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The optimal method of lateral lengthening osteotomy of the calcaneus: CT study in the Russian population

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Abstract

Introduction In the current professional literature, lengthening of the lateral column is considered to be one of the most effective and pathogenetically sound joint salvage methods for correction of plano-valgus deformity of the foot. The most widely used osteotomies in clinical practice are those of Evans and Hintermann. However, the articular facets of the subtalar joint are at risk of damage due to the variety of their number, shapes and location in different nationalities.

The **purpose** of the work was to reveal the anatomical variants of the structure of the articular facets of the subtalar joint in the Russian population in order to determine the optimal method of lateral lengthening osteotomy of the calcaneus, based on personal characteristics.

Material and methods The results of multispiral computed tomography (MSCT) of the feet of 250 patients were analyzed on the basis of the Tsivyan Novosibirsk Research Institute of Traumatology and Orthopedics. After applying the exclusion criteria, the final sample consisted of 150 patients. 3D modeling of their calcaneal bones with visualization of articular facets of the subtalar joint was performed on a workstation using the syngo.via–Siemens Viewer program. Patients were systematized according to the classification of P. Bunning and C. Barnett (1965). On 3D models of calcaneal bones, the distance between the anterior and middle, as well as between the middle and posterior articular facets was measured.

Results The anterior and middle articular facets of the subtalar joint were separated (type A) in 40.7 % (61 feet), the remaining 59.3 % (89 feet) had fused anterior and middle facets (type B). Fully fused anterior, middle and posterior facets (type C) were not found. The average distance between the anterior and middle articular facets was 4.2 ± 0.08 mm, and the average distance between the middle and posterior facets was 5.3 ± 0.0027 mm.

Discussion Articular facets of type B prevailed in the Russian population. Evans osteotomy will damage them 100 % of the cases. Hintermann osteotomy decreases the chance of their damage. However, the distance between the facets is very small, visualization during osteotomy is difficult, what can lead to damage to the subtalar joint. Thus, the development of a new method for determining and controlling the level of calcaneal osteotomy that would exclude joint damage is an urgent problem for further research.

Conclusion Hintermann's lateral lengthening osteotomy of the calcaneus may be successfully applied in the Russian population with the least complications in the postoperative period and less damage to the articular facets of the subtalar joint.

Keywords: lateral lengthening osteotomy, articular facets of the subtalar joint, plano-valgus deformity of the foot

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INTRODUCTION

Acquired flatfoot is characterized by a decrease in the height of the arch of the foot, valgus deformity of the posterior part and abduction of the anterior part [1]. The prevalence of the disease is 26.6–60.0 %; it is one of the most common reasons for visiting an orthopaedist [2, 3]. Among the existing surgical methods for treating abducted flat-valgus deformity of the foot, lateral lengthening osteotomy of the calcaneus is one of the most effective joint-sparing operations [4–6]. The method of performing lengthening osteotomy of the calcaneus between the anterior and middle articular facets of the subtalar joint was first proposed by D. Evans in 1975 [7]. Initially, Evans performed this variant of osteotomy of the calcaneus in children with valgus foot deformity, which resulted from hypercorrection of clubfoot, but, observing the high efficiency of the operation, began to use it to correct flatfoot in adolescents. Classically, the Evans osteotomy is performed 1.5 cm proximal to the calcaneocuboid joint and parallel to it [7]. The operation had good clinical results and became widely popular among surgeons; over time, it began to be used not only in children but also in adults with forefoot abduction, valgus deformity of the calcaneus, and dorsolateral peritalar subluxation [8]. However, despite good clinical and radiographic results, complications in the postoperative period included insufficient correction, nonunion, arthrosis of the subtalar joint, subluxation of the calcaneocuboid joint, damage to the sural nerve, peroneal tendons, and infection of the surgical site [8–11]. In his work, Evans did not consider the variability of the subtalar joint structure and, according to the data obtained after 13 years of observation of his operated patients, only 17 of 23 had good and very good results [10]. The remaining 6 patients had complications in the late postoperative period. Three patients continued to experience pain during exercise, but it did not interfere with sports and their normal lifestyle; osteoarthrosis of the talonavicular joint was noted. Three other patients showed clinical and radiographic regression of the treatment results as valgus of the hindfoot persisted, and osteoarthrosis of the subtalar joint and other joints, except the calcaneocuboid, developed. In order to reduce postoperative complications and the risk of damage to the subtalar joint, V. Mosca [12] modified the Evans osteotomy in 1995. In his variant, a bone raspatory was first inserted into the subtalar joint between the anterior and middle articular facets to determine their location and then an osteotomy was performed at a certain interval at a level of 1.5–2 cm posterior to the calcaneocuboid joint. However, this method had shortcomings associated with the need to open the capsule of the subtalar joint, as well as difficulties in determining the acceptable interval for osteotomy during surgery due to limited surgical visibility, which makes the creation of a new effective method for determining and monitoring the level and direction of osteotomy a significant issue in improving the results of lateral lengthening osteotomy of the calcaneus.

The first study of the structures at risk during the Evans operation was conducted by R. Raines and M. Brage in 1998 [9]. They concluded that the ideal osteotomy level to prevent damage to the anterior and middle articular facets of the subtalar joint is 10 mm proximal to the calcaneocuboid joint. Nevertheless, Hyer et al. [13] determined that the average distance between the calcaneus and middle articular facets is 3.9 mm and recommended the optimal osteotomy level at 1.1–1.5 cm (1.3 cm on average) posterior to the calcaneocuboid joint. However, Bussewitz et al. [14] reported that with a saw entry point at a level of 1.3 cm posterior to the calcaneocuboid joint, the articular facets of the subtalar joint and the support of the talus are at risk. The lack of consensus among researchers on the level and direction of osteotomy might be due to significant individual anatomical variability. In order to protect the anterior and middle articular facets of the subtalar joint, Hintermann et al. [15] proposed in 1999 a new version of lateral extension osteotomy of the calcaneus, the line of which runs along the anterior border of the posterior articular facet of the subtalar joint. The described surgical treatment methods according to Evans and Hintermann show excellent clinical and radiographic results [16].

The morphology of the articular facets of the subtalar joint in European, African and Indian populations was first studied by P. Bunning and C. Barnett [17] in 1965, and the first classification was proposed. Later, studies were conducted in many countries, and a variety of classification options were published. Thus, Madhavi et al. [18] expanded the classification of P. Bunning and C. Barnett in 2008, and proposed six types of articular facets of the subtalar joint. They identified different variants of fusion of the anterior and middle articular facets, including a type where the anterior facet is completely absent. However, such a detailed approach to describing significant variability does not make it easier for surgeons to choose a method of surgical treatment that would not damage the articular facets of the subtalar joint. Due to significant differences in the anatomical structure of the subtalar joint region in people of different nationalities and the variable approach of researchers to systematization of data, a single classification has not yet been adopted [13, 17, 19–26]. However, none of the studies presented to date on studying the anatomical features of the subtalar joint and their relationship with the risk of damage to the articular facets during lateral lengthening osteotomy of the calcaneus have assessed the population of Russia. Consequently, the optimal method of surgical treatment of abducted flat-valgus foot deformity in the population of the Russian Federation still remains uncertain.

The **purpose** of the work was to show the anatomical variants of the structure of the articular facets of the subtalar joint in the Russian population in order to determine the optimal method of lateral lengthening osteotomy of the calcaneus, based on personal characteristics.

MATERIALS AND METHODS

An analysis of MSCT scans of 250 patients (92 (36.8 %) men and 158 (63.2 %) women) taken between October 2023 and March 2024 at the Tsivyan Research Institute of Traumatology and Orthopedics was conducted. The average age of patients was (45 ± 19) years. Patients with recent and old calcaneus fractures, severe degenerative lesions of the subtalar joint, a history of surgical interventions in the subtalar joint area and metal implants in the calcaneal area were excluded from the sample, since in such cases it was not possible to visualize the articular facets of the subtalar joint with reliable accuracy after 3D reconstruction of the image and its manual processing. The final sample consisted of 150 individuals (66 men (44 %), 84 (56 %) women) in the average age of (46 ± 16) years.

In each studied patient, individual features of the articular facets of the subtalar joint were assessed on 3D models of the calcaneus based on MSCT of the feet at the CT workstation. Before assessment, 3D models of the calcaneus underwent a certain processing algorithm. Processing began with loading a standard MSCT study of the foot in Dicom format on the CT workstation (Fig. 1 a). Next, 3D reconstruction of the foot was performed in bone mode using the syngo.via — SiemensViewer program (Fig. 1, b). Using the Punch tool, all bones except the calcaneus were removed. Artifacts from soft tissues were also removed (Fig. 1 c). Then, the high-resolution Cinematic VRT mode was switched and the remaining artifacts were cut out (Fig. 1 d). The 3D model of the calcaneus was aligned. All the manipulations resulted in a fully prepared 3D model (Fig. 1 d). The Distanceline tool was then used to calculate the facet spacing in milimeters. The measurement was performed by setting two points at the narrowest site between the subtalar joint facets and automatically calculating the length of the resulting segment between them. For calcaneus with type A facets, the distance from the posterior edge of the anterior facet to the anterior edge of the middle facet was measured at the narrowest point between them (Fig. 2). For types A and B, the width from the posterior edge of the middle facet to the anterior edge of the posterior facet was additionally measured at the narrowest point between them (Fig. 3).

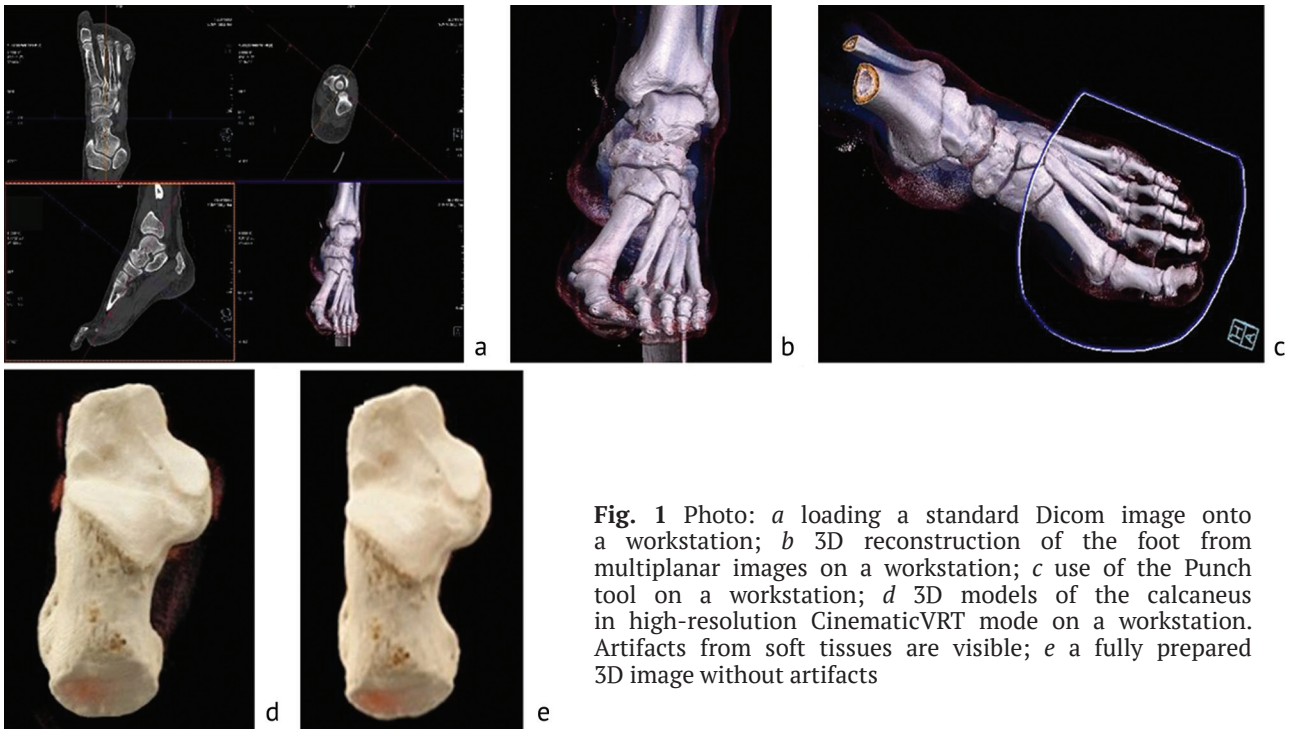

Fig. 1 Photo: *a* loading a standard Dicom image onto a workstation; *b* 3D reconstruction of the foot from multiplanar images on a workstation; *c* use of the Punch tool on a workstation; *d* 3D models of the calcaneus in high-resolution CinematicVRT mode on a workstation. Artifacts from soft tissues are visible; *e* a fully prepared 3D image without artifacts

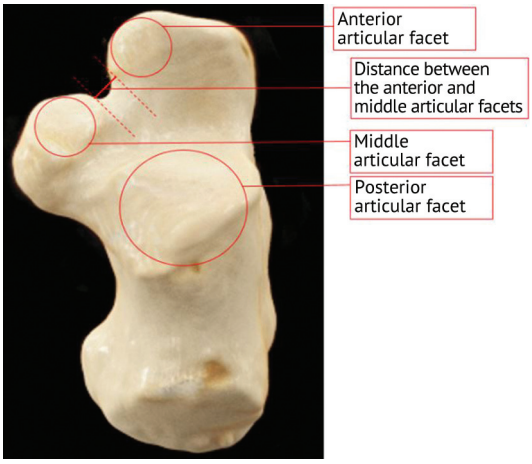

Fig. 2 Technique for measuring the distance between the anterior and middle articular facets in type A subtalar joint using the Distanceline tool

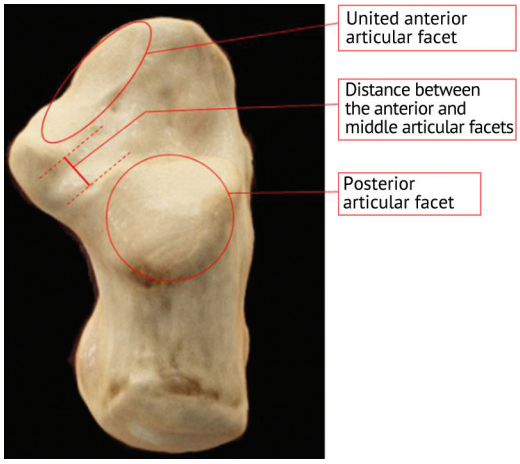

Fig. 3 Technique for measuring the distance between the middle and posterior articular facets in type B subtalar joint structure

The patients were grouped according to the classification of P. Bunning and C. Barnett [17]:

— Type A: there are three articular facets on the surface of the calcaneus, the anterior and the middle ones are separated from each other;

— Type B: there are two articular facets on the surface of the calcaneus, the anterior and the middle ones connected to each other;

— Type C: there is one articular facet on the surface of the calcaneus, since all three are fused together.

The obtained data were summarized in a table. For all the obtained measurements, the ratio between men and women in each group, their percentage in the entire sample, the average age and standard deviation for each of the given values, as well as the standard deviation for the spaces between facets measured in millimeters were calculated. All calculations were performed using the spss21 program.

RESULTS

According to the classification of P. Bunning and C. Barnett, 61 (40.7 %) patients (34 (55.7 %) women and 27 (44.3 %) men; average age (42.9 ± 14) years) were classified as type A (Fig. 4). 89 (59.3 %) patients (50 (56.2 %) women, 39 (43.8 %) men; average age (48.1 ± 21.3) years) were classified as type B (Fig. 5). There were no patients with type C in the study.

Fig. 4 Photo of a 3D model of the calcaneus of patient A.: separated articular facets, type A according to the classification of P. Bunning and C. Burnett

Fig. 5 Photo of a 3D model of the calcaneus of patient B.: fused articular facets, type B according to the classification of P. Bunning and C. Burnett

According to measurements, the average distance at the narrowest point between the anterior and middle articular facets of the subtalar joint was (4.20 ± 0.08) mm in type A individuals. The average distance between the middle and posterior facets in types A and B was (5.3 ± 0.0027) mm.

DISCUSSION

The types of articular facets of the subtalar joint have been studied in different nationalities, living in America [13], Africa [17], Japan [20], Korea [21], India [17, 22], Egypt [23], Spain [24], Turkey [25], China [26], Russia [27]. Despite the differences in the classifications used, in most studies, the proportion of separated anterior and middle articular facets of the subtalar joint varied from 30 to 40 % in different countries; fused articular facets are the most common. Type A predominantly was detected only in the population of Belgium [19] and Great Britain [17], (61 % and 67 %, respectively). The variability of the subtalar joint structure in the Russian population was studied in 2014 by Bayroshevskaya et al. [27]. They conducted an autopsy study of 57 feet in the subjects of the age range from 20 to 70 years and presented their own classification, based on which fused anterior and middle articular facets of the subtalar joint were found in 26 (45.61 %) cases, all separated articular facets accounted for 26 (45.61 %) cases, in 4 (7.02 %) cases the anterior facet was absent, and completely fused all three articular facets were found in one (1.76 %) case. According to their findings, fused anterior and middle facets as well as separated anterior and middle articular facets had the same incidence of occurrence.

Our study found that type B articular facets of the subtalar joint according to the classification of P. Bunning and C. Burnett are dominant in the Russian population (59.3 %). Accordingly, the fused articular facet would be damaged in 100 % of cases if Evans osteotomy is performed in such patients. Moreover, according to our results, the average distance between the anterior and middle articular facets is only (4.20 ± 0.08) mm in the group with type A. However, the thickness of the oscillating saw blade used to perform osteotomy ranges from 0.5 to 1.47 mm, and intraoperative visualization of the articular facets of the subtalar joint is extremely difficult. Currently, there is no method to accurately determine and monitor the level and direction of osteotomy. Accordingly, performing an operation in a safe space not damaging the subtalar joint is a difficult task.

In regard to the above-mentioned difficulties arising during surgery, popularization of the use of MSCT with 3D modeling at the stage of preparation for surgical intervention would allow visualization of the articular facets of the subtalar joint, determination of their type and choice of the method of performing the operation, as well as calculation of the level and angle of the osteotomy direction based on individual features of the anatomical structure, as a result of which the risk of damage to the subtalar joint will be reduced [28]. Thus, it is necessary to create a new method of effective and safe intraoperative determination and control of the level and direction of osteotomy using the data that are calculated with computer modeling for each patient during preoperative planning considering the type of articular facets of the subtalar joint. Such an approach to preoperative preparation would help to avoid damage to the subtalar joint and, accordingly, improve the results of surgical treatment.

The methods proposed by Evans and Hintermann of lateral lengthening osteotomy of the calcaneus were compared with each other by different authors. The anatomical structures at risk during surgery were analyzed by Ettinger et al. [29]. The researchers report that the Hintermann method is the best option in terms of potential damage to the articular facets of the subtalar joint and leads to rare complications such as degenerative changes in the calcaneocuboid joint [30]. Thus, Xu et al. [16] report that with the application of grafts of the same length and thickness, the corrective ability of the Hintermann operation is higher, but the characteristics of the contact stress in the surrounding joints are more abnormal. At the same time, the pressure in the calcaneocuboid joint during the Evans osteotomy did not increase as compared to the pressure in the same joint of the deformed foot [31]. Also Ettinger et al. [29] reported that the anterior and middle facets of the subtalar joint remain intact in 100.0 % and 85.7 % of cases, respectively, if the Hintermann procedureis used. In contrast, in the Evans procedure, they remain intact in only 42.9 % of cases for the anterior and 71.4 % of cases for the middle facet. The posterior facet of the subtalar joint is intact in all cases [29]. Several studies focused on the outcomes of the Evans and Hintermann procedures, which showed good clinical and radiographic results [16]. Overall, with a lower risk to the subtalar and calcaneocuboid joints but similar clinical outcomes, the Hintermann procedure appears to be the best alternative to the Evans procedure for the population of the Russian Federation.

We recognize that our study had a number of limitations. Firstly, the sample included not only patients with abducted flat-valgus foot deformity, but also those with other diagnoses (except for calcaneal fractures, any previous surgical interventions in the subtalar joint area and severe degenerative changes in the subtalar joint). Secondly, the size of our sample (150 feet) cannot fully reflect the diversity among the large population of Russia. Thirdly, the study was conducted using 3D CT reconstruction methods, which do not visualize articular cartilage; measurements were taken between bone structures that have different shapes and heights, what in controversial cases could lead to inaccuracies.

CONCLUSION

The anatomy of the subtalar joint has significant personal differences in the Russian population. Fused anterior and middle articular facets of the subtalar joint were found in more than half of the examined patients. Thus, the Evans osteotomy in this group of patients will always result in damage to the subtalar joint. In separated anterior and middle articular facets, the average distance between them was only 4.2 mm. Due to the fact that the facets are inaccessible for visualization during the operation, and the average saw blade thickness is 1 mm, it is an impossible task to blindly target the approachable space interval. Thus, the Hintermann operation may be more preferable in the Russian population; however the safe window for performing the osteotomy is only 5.3 mm.

Conflict of interests *None.*

Funding source *There was no external funding in this study.*

Ethical approval *The study was approved by the institutional ethics committee of the Tsivyan Novosibirsk Research Institute of Traumatology and Orthopaedics of the Ministry of Health of the Russian Federation (protocol No. 01-18/4853 dated July 11, 2024) and was conducted in accordance with the ethical standards developed in accordance with the Declaration of Helsinki of the World Medical Association.*

Informed consent *The patients gave voluntary written informed consent for inclusion in the study.*

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