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The Most Effective Methods of Surgical Correction of Deformities of the Forefoot

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Abstract Forefoot valgus deformity is one of the most frequent static disorders of the foot and remains a complex challenge in orthopedic surgery. Traditional surgical planning has primarily focused on correcting the first intermetatarsal angle (M1M2) and hallux valgus angle (HVA). However, numerous recent studies emphasize the crucial role of sesamoid positioning and metatarsal parabola reconstruction in achieving stable and lasting correction. The sesamoid apparatus and the second metatarsal constitute the most constant structural reference points in forefoot biomechanics, and their alignment serves as a foundation for modern corrective strategies. Radiographic planning systems, such as Maestro's parabola criteria and the tibial sesamoid–second metatarsal distance (TSMD), have improved the accuracy of preoperative evaluation. However, despite detailed planning, achieving an optimal cosmetic and functional result remains challenging. Soft tissue correction alone has shown limited long-term effectiveness and a high recurrence rate. Modern surgical approaches therefore prioritize osteotomies that provide reliable stability, preserve the length of the first ray, allow multidirectional correction, and minimize the risk of metatarsalgia. Among these, Scarf osteotomy has become one of the most widely used techniques due to its biomechanical stability, versatility, and ability to correct severe deformities with early postoperative weight-bearing. Comparative clinical results demonstrate lower complication rates (4–11%) compared to proximal osteotomies and predictable correction of HVA, M1M2, and PASA. For advanced deformity and accompanying degenerative changes, tarsometatarsal arthrodesis remains indicated. This analysis highlights that successful treatment of forefoot valgus deformity depends on individualized radiographic assessment, biomechanically grounded surgical planning, and the appropriate selection of osteotomy type to reconstruct the anatomical metatarsal parabola and restore forefoot function.

Keywords Research methods of static deformations of the human foot

1. Introduction

Most of the studies conducted to determine the effectiveness of surgical correction of deformities of the forefoot have focused on reducing the first intermetatarsal angle (M1M2). Also, most of the preoperative planning algorithms are based on classifications that focus on the ratio of the first two metatarsals (M1M2) and the angle of the hallux valgus deformity of the first finger (HVA) and perform various operations depending on the angle of M1M2. At the same time, the importance of the position of the sesamoid bones in relation to the head of the first metatarsal has also been the subject of numerous studies, in which the authors convincingly proved that the most static structure in the forefoot is the lateral sesamoid bone and the axis of the second metatarsal. Proved that as varus deviation M1 progresses the location of the base of the main phalanx and sesamoid bones relative to the second metatarsal does not change. The authors explained this constancy of the relationship by the intimate connection of the thumb with the sesamoid apparatus through the plantar plate and concluded that it was necessary to move the head of the first metatarsal bone outward as the main component of correction. Multicenter study demonstrated the constancy of the distance between the inner edge of the lateral sesamoid bone and the second metatarsal bone and even introduced a new radiological feature – TSMD (the tibial sesamoid-second metatarsal distance), claiming that this feature is static. The construction of a "correct" metatarsal parabola is an important principle of surgical tactics for the treatment of static deformity of the forefoot. He described the metatarsal parabola as "a line passing through the metatarsophalangeal joints and forming a segment of the parabola, gradually descending outward and from front to back." The founder of lateral ray surgery, M. Maestro, described radiological criteria, which are the main parameters that determine the scope of surgical intervention. During preoperative planning, it is necessary to carry out two main axes of the foot. The sagittal axis is a line drawn through the middle of the articular surface of the head of the talus and the center of the head of the second metatarsal (M2). The transverse axis is

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a line drawn through the center of the lateral sesamoid bone and is perpendicular to the sagittal axis (SM4). In normal foot anatomy, this perpendicular often passes through the middle of the fourth metatarsal bone [1,3,5,7,9,11,13,14].

Studies have shown that for the normal anatomy of the foot, the heads of the metatarsal bones are arranged geometrically in such a way that they form a parabola. Three radiological Maestro criteria are determined: I – the distance from the distal edge of the head M2 to SM4 – the distance from the distal edge M3 to SM4; II – the distance from the distal edge of the head M3 to SM4 – the distance from the distal edge of the head M4 to SM4; III – the distance from the distal edge of the head M4 to SM4 – the distance from the distal edge of the head is M5 to SM4. At the same time, the equality of the first and second metatarsal bones is observed. It is possible that the second metatarsal bone may be slightly longer than the first. These two landmarks are taken as the 0 point, from which further, moving to the head of the fifth metatarsal bone, their lengths decrease. Thus, the length of the third metatarsal should be 3 mm shorter than the second, the length of the fourth metatarsal should be 6 mm shorter than the third, and the fifth metatarsal should be 12 mm shorter than the fourth.

2. Results and Analyzes

These data correspond to the anatomy of a normal foot. Additional morphotypes of the feet are distinguished: – with long second (M2) and third (M3) metatarsal bones (the transverse line passes through the center of the lateral sesamoid bone and the center of the M4 head, but the geometric progression is disrupted due to the excessive length of M2 and M3); – with short fourth (M4) and fifth (M5) metatarsal bones - foot hypoplasia (a transverse line runs through the center of the lateral sesamoid bone, but distal to the center of the M4 head). Thanks to the study, surgeons began to study foot radiographs more closely, however, despite careful preoperative planning, it remains difficult to obtain an excellent cosmetic result. Minimal interventions have been attempted to correct the deformity of the forefoot, such as bursectomy and resection of the capsular fold. However, their inefficiency has been proven, for example, in these operations, HVA increases by 4.8 °and M1M2 by 1.7 °within five years after surgery. Patients were dissatisfied with the result in 41% of cases. He emphasized the importance of muscle balance, and in 1923 defined soft tissue surgery as excision of the medial exostosis, release of the tendon by the adductor muscle and the lateral capsule of the joint, which allows the sesamoid bones to return to their original position under the head of the first metatarsal. He modified the Silver method and proposed cutting off the tendon of the muscle leading the first finger from the lateral sesamoid bone, followed by transposition to the head of the first metatarsal bone. Until now, many surgeons use McBride surgery to treat hallux valgus deformity and are most often used for moderate deformity (angle HVA less than 25 °, M1M2 less than 15 °). With modern approaches to the treatment of hallux valgus deformity of the first finger, soft tissue surgery is usually an addition to bone surgery. Isolated operations on soft tissues have been shown to reduce HVA by 14.8 °and M1M2 by 5.2 °, but the frequency of varus curvature of the first finger increases by 11%, while the worst results were obtained with pronounced deformities (M1M2 > 15 °). Osteotomy can be performed proximally, through the diaphysis, or distally. There are a number of important principles to keep in mind when choosing an osteotomy of the first metatarsal:

– the operation should be technically easy to implement and reproducible.; – osteotomy should be stable so that there is no repeated displacement.; – to prevent the development of metatarsalgia, the length of the first metatarsal should be maintained. Bending of the first finger should also be avoided.; – the technique should be universal enough so that HVA, M1M2 and PASA can be fixed simultaneously.; – in order to avoid aseptic necrosis of the metatarsal head, its blood supply should be maintained; – the long-term result should show a low frequency of deformity recurrence. Currently, correction of bone deformities of the foot is the most popular among orthopedists. Keller surgery involves resection of approximately one third of the base of the proximal phalanx of the first finger. This reduces the pressure in the joint and relaxes the strained longitudinal structures, which makes it possible to correct the deformation [2,4,6,8,10,12,14].

This method has been widely used, but now it has significant limitations. Some authors have concluded that after Keller surgery, the degree of recurrence of deformity remains high, and the M1M2 angle does not decrease much or does not decrease at all. The operation reduces the function of the first ray: for example, the force of plantar flexion of the first finger is reduced by 40%. Metatarsalgia is noted in 20-40% of cases. A decrease in the amplitude of movements in the first metatarsophalangeal joint is also a common phenomenon. Therefore, Keller surgery should be considered only in elderly people with extremely low "functional requirements" who may not be able to undergo a major operation. Currently, the Keller operation is not a "choice operation" for hallux valgus. This is an oblique metaphyseal osteotomy extending from the distal medial to the proximal lateral margin, allowing the metatarsal head to be displaced laterally and proximally. This technique allows you to adjust M1M2 and HVA. Satisfactory results were described in about 90% of patients. However, later metatarsalgia began to bother 35% of patients, and 78% of patients had corns under the head of the second metatarsal. It has been proven that shortening by more than 5 mm is closely related to the appearance of metatarsalgia. Due to these disadvantages, this operation is currently not recommended. This osteotomy involves a U-shaped osteotomy with lateralization of the head fragment. Good clinical results were reported in 91% of patients. It is recommended for M1M2 up to 15 °and HVA up to 35 °. Nevertheless, there is a shortening of the first metatarsal bone due to the removal of its part to create a "step", which, combined with the lack of stability, leads to the appearance of metatarsalgia in 10-30%

of patients. This is a V-shaped osteotomy of the metatarsal bone through the neck, followed by lateral displacement of the fragment outward.

This procedure results in minimal shortening and is stable with respect to back flexion. It is indicated for moderate deformity. Excellent clinical results have been shown with infrequent or no occurrence of metatarsalgia. Some authors, however, claim that the results are not so good in patients over 60 years of age. This is an osteotomy performed distally downwards from the dorsal cortical layer, 2 mm more distal than the metatarsal joint, to the plantar cortical layer. The osteotomy forms an angle of 30 ° with respect to the axis of the metatarsal bone. The distal fragment rotates outward from the proximal fragment and is fixed with two screws. It is also possible to shift the head of the metatarsal bone even more plantarically by changing the angle of the osteotomy. In addition, M1 plantarization reduces the pressure on the head of the second metatarsal. Excellent clinical results were obtained, with good correction of deformity. Ludloff osteotomy is performed with minimal M1 shortening and is more biomechanically stable than with conventional chevron osteotomies.

Contraindications for modified Ludloff osteotomy are instability, as well as osteoarthritis PKC1. Ludloff osteotomy is a rotational osteotomy and therefore does not involve PASA correction. In these cases, chevron or scarf osteotomies are used. The lock joint of the scarf type has been used for many centuries in carpentry, for example, to lengthen beams in the roof of a house or in the construction of boats. This type of connection combined the capabilities of a strong connection and the ability to carry a load. Scarf allows performing almost any type of displacement of the osteotomated metatarsal head in accordance with preoperative planning. By changing the geometry of osteotomies, the metatarsal bone can be shortened, or an abnormally high PASA can be reduced. This osteotomy has a high degree of biomechanical stability and is more stable than basal osteotomies. Scarf osteotomy is a universal procedure for correcting the hallux valgus deformity of the first finger. It allows patients to be given an early load, since osteotomy is very stable and to return to work at an earlier date compared to other operations. Provides predictable and satisfactory results. It can be either an independent operation or combined with others. It is effective in severe deformities, including secondary deformities, for example, juvenile and rheumatoid valgus deviation of the first finger. Like other osteotomies, scarf osteotomies have modifications and are often supplemented with osteotomies, such as Akin. Fixation of the scarf osteotomy is also performed with various implants: Baruch screws with a threaded head, AO sponge screws, as well as threaded spokes at the end. Studies have shown that the clinical results of scarf osteotomies compare favorably with basal osteotomies, and the complication rate varies from 4% to 11%. While up to 19% of basal osteotomies result in complications of various kinds. Scarf is traditionally recommended at M1 M2 from 18 ° to 20 °. But experienced surgeons can use this osteotomy for more severe deformities. In recent years, diaphyseal osteotomies such as scarf and Ludloff in various modifications have been the most popular among orthopedists. The last group is a group of proximal or basal osteotomies. Open and closed wedge osteotomies and basal chevron osteotomies are usually used in combination with soft tissue surgery. Basal osteotomies are used for moderate to severe deformities, but they cannot effectively normalize PASA. V-shaped osteotomy, in which the axis of the metatarsal is rotated outward, and the achieved position is fixed with a screw between the first and second metatarsal bones, although other types of internal fixation can be used. This is technically the simplest and most stable of the proximal osteotomies, with the lowest percentage of complications. Arthrodesis is indicated when valgus deformity of the first toe is combined with pronounced degenerative changes in the first metatarsophalangeal joint. It is also a treatment option for severe or recurrent clubfoot, especially in elderly patients.

3. Conclusions

This arthrodesis is used in combination with soft tissue surgery in patients with hypermobility of the first metatarsoid joint, especially if it is associated with generalized weakness of the ligamentous apparatus of the feet. According to the data, this pathology occurs in approximately 3-5% of patients. The procedure is also indicated in the presence of dystrophic changes in the first or second tarsal-metatarsal joint and, alternatively, in severe deformity with a M1M2 of more than 20 °. Arthrodesis is contraindicated in adolescents with open growth zones, as well as in patients with a short first metatarsal. The procedure is technically complex and involves a long recovery period. The patient satisfaction rate ranges between 75% and 90%.

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