon magnified inspection of photographs, with dimensions ranging from 0.5 to 1 mm² based on comparison with graph paper. Small foramina were detectable only with the aid of a magnifying glass and measured less than 0.5 mm² (Fig. 2).

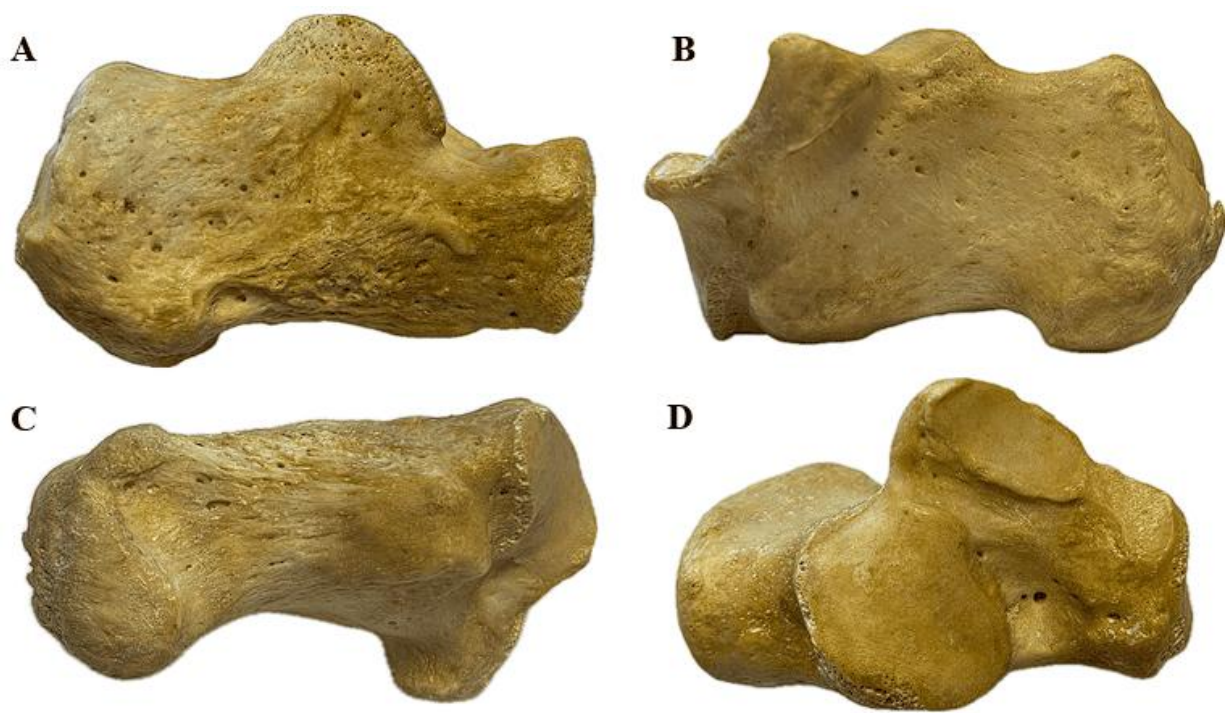


Figure 1. Photographs of different surfaces of a human calcaneus anatomical specimen.
A – lateral surface; B – medial surface; C – inferior surface; D – superior surface.

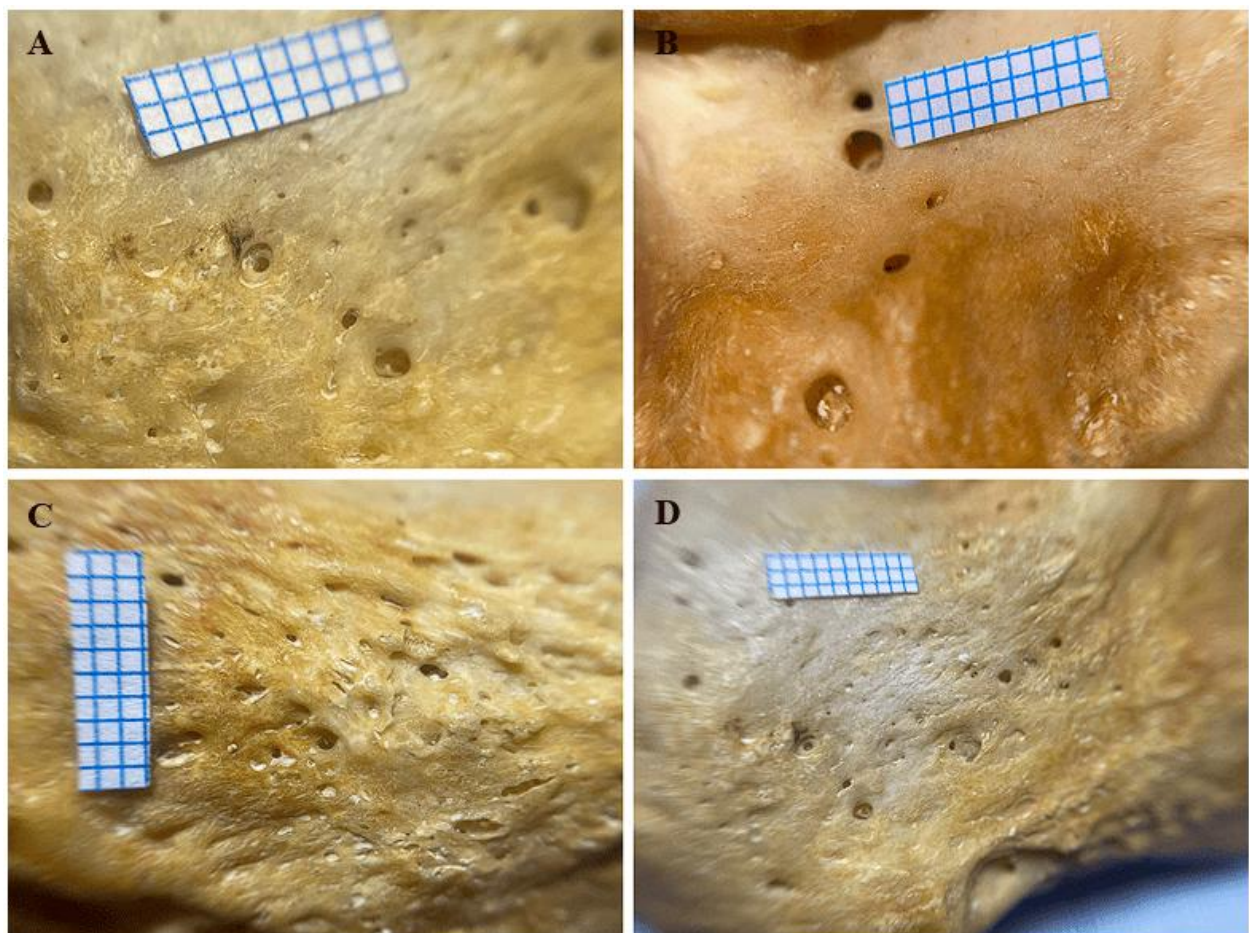


Figure 2. Magnified photographs of nutrient foramina in various locations on a human calcaneus anatomical specimen.
A – lateral surface of the calcaneal tuberosity; B – area of the tarsal sinus; C – inferolateral surface of the calcaneal body; D – lateral surface of the calcaneal body.

The obtained results were analyzed using methods of biomedical statistics, specifically applying the non-parametric Mann–Whitney U test, as the sample sizes were small and did not follow a normal distribution. This statistical test determines the significance of differences in the distribution of a studied variable between two independent samples when normal distribution cannot be assumed. Differences were considered statistically significant at $p < 0.05$. Data analysis was performed using Microsoft Excel 2019 and IBM SPSS Statistics v.26.

To simulate the placement of nutrient vascular foramina relative to various types of osteosynthetic hardware, the computer application Microsoft Paint 3D was used. Onto the previously photographed surface of the calcaneus, schematic representations of commonly used fixation devices for surgical treatment of calcaneal fractures were overlaid: angular-stable AO-type calcaneal locking plates, pre-contoured angular-stable mini-plates, and intramedullary calcaneal nails.

Based on the constructed 3D model of the calcaneus with marked points of interest, the topographic relationship between the nutrient foramina and the metal implants was analyzed.

Results

The analysis of nutrient foramina was conducted on the lateral, medial, anterior, posterior, superior, and inferior surfaces of the calcanei. Given that the anterior surface of the calcaneus is entirely covered with articular cartilage, no nutrient foramina were identified

on this surface in any of the specimens. The distribution and mean number of foramina across the various surfaces in all anatomical samples are presented in Table 1.

The highest number of nutrient foramina was observed on the lateral and medial surfaces, accounting for 44.4% and 24.4%, respectively. On the lateral surface, the majority of foramina were clearly concentrated in the region of the calcaneal tuberosity (70.69%), whereas the medial surface exhibited a more uniform distribution, with 41.73% located in the posterior projection and 58.27% in the anterior. A slightly lower number of foramina was identified on the superior and inferior surfaces, comprising 12.99% and 14.64%, respectively. The posterior surface demonstrated the lowest incidence, with only 3.12% of the total nutrient foramina identified.

A comparison of the number of nutrient vascular foramina in right and left calcanei revealed no statistically significant difference ($U = 29.5000$; $p = 0.5177$). As shown in Table 2, the distribution of foramina on both feet is similar in terms of quantitative and topographic characteristics. According to the obtained results, the highest density of nutrient foramina is observed on the lateral and medial surfaces of the calcanei, whereas the posterior surface is the least densely supplied, followed by the superior and inferior surfaces, respectively.

Table 1. *Distribution of Nutrient Foramina by Calcaneal Surface*

Calcaneal surface	Number of nutrient foramina (n)	Percentage (%)
Lateral	52,57 ± 2,67	44,40
Calcaneal tuberosity	37,21 ± 2,01	70,69
Body and anterior part	15,36 ± 0,84	29,31
Medial	29,00 ± 0,70	24,84
Calcaneal tuberosity	12,14 ± 0,59	41,73
Body and anterior part	15,36 ± 0,63	58,27
Superior	15,21 ± 0,39	12,99
Inferior	17,21 ± 1,08	14,64
Posterior	3,71 ± 0,29	3,12
Total	117,71 ± 3,00	100

Table 2. Comparative analysis of nutrient foramina on the surfaces of right and left calcanei

Calcaneal surface	Right calcanei, mean number by surface		Left calcanei, mean number by surface		U	P-value
	n	%	n	%		
Lateral	52,38 ± 4,17	47,37	52,83 ± 3,29	49,28	21,5	0.9482
Medial	29,50 ± 1,05	27,28	28,33 ± 0,88	26,69	30,5	0.4350
Superior	15,00 ± 0,57	12,73	15,50 ± 0,56	13,34	18,5	0.5067
Inferior	18,00 ± 1,31	16,54	16,17 ± 1,87	15,07	30,0	0.4718
Posterior	3,75 ± 0,37	3,38	3,67 ± 0,49	3,40	25,0	0.9467
Total	118,63 ± 3,99	100,00	116,50 ± 4,95	100,00	29,5	0.5177

The next stage involved the analysis of the distribution of nutrient vascular foramina of varying sizes across all examined surfaces of the calcaneus. On the lateral surface, foramina of different calibers were present in approximately equal proportions (18.14 ± 0.93 large, 19.07 ± 1.36 medium, and 15.36 ± 0.96 small). On the medial surface, large foramina predominated (14.14 ± 0.51), while medium and small ones showed a similar distribution (8.14 ± 0.38 and 6.71 ± 0.45 , respectively). The superior surface of the calcaneus, according to the analysis, exhibited a slight predominance of large foramina over medium and small (6.00 ± 0.31 , 4.43 ± 0.31 , and 4.79 ± 0.32 , respectively). Notably, 100% of the large vascular foramina on the superior surface were located exclusively within the sinus tarsi. The inferior surface of the calcaneus showed an even distribution of foramina of all calibers (5.86 ± 0.39 large, 5.29 ± 0.49 medium, and 6.07 ± 0.54 small). Regarding the posterior surface, large foramina were rarely observed (0.43 ± 0.14), while medium and small ones were present in roughly equal proportions (1.71 ± 0.19 and 1.51 ± 0.27 , respectively).

Discussion

Calcaneal fractures have a significant socio-economic impact, as undiagnosed or inadequately treated injuries directly contribute to temporary or permanent disability.

Given that approximately 75% of such fractures are intra-articular, most cases require surgical intervention. It is well established that anatomical reduction and stable fixation – especially of intra-articular fragments – are essential criteria for achieving a favorable and predictable outcome.

The most commonly used surgical tech-

niques involve direct anatomical reduction via a lateral L-shaped approach or access through the sinus tarsi, followed by fixation with locking plates of various types and modifications.

It is known that the calcaneus receives its primary blood supply from branches of the posterior tibial and fibular arteries, which form the so-called "calcaneal vascular network." In their study, Andermahr et al. reported that approximately 45% of the calcaneus's blood supply originates from the medial calcaneal arteries (branches of the posterior tibial artery), 45% from the lateral calcaneal arteries (branches of the fibular artery), and the remaining 10% from the tarsal artery. The results of the present study demonstrate a similar pattern; however, the number of nutrient foramina was slightly higher on the lateral surface (44.40% compared to 24.84% on the medial surface) [8,9].

According to other studies, the vascular anatomy of the calcaneus closely correlates with angiosome research and theories of regional blood supply throughout the body. Based on these data, it can be inferred that branches of the calcaneal arteries also supply the surrounding soft tissues, including the skin [10, 11].

These studies indicate that the lateral surface of the ankle and foot, in the projection of the calcaneus, contains two angiosomes: the dorsalis pedis artery (DPA) angiosome, supplied by the artery of the same name – a continuation of the anterior tibial artery – and the lateral calcaneal artery (LCA) angiosome, supplied by branches of the fibular artery. The boundary between these angiosomes is conventionally defined by a line drawn from a point 1 cm below the tip of the lateral malleolus to the base of the fifth metatarsal bone. The medial surface of the ankle

and foot, in the region of the calcaneus, is the site of overlap of three distinct angiosomes: the medial calcaneal artery (MCA), the medial plantar artery (MPA), and the lateral plantar artery (LPA) angiosomes. These are supplied by branches of the posterior tibial artery and provide vascularization to the entire medial and plantar surfaces of the foot [12, 13].

Thus, the maximal preservation of the branches of the aforementioned arteries during surgical interventions in the calcaneal region is of utmost relevance and importance, as it directly affects the rate and quality of healing of both the soft tissues and the bone itself. Accordingly, the surgical approach must be gentle, well-planned, and involve a carefully justified selection of fixation implants.

A detailed analysis of the lateral surface of the calcaneus – since it is the main site for implant placement – as well as schematic modeling of implant positioning and their interaction with the bone, leads to the conclusion that classical calcaneal plates provide excellent coverage of the majority of the lateral surface. However, their implantation typically requires wide exposure and thorough preparation of the bone surface, making the procedure predictably more traumatic for an already injured segment. Based on practical experience, it is often necessary to dissect the

postero-lateral and infero-lateral surfaces of the bone to ensure proper plate positioning. Therefore, considering the potential damage to a significant proportion of nutrient vessels during such an intervention, this may adversely affect both wound healing and fracture consolidation (Figure 3 A, B).

Pre-contoured calcaneal mini-plates are gaining increasing popularity. As demonstrated in the figure, this type of implant does not cover the entire surface of the bone, yet it provides secure fixation of all major calcaneal segments (Fig. 3C). Considering that implantation of such a plate requires only a minimally invasive approach to the sinus tarsi, its use significantly reduces intraoperative trauma to the nutrient vessels and surrounding soft tissues. This aligns well with the angiosome theory, as this surgical approach lies along the border between the dorsalis pedis artery (DPA) angiosome and the lateral calcaneal artery (LCA) angiosome. Consequently, vascular trauma is minimized, and soft tissue healing potential is optimized. Based on our own experience, the majority of calcaneal mini-plate implantations can be performed through an incision of up to 4 cm, with additional small incisions used for distal screw locking – similar to the minimally invasive plate osteosynthesis (MIPO) technique.

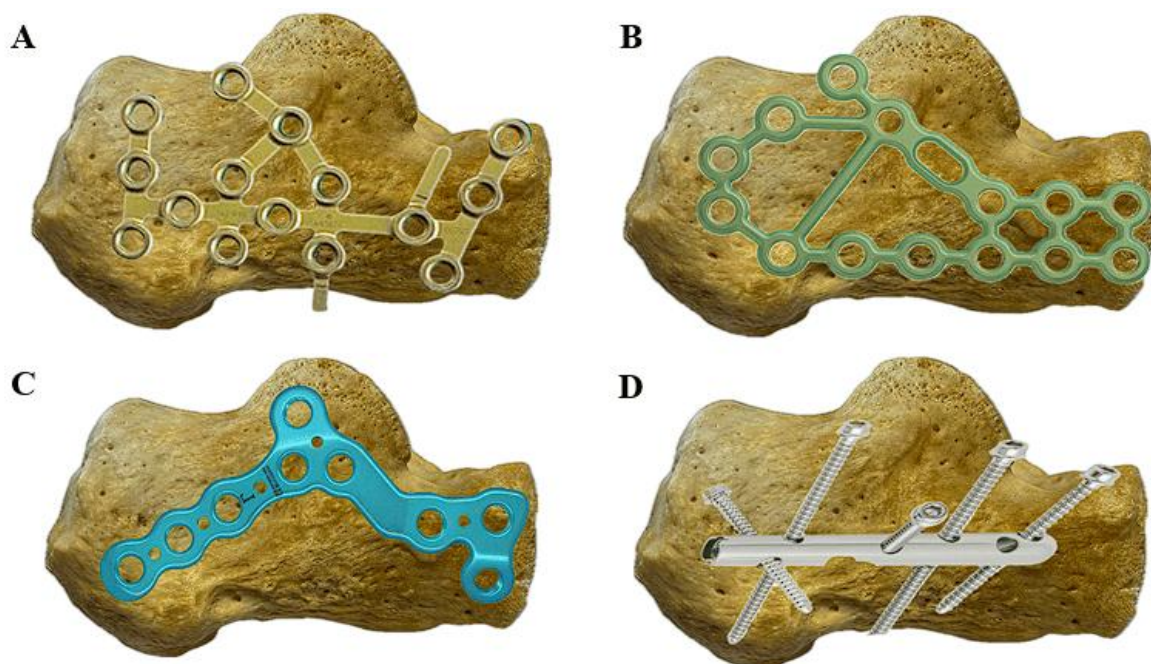


Figure 3. Schematic modeling of implant positioning and their relationship to the calcaneus.
A, B – classic lateral calcaneal plates; C – pre-contoured calcaneal mini-plate with angular stability;
D – intramedullary calcaneal nail.

Calcaneal locking intramedullary nails are currently less popular than locking plates, primarily due to the higher cost of surgery associated with the need for specialized instrumentation and navigation systems. However, this fixation method is gaining traction, particularly due to its minimal soft tissue disruption, which promotes faster healing and reduces the average hospital stay (Fig. 3D). Recent studies and meta-analyses suggest that, for certain fracture types, the stability of fixation using locking nails is comparable to, or even superior to, that of locking plates [12, 13].

However, the question remains open as to how the implantation of such constructs affects intraosseous blood supply – particularly concerning the disruption of the so-called “watershed zone,” where medial and lateral intraosseous arteries meet and anastomose, facilitating a balanced distribution of blood. This region is highly vulnerable to ischemic damage during surgical interventions or traumatic injuries [14].

The term “watershed” is derived from geographical terminology – just as a watershed in terrain denotes the boundary between river basins, in anatomy, it refers to the borderline between vascular territories. Currently, there is a lack of sufficient research on the impact of intramedullary implants on intraosseous perfusion, and therefore, the question of potential impairment of fracture healing (consolidation) in this context remains unresolved.

Conclusions

The obtained data confirm the advisability of using minimally invasive surgical approaches that correspond to the angiosome principle, which contributes to reduced trauma to the nutrient vessels, the majority of which are located on the lateral surface of the bone, and also helps decrease the risk of complications in wound healing and fracture consolidation. The presented results have practical significance for the rational choice of surgical approach and fixation method in the treatment of calcaneal fractures.

REFERENCES

1. Jyotsna G., Mamidi A. The morphometric analysis of calcaneus and its articular facets // *Indian J Clin Anat Physiol.* 2022;9(1):22–24.
2. Anbumani L., Sridharan R., Thamarai A. An anatomical study of morphology and morphometric analysis of calcaneum and its talar articular surfaces // *Int J Anat Res.* 2017;5:4223–4229. doi:10.16965/ijar.2017.291.
3. Kumar A., Rastogi S., Haider Y., Kumar S., Chauhan S., Passey J. Morphometric variations of the lateral surface of calcaneus: Can standard plate sizes fit all? // *J Clin Orthop Trauma.* 2020;13:156–162. doi:10.1016/j.jcot.2020.11.012. PMID: 33717888; PMCID: PMC7920148.
4. Biz C., Refolo M., Zinnarello F.D., Crimi A., Dante F., Ruggieri P. A historical review of calcaneal fractures: from the crucifixion of Jesus Christ and Don Juan injuries to the current plate osteosynthesis // *Int Orthop.* 2022;46(6):1413–1422. doi:10.1007/s00264-022-05384-3. PMID: 35333959; PMCID: PMC9117339.
5. Cotton F., Henderson F. Results of fracture of the os calcis // *Am J Orthop Surg.* 1916;14(5):290–298.
6. Hoduadze H., Pelypenko O., Malyk S., Honcharov A. Minimally invasive surgical techniques in treatment of intraarticular calcaneus fractures // *Actual Probl Mod Med.* 2023;23(1):8–12. (In Ukrainian). doi:10.31718/2077-1096.23.1.8.
7. Kozopas V., Lobanov V., Siklitskyy V., Humenyuk V., Lytvynchuk V., Zhukovskyy V., Melnyk V. The clinical aspects of diagnosis and treatment of intra-articular calcaneal fractures // *Trauma.* 2017;18(6):174–179. (In Ukrainian). doi: 10.22141/1608-1706.6.18.2017.121197.
8. Anderson J.E. editor. *Grant's Atlas of Anatomy.* 8th ed. Baltimore: Williams & Wilkins; 1983. 960 p. ISBN: 9780683041912.
9. Wakode NS, Wakode S, Kujur B. Morphometric analysis of vascular foramina in Indian dry calcaneus and its clinical applications // *J Nat Sci Biol Med.* 2018;9:132. doi:10.4103/jnsbm.JNSBM_35_18.
10. Flores R., Bui-Mansfield L.T. Vascular anatomy of the calcaneus and its implication in stress fractures and avascular necrosis // *Contemp Diagn Radiol.* 2013;36(5):1–6. doi:10.1097/01.CDR.0000427469.46775.48.
11. Attinger C.E. The Limb Center, Georgetown University Medical Center. Vascular territories of the foot and ankle. *Plast Reconstr Surg.* 2006;117(7 Suppl):261S–293S. doi:10.1097/01.prs.0000222582.84385.54.
12. Fu X., Deng Z.B., Wang G.X., Wang C.G., Li Z.J. Comparison between intramedullary nail and conventional plate for displaced intra-articular calcaneal fractures: A meta-analysis. *Jt Dis Relat Surg.* 2024;35(2):276–284. doi:10.52312/jdrs.2024.1542. PMID: 38727105; PMCID: PMC11128945.
13. Wu J., Zhang L., Shen C., Wang X., Zhou X. Comparative 3D finite element analysis of intramedullary fixation versus locking plate fixation in calcaneal fractures using micro-CT image technology. *BMC Musculoskelet Disord.*

14. Razik A., Harris M., Trompeter A. Calcaneal fractures: Where are we now? *Strategies Trauma Limb Reconstr.* 2018;13(1):11. doi:10.1007/s11751-017-0297-3.

Conflict of interest

The authors declared no potential conflicts of interest.

Author Contributions

All authors have significantly contributed to both the initial drafting and subsequent revisions of this manuscript. They take full responsibility for the content and for addressing any concerns regarding the accuracy or integrity of the data presented.

АНАТОМО-ТОПОГРАФИЧЕСКИЕ ОСОБЕННОСТИ ПИТАТЕЛЬНЫХ ОТВЕРСТИЙ ПЯТОЧНОЙ КОСТИ: ЗНАЧЕНИЕ ДЛЯ ВЫБОРА ХИРУРГИЧЕСКОГО ДОСТУПА И ФИКСАЦИИ

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Резюме. Представлены результаты исследования, проведенного с целью анатомо-топографического анализа питательных отверстий на различных поверхностях пяточной кости человека и оценке их соотношения с различными конструкциями остеосинтеза. Материалы включали макропрепараты пяточной кости и схематическое 3D-моделирование. Наибольшая концентрация отверстий выявлена на латеральной поверхности — 44,40% от общего количества. Среди них отмечено равномерное распределение по размерам: крупных — $18,14 \pm 0,93$, средних — $19,07 \pm 1,36$, мелких — $15,36 \pm 0,96$. Проведено сравнительное исследование различных конструкций остеосинтеза, включая классические латеральные пяточные пластины, промоделированные мини-пластины и внутрикостные штифты, с точки зрения их потенциального влияния на сосудистое русло и травматизацию мягких тканей и костной структуры. Полученные данные подтверждают целесообразность использования малоинвазивных доступов, соответствующих ангиосомальному принципу, что способствует снижению риска осложнений заживления ран и консолидации переломов. Представленные результаты имеют практическое значение для рационального выбора хирургического доступа и способа фиксации при лечении переломов пяточной кости.

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