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## Biomechanical substantiation of the algorithm for choosing the option of distal corrective osteotomy of the II–IV metatarsal bones in the treatment of metatarsalgia

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*Deformations of the front part of the foot with valgus deformity of the first toe lead to a redistribution of the body weight load during walking between the heads of the metatarsal bones. At the same time, the load on the head of II and III, and sometimes IV metatarsal bones increases significantly. Objective. To substantiate the choice of the most correct distal metatarsal osteotomy for the treatment of patients with metatarsalgia. Materials and methods. Three variants of distal metatarsal osteotomy were simulated: Weil, Helal, and distal wedge-shaped metatarsal osteotomy. Result. Weil osteotomy allows you to raise the support point of the metatarsal head above the support surface from 2 to 7 mm, depending on the amount of displacement of the head in the proximal direction and the angle of inclination of the metatarsal bone relative to the plane of the support surface, which effectively reduces the load on the metatarsal head during walking, but under conditions of magnitude the angle of inclination of the axis of the metatarsal bone is more than 20°. Helal osteotomy with the subsequent displacement of the separated part proximally, ensures the lifting of the head above the conventional plane of support from 1 to 4 mm, contributes to the effective unloading of the head while standing and while walking. They are used only for severe metatarsalgia. The range of correction of the standing height of the support surface of the metatarsal head for performing a distal wedge-shaped osteotomy is determined to be from 0.6 to 2.9 mm. Its advantage is the independence of the amount of correction from the presence or absence of a decrease in the longitudinal arch of the foot. Conclusions. Weil osteotomy has the worst corrective possibilities of raising the head of the metatarsal bone, but is very easy to perform, so its use is advisable in the absence of reduction of the longitudinal arch of the foot. A wedge-shaped distal osteotomy has a range of correction of the metatarsal head elevation up to 3 mm, but it depends on its diameter, so it is used in the case of a head diameter of at least 10 mm. Helal osteotomy provides the widest range of elevation of the metatarsal head, which does not depend on the presence of any degree of flat feet, but has some technical limitations.*

*Виправлення переднього відділу стопи з вальгусною деформацією першого пальця призводять до перерозподілу навантаження ваги тіла під час ходьби між головками плеснових кісток. При цьому значно збільшується навантаження на головку II та III, а іноді і IV плеснових кісток. Мета. Обґрунтувати вибір найбільш коректної дистальної остеотомії плеснової кістки для лікування пацієнтів із наявністю метатарзалгії. Матеріал і методи. Змодельовано три варіанти дистальної остеотомії плеснової кістки: Weil, Helal і дистальна клиноподібна. Результати. Weil остеотомія дозволяє підняти точку опори головки плеснової кістки над опорною поверхнею від 2 до 7 мм залежно від величини здвигу головки в проксимальному напрямку та кута нахилу плеснової кістки відносно площини опорної поверхні, що ефективно знижує навантаження на головку плеснової кістки за ходьби, але в разі величини кута нахилу осі плеснової кістки більше 20°. Helal остеотомія з наступним зміщенням відокремленої частини проксимально, забезпечує підйом головки над умовною площиною опори від 1 до 4 мм, сприяє ефективному розвантаженню головки за стояння і під час ходьби. Її використовують лише за важкої метатарзалгії. Діапазон корекції висоти стояння опорної поверхні головки плеснової кістки для виконання дистальної клиноподібної остеотомії, визначають у межах від 0,6 до 2,9 мм. Її перевагою є незалежність величини корекції від наявності чи відсутності зменшення повздожнього склепіння стопи. Висновки. Weil остеотомія має найгірші коригувальні можливості підйому головки плеснової кістки, але дуже проста у виконанні, тому її використання доцільне за умов відсутності зменшення повздожнього склепіння стопи. Клиноподібна дистальна остеотомія має діапазон корекції підйому головки плеснової кістки до 3 мм, але він залежить від її діаметра, тому її застосовують у разі величини діаметра головки не менш ніж 10 мм. Helal остеотомія забезпечує найширший діапазон підйому головки плеснової кістки, який не залежить від наявності будь-якого ступеня плоскостопості, але має деякі технічні обмеження. Ключові слова. Плеснова кістка, деформація, коригувальна остеотомія.*

**Keywords.** Metatarsal bone, deformity, corrective osteotomy

## Introduction

Various variants of the pain syndrome in the anterior part of the foot on its plantar surface are united by the general term metatarsalgia. This pain can be a sign of both systemic diseases and local disorders due to biomechanical disorders of the front part of the foot [1, 2]. Most often, static distortions of the front part of the foot with valgus deformation of the first toe lead to biomechanical disorders [3]. Structural and functional changes in the front part of the foot due to such deformations cause a redistribution of the body weight load during walking between the heads of the metatarsal bones, and significant distortions can be associated with the formation of the so-called «round foot» (Fig. 1) [4]. At the same time, the load on the head of the 2<sup>nd</sup> and 3<sup>rd</sup>, and sometimes 4<sup>th</sup> metatarsal bones increases significantly.

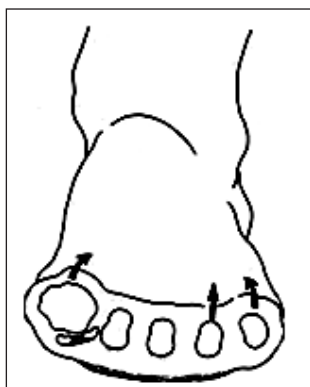
Many researchers state that metatarsalgia results from a change in the ratio of the length of the metatarsal bones one relative to the other, therefore violating the Lelievre's parabola, changing the Maestro criteria, which, in turn, leads to the development of a pain syndrome under the heads of the 2<sup>nd</sup> and 3<sup>rd</sup> metatarsal bones [5, 6].

Taking into account the above, common proposed surgical interventions solve the problem either by lifting the metatarsal head, or in the case of changing the length of the metatarsal bones with simultaneous lifting of the metatarsal head [7]. Most often, this can be achieved by using distal osteotomies of the 2<sup>nd</sup>, 3<sup>rd</sup>, and sometimes 4<sup>th</sup> metatarsal bones of the foot.

*Purpose.* On the basis of biomechanical studies, to justify the choice of the most correct distal metatarsal osteotomy for the treatment of patients with metatarsalgia.

## Material and methods

Three variants of distal metatarsal osteotomy are modeled, namely:



**Fig. 1.** Schematic representation of the formation of a «round foot» as a result of biomechanical changes in the front part of the foot [4]

– Weil osteotomy is the most common operation in the treatment of metatarsalgia [8–10];

– Helal osteotomy, proposed in 1975, is the most optimal intervention from a biomechanical point of view [11–13];

– distal wedge-shaped osteotomy of the metatarsal bone, proposed by us.

*Weil osteotomy* is a linear corrective osteotomy, in which the dissection of bone tissue is performed along the metatarsal bone in the direction from the back of the foot to the sole and from the distal direction to the proximal one, followed by displacement of the head of the metatarsal bone to the proximal side (Fig. 2). It is necessary to mention that the greater the angle between the axis of the metatarsal bone and the surface of the support, the higher the head of the metatarsal bone can be raised and shortened if necessary. In case of a small angle between the axis of the metatarsal bone and the surface of the support, which mostly occurs in a decrease in the longitudinal arch of the foot, there is less possibility of shifting the head to the top and shortening the length of the metatarsal bone.

*Helal* is a variant of linear osteotomy, which is performed at an angle of 45° in the direction from the back of the foot to the sole, and from the proximal to the distal direction. At the same time, the distal bone fragment is displaced to the proximal and posterior side, due to which the head is displaced to the back of the foot (Fig. 3).

In *wedge-shaped distal osteotomy* a dissection of the bone tissue of the epimetaphyseal part of the metatarsal bone is performed in the form of a wedge with the base to the back of the foot, being removed. Displacement of the head of the metatarsal bone occurs on the account of the removed wedge (Fig. 4).

For modeling, the elevation of the support point of the metatarsal head above the conditional support surface as a result of manipulations related to the features of each variant of corrective osteotomies was calculated. The following parameters were taken into account: the angle of installation of the metatarsal bone to the supporting surface, the size of the wedge angle and the diameter of the head of the metatarsal bone.

## Results and their discussion

The first stage of the study involved modeling of the Weil version of metatarsal osteotomy with horizontal dissection and subsequent displacement of the distal part in the proximal direction. The scheme of Weil osteotomy is shown in Fig. 5.

As shown in the diagram, the variant of osteotomy with horizontal dissection of the bone tissue, parallel to the plane of support, and the subsequent displacement of the head of the metatarsal bone in the proximal direction leads to the displacement of point A of the head support to point  $A_1$  by a distance of displacement  $l$ , and the center of head rotation O to point  $O_1$  to the same distance  $l$ . At the same time, there was no upward displacement of the support point, because it occurs parallel to the area of the support. But shortening of the metatarsal bone by the amount of  $l$  was recorded. A schematic representation of this process is shown in Fig. 6.

The main load of the front part of the foot occurs along a line that passes through the centers of the heads of the metatarsal bones. Following Weil osteotomy, the metatarsal bone is shortened and, as

a result, its head is displaced in the proximal direction beyond the line of the main load. This may be a factor in reducing the load on the operated metatarsal bone during standing.

We observe a completely different picture in the time course during walking in the phase of support on the front part of the foot. The diagram of the movement of the head of the metatarsal bone following Weil osteotomy during support on the front part of the foot is shown in Fig. 7.

In rolling of the foot during walking, support is transferred from the back of the foot to the front. This is done by separating the heel from the surface of the support, increasing the angle of installation of the metatarsal bone to the plane of the support. Normally (Fig. 7 a), the rotation of the metatarsal bone occurs around the center O of its head, and the support point A with the surface remains in place. As a result of Weil osteotomy, the point of rotation of the head of the metatarsal bone is shifted in the proximal direction to the  $O_1$  position, but due to the fact that the heads of all other metatarsal bones remained in their places on the line of the main load, the rotation of the operated head occurs around the old center of rotation O. This brings the center of rotation  $O_1$  of the head of the metatarsal bone to the position  $O_2$ , and the support point A of the head rises up to the position  $A_1$ . The result of Weil osteotomy in supporting the forefoot is shown in Fig. 8.

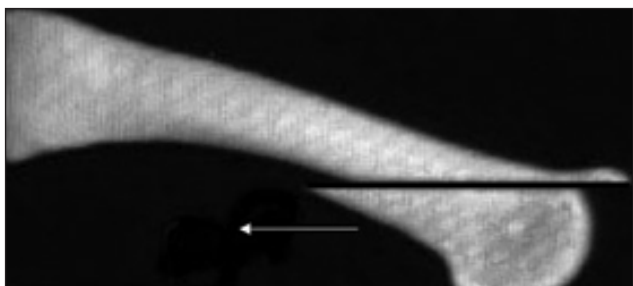


Fig. 2. Corrective osteotomy of the head of the metatarsal bone according to Weil



Fig. 3. Helal osteotomy



Fig. 4. Wedge-shaped corrective osteotomy of the metatarsal head

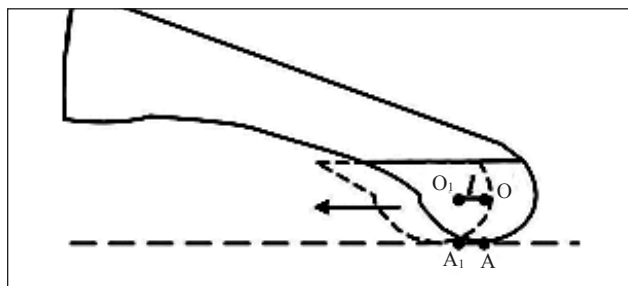


Fig. 5. Scheme of corrective metatarsal bone osteotomy according to Weil

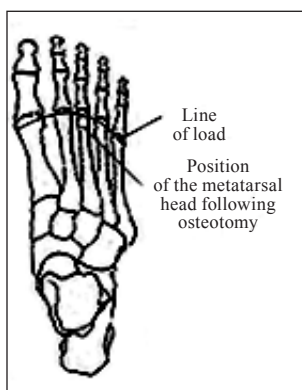


Fig. 6. Diagram of the movement of the 3<sup>rd</sup> metatarsal head following Weil osteotomy

To calculate the elevation of the support point of the metatarsal head above the support surface, it is necessary to consider the enlarged calculation scheme shown in Fig. 9.

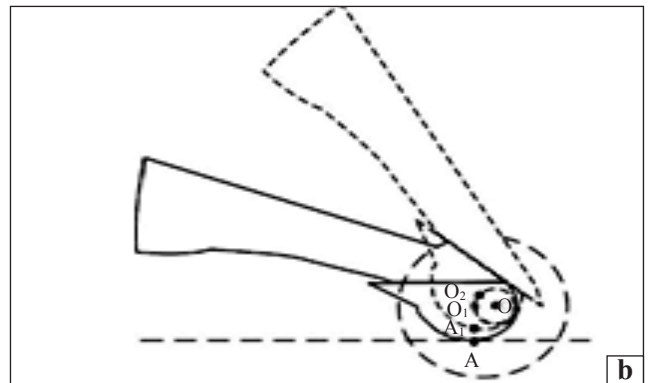
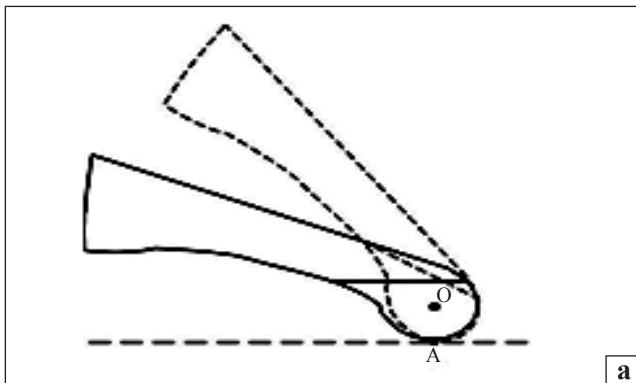
Following Weil osteotomy, the center of rotation  $O$  of the metatarsal head is moved in the proximal direction by the amount of  $l$  to the position  $O_1$ . During walking, in rolling of the foot in the phase of support on its front part, the metatarsal bone turns around the point  $O$  to the angle  $\gamma$ , which brings the center  $O_1$  of the head of the metatarsal bone to the position  $O_2$ . As a result of these movements, an equilateral triangle  $\Delta OO_1O_2$  is formed with sides equal to the displacement of  $l$  of the metatarsal head in osteotomy:

$$[OO_1] = [OO_2] = l \quad (1)$$

and angle  $\gamma$  from the vertex  $O$ .

The dimension  $h$  of the height of the triangle, from the vertex  $O_2$ , determines the amount of elevation of the point  $A$  of the support of the metatarsal head above the support plane, and is as follows:

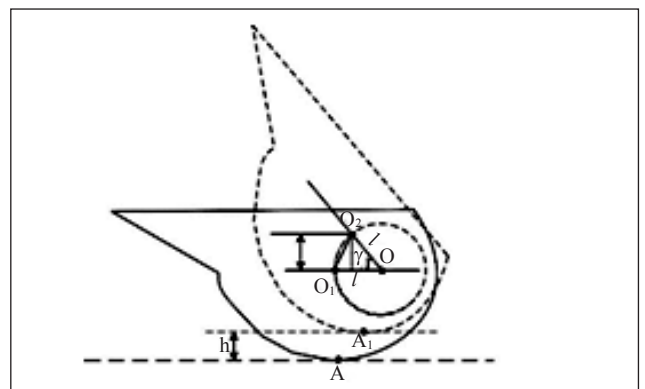
$$h = l \cdot \sin \gamma, \quad (2)$$



**Fig. 7.** Scheme of the movement of the head of the metatarsal bone following Weil osteotomy during support on the front part of the foot: a — before; b — after



**Fig. 8.** Diagram of the location of the heads of the metatarsal bones following Weil osteotomy of the 3<sup>rd</sup> metatarsal bone for support on the front part of the foot



**Fig. 9.** Calculation diagram of the movement of the head of the metatarsal bone following Weil osteotomy in supporting the front part of the foot

where  $l$  is the amount of displacement of the head as a result of osteotomy;  $\gamma$  is the the angle of elevation of the metatarsal bone relative to the plane of support.

Results of the calculation of dependence of the elevation of the support point of the metatarsal head above the support surface depending on the size of the displacement of the head in the proximal direction and the angle of inclination of the metatarsal bone relative to the support plane are shown in Table 1.

The graph shown in Fig. 10, gives a visual representation of the elevation of the head of the metatarsal bone depending on the size of its displacement in the proximal direction following Weil osteotomy and the angle of inclination of the metatarsal bone relative to the plane of support in the phase of support on the front part of the foot during walking.

Thus, it can be concluded that the reduction Weil osteotomy allows raising the support point of the metatarsal head above the support surface from 2 to 7 mm, depending on the size of the displacement of the head in the proximal direction and the angle of inclination of the metatarsal bone relative to the plane of the support surface. It also effectively

reduces the load on the head of the metatarsal bone during walking if it is performed under the conditions of the angle of inclination of the axis of the metatarsal bone greater than 20°. That is, in a decrease in the height of the longitudinal arch of the foot, or in severe transverse flat feet, «round foot», Weil osteotomy is not advisable, because the necessary elevation of the head of the metatarsal bone will not occur, and the symptoms of metatarsalgia will not be eliminated.

The second stage involved simulation of Helal osteotomy at an angle of 45°. The calculation scheme of this variant of corrective osteotomy is shown in Fig. 11.

It is for this variant of corrective osteotomy that the dissection of the distal part of the metatarsal bone is performed at an angle  $\alpha$ . Displacement of the separated distal part of the metatarsal bone in the proximal direction by the amount  $l$  moves point A of the support of the metatarsal head to point A<sub>1</sub>. At the same time, point A<sub>1</sub> rises relative to the conventional support plane to a height of  $h$ . The size of the height  $h$  depends on the angle  $\alpha$  and the linear displacement  $l$  of the distal fragment proximally and is determined by the following formula:

$$h = l \cdot \sin\alpha. \tag{3}$$

In the classic Helal variant, osteotomy is performed at an angle  $\alpha$  equal to 45°, and the displacement  $l$  of the distal part of the metatarsal bone is from 1 to 10 mm. Equation (3) can be used to obtain indicators of the amount of lifting of the head of the metatarsal bone depending on its shift at different angles of the osteotomy of the metatarsal bone to the plane

of support. Results of the calculations are given in Table 2.

For a visual representation of the calculations of corrective possibilities of Helal osteotomy, taking into account the displacement values of the distal part of the metatarsal bone and the angle of installation of the metatarsal bone to the support surface, a graph was drawn, which is shown in Fig. 12.

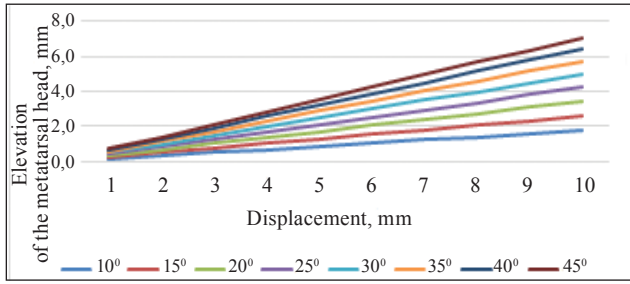
Results of the calculations showed that Helal osteotomy at an angle to the support surface followed by displacement of the separated part proximally, in the classical version (45° osteotomy angle), allows for the head to be lifted above the conventional support plane in a fairly wide range from 1 to 4 mm. The most effective, from the point of view of geometric calculations, is the option of performing osteotomy at an angle of 90°. During which it is possible to achieve the maximum displacement of the head to the top, significantly extending the range of correction up to 10 mm and eliminating signs of metatarsalgia. But this variant of osteotomy causes technical problems in its clinical application, due to the fixation of bone fragments. This fact must be considered as its drawback. This osteotomy allows to ensure the displacement of the head of the metatarsal bone both in the proximal direction and to the top, which contributes to the effective unloading of the head, both in the case of standing and while walking. Therefore, its use is advisable only if the patient has severe metatarsalgia due to deformations in the form of a «round foot».

As a next step, we will consider the corrective possibilities of the proposed distal wedge-shaped

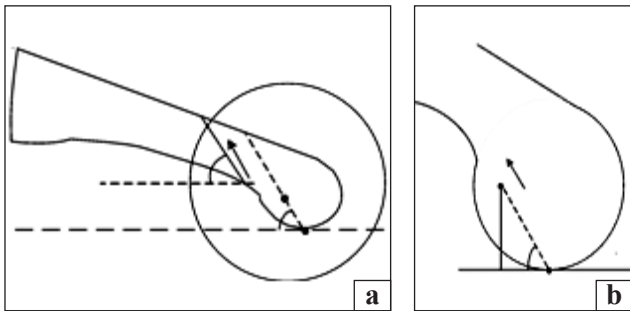
Table 1

**Height of elevation of the head of the metatarsal bone depending on the amount of its displacement in the proximal direction following Weil osteotomy and the angle of inclination of the metatarsal bone relative to the plane of support**

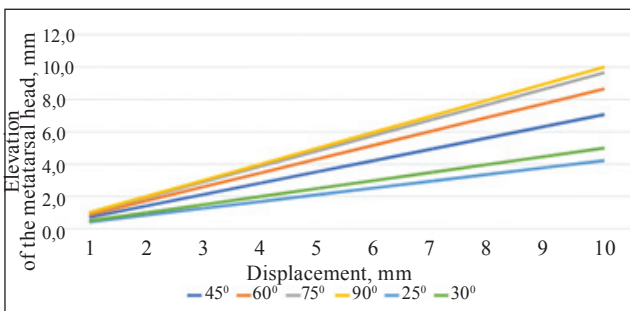
Head displacement (mm)	Amount of elevation of the metatarsal head (mm)							
	angle of inclination of the metatarsal bone 10°	angle of inclination of the metatarsal bone 15°	angle of inclination of the metatarsal bone 20°	angle of inclination of the metatarsal bone 25°	angle of inclination of the metatarsal bone 30°	angle of inclination of the metatarsal bone 35°	angle of inclination of the metatarsal bone 40°	angle of inclination of the metatarsal bone 45°
1	0.2	0.3	0.3	0.4	0.5	0.6	0.6	0.7
2	0.3	0.5	0.7	0.8	1.0	1.1	1.3	1.4
3	0.5	0.8	1.0	1.3	1.5	1.7	1.9	2.1
4	0.7	1.0	1.4	1.7	2.0	2.3	2.6	2.8
5	0.9	1.3	1.7	2.1	2.5	2.9	3.2	3.5
6	1.0	1.6	2.1	2.5	3.0	3.4	3.9	4.2
7	1.2	1.8	2.4	3.0	3.5	4.0	4.5	4.9
8	1.4	2.1	2.7	3.4	4.0	4.6	5.1	5.7
9	1.6	2.3	3.1	3.8	4.5	5.2	5.8	6.4
10	1.7	2.6	3.4	4.2	5.0	5.7	6.4	7.1



**Fig. 10.** Graph of changes in the height of the lifting head of the metatarsal bone from its shift after Weil and the angle of inclination of the support plane separately in the support phase on the front part of the foot during walking



**Fig. 11.** Calculation scheme of Helal osteotomy: a — general appearance; b — enlarged view



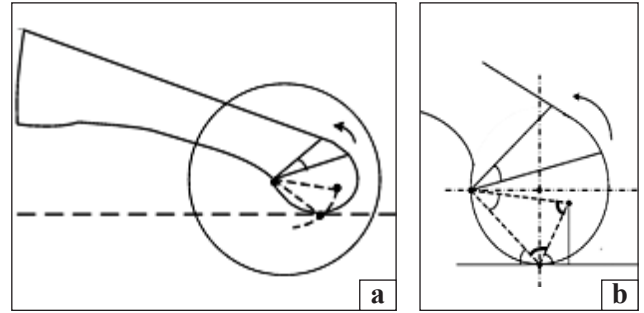
**Fig. 12.** Graph of dependence of the elevation height of the metatarsal head on its displacement at different angles of Helal osteotomy

osteotomy of epimetaphysis of the metatarsal bone, the calculation scheme of which is shown in Fig. 13.

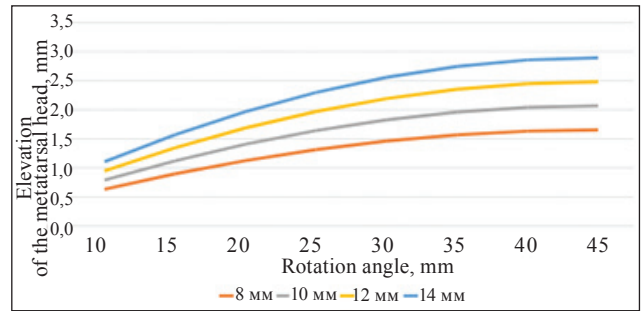
In wedge-shaped osteotomy, a wedge with an angle  $\alpha$  at its apex  $O_1$  is removed from the epimetaphysis of the metatarsal bone. The correction occurs due to the shift of the separated distal part of the metatarsal bone around point  $O_1$  by the angle  $\alpha$ . After these manipulations, point A of the head support moves to position  $A_1$ , and is located at a height  $h$  above the conventional support plane.

The value of  $h$  is determined by the following equation:

$$h = b \cdot \sin\phi, \quad (4)$$



**Fig. 13.** Calculation scheme of the wedge-shaped distal corrective osteotomy of epimetaphysis of the metatarsal bone: a — general view; b — enlarged view



**Fig. 14.** Graph of dependence of the height of the metatarsal head on its diameter and the angle of the wedge being removed

where  $b$  is the length of the segment  $[AA_1]$ ;  $\phi$  is the angle of inclination of the segment  $[AA_1]$  to the support plane.

The magnitude of the angle  $\phi$  can be determined as

$$\phi = 180^\circ - \beta + \gamma. \quad (5)$$

Segment  $[O_1A]$  is a chord resting on an angle of  $90^\circ$ , and the plane of support is tangent at point A, so the angle  $\gamma$  will be equal to  $45^\circ$ :

$$\gamma = 45^\circ. \quad (6)$$

To determine the value of the angle  $\beta$ , it is necessary to consider the triangle  $O_1AA_1$ , which is equilateral, and the angle from the vertex A will be determined by the equation:

$$\beta = 180^\circ - \alpha 2. \quad (7)$$

If we substitute the values from equations (6) and (7), we will get the equation for determining the angle  $\phi$ :

$$\phi = 180^\circ - 180^\circ - \alpha 2 + 45^\circ, \quad (8)$$

which, after opening the brackets, will have the following final form:

$$\phi = 45^\circ + 2. \quad (9)$$

Table 2

**The height of the metatarsal head elevation depending on the size of its displacement at different angles of metatarsal osteotomy to the plane of support**

Head displacement (mm)	Amount of elevation of the metatarsal head (mm)			
	osteotomy angle 45°	osteotomy angle 60°	osteotomy angle 75°	osteotomy angle 90°
1	0.7	0.9	1.0	1.0
2	1.4	1.7	1.9	2.0
3	2.1	2.6	2.9	3.0
4	2.8	3.5	3.9	4.0
5	3.5	4.3	4.8	5.0
6	4.2	5.2	5.8	6.0
7	4.9	6.1	6.8	7.0
8	5.7	6.9	7.7	8.0
9	6.4	7.8	8.7	9.0
10	7.1	8.7	9.7	10.0

Table 3

**Values of the elevation of the metatarsal head depending on the size of its diameter and the angle of the wedge being removed**

Diameter of the metatarsal head (mm)	Amount of elevation of the metatarsal head (mm)							
	wedge angle 10°	wedge angle 15°	wedge angle 20°	wedge angle 25°	wedge angle 30°	wedge angle 35°	wedge angle 40°	wedge angle 45°
8	0.6	0.9	1.1	1.3	1.5	1.6	1.6	1.7
10	0.8	1.1	1.4	1.6	1.8	2.0	2.0	2.1
12	0.9	1.3	1.7	2.0	2.2	2.4	2.4	2.5
14	1.1	1.6	2.0	2.3	2.6	2.7	2.9	2.9

The length of the base [AA<sub>1</sub>] of the equilateral triangle O<sub>1</sub>AA<sub>1</sub> is determined by the formula:

$$b = 2a \cdot \sin 2, \tag{10}$$

where a is length of the side [O<sub>1</sub>A] of the equilateral triangle O<sub>1</sub>AA<sub>1</sub>,

As mentioned, the side [O<sub>1</sub>A] of the equilateral triangle O<sub>1</sub>AA<sub>1</sub> is a chord of a circle with center O, its length can be determined as the multiplication of the diameter of the circle by the sinus of half the angle on which the chord rests, i. e.:

$$a = 2r \cdot \sin 45^\circ, \tag{11}$$

where r is the radius of circumference of the head of the metatarsal bone.

If we apply the value of the quantity a from equation (11) to equation (10), we will get the formula for determining the length of the segment [AA<sub>1</sub>]:

$$b = 4r \cdot \sin 45^\circ \cdot \sin 2. \tag{12}$$

If we substitute the value of the angle φ from equation (9) and the length of the segment [AA<sub>1</sub>] from equation (12) into formula (3), we will get the equation for determining the parameter h:

$$h = 4r \cdot \sin 45^\circ \cdot \sin 2 \cdot \sin 45^\circ + 2. \tag{13}$$

According to the calculation scheme, if the value of the angle γ is equal to 45°, then the angle α of the wedge removed during the osteotomy cannot exceed 45°. Therefore, to calculate the amount of correction, we set the range of the wedge angle α from 10° to 45°.

The size of the heads of the metatarsal bones differs on different toes, and also depends on the anatomy of the skeleton of different patients, therefore, for the calculation we choose the range of the diameter of the head from 8 to 14 mm. Results of calculations of the height of the metatarsal head lift depending on the size of its diameter and the angle of the wedge, being removed, are shown in the Table 3.

The graph shown in Fig. 14 can be used to get a visual representation of the amount of correction regarding the elevation of the metatarsal head depending on its diameter and the angle of the wedge, being removed during wedge-shaped osteotomy.

The conducted modeling showed that the range of correction of the standing height of the support surface of the metatarsal head in distal wedge-shaped osteotomy is determined in the range from

0.6 mm to 2.9 mm. The advantage of this method can be considered the independence of the amount of correction from the presence or absence of a decrease in the longitudinal arch of the foot (longitudinal flat feet). That is, the presence or absence of flat feet does not affect the amount of correction. But this type of osteotomy does not provide a possibility to adjust the length of the metatarsal bones relative to each other. Therefore, we modeled a combination of a wedge-shaped distal osteotomy with elements of a Weil osteotomy.

This version of the wedge-shaped osteotomy is essentially a sequential wedge-shaped distal osteotomy with the removal of the osteotomized wedge of the metatarsal bone at the angle of the removed wedge and its subsequent linear displacement in the proximal direction.



Fig. 15. shows the calculation scheme of the distal wedge-shaped osteotomy of the metatarsal bone in combination with a linear shift in the proximal direction

Taking into account the data obtained during biomechanical modeling, to facilitate the selection of the variant of corrective osteotomy of the metatarsal bone in order to eliminate the clinical presentation of metatarsalgia, an algorithm was proposed, which is shown in Fig. 16.

In practice, the algorithm works as follows:

- X-ray of the foot;
- X-ray measurement of the angle of the axis of the metatarsal bone to the support plane and the diameter of its head;
- if the angle of the axis of the metatarsal bone to the support plane is  $\geq 20^\circ$ , Weil osteotomy is performed;
- if the value of the angle of formation of the metatarsal bone to the plane of support is  $< 20^\circ$ , it is necessary to take into account the diameter of the metatarsal head;
- if the diameter of the head is more than 10 mm, wedge-shaped osteotomy is performed (the size of the wedge is chosen using Table 2);
- if the diameter of the head is less than or equal to 10 mm, Helal osteotomy is chosen (osteotomy angle is chosen according to Table 1).

### Conclusions

Weil osteotomy has the lowest corrective possibilities of lifting the head of the metatarsal bone when standing and walking when the angle between the axis of the metatarsal bone and

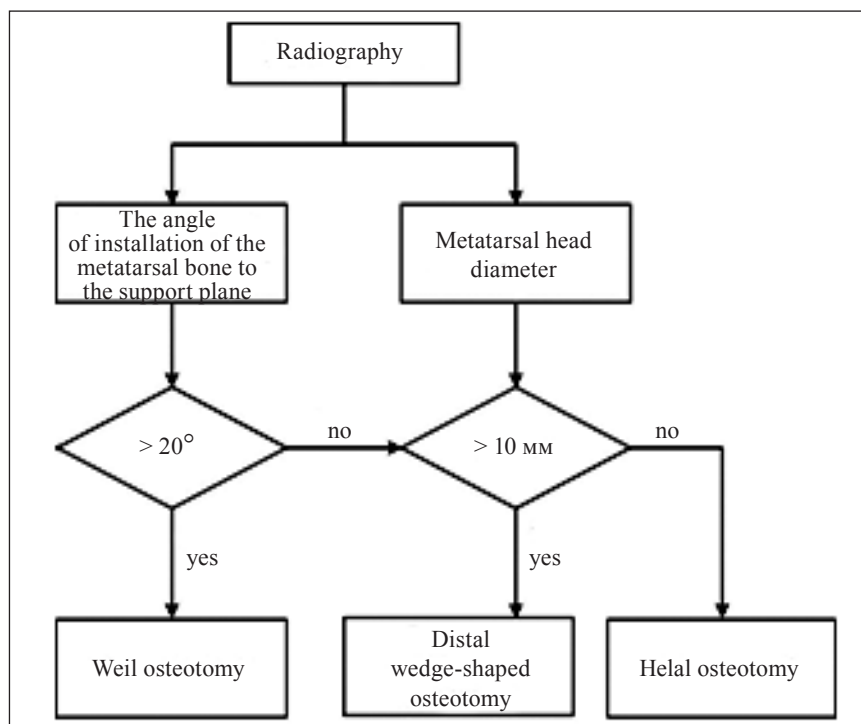


Fig. 16. Algorithm for choosing the variant of corrective osteotomy of the metatarsal bone



the plane of support is less than 20°, but it is very easy to perform, so its use is advisable to eliminate metatarsalgia in the absence of reduction of the longitudinal arch of the foot.

The wedge-shaped distal osteotomy is also easy to perform, has a range of correction of the elevation of the metatarsal head up to 3 mm, but it depends on its diameter, so its use is appropriate for the treatment of metatarsalgia when the diameter of the head is at least 10 mm. Helal osteotomy provides the widest range of elevation of the metatarsal head at its size up to 10 mm, which does not depend on the presence of any degree of flat feet, but has some technical limitations when fixing bone fragments of the metatarsal bone.

**Conflict of interest.** The authors declare no conflict of interest.

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## BIOMECHANICAL SUBSTANTIATION OF THE ALGORITHM FOR CHOOSING THE OPTION OF DISTAL CORRECTIVE OSTEOTOMY OF THE II–IV METATARSAL BONES IN THE TREATMENT OF METATARSALGIA

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