302. Theoretical basis for surgical operation with pes plano-valgus foot deformation from the view-point of biomechanics

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Abstract. The author proposes a new, biomechanically grounded method of surgical treatment of severe forms of pes plano-valgus; the author provides results of surgical treatment of 40 patients (55 feet).

Introduction

Podiatrics as a part of orthopedics which studies foot pathologies of inborn, acquired, traumatic genesis, diverse variants of the norm and borderline conditions with pre-clinical manifestations of pathologyб as well as supplying the patients with corrective orthopedic insoles and footwear, has not achieved proper development in recent time in the countries of the former USSR. At the same time, according to literary data, static deformities of the foot are the most common pathology of the musculoskeletal system [1,3,4]. In this group the principal position is occupied by pes plano-valgus (flat-foot). This type of pathology is encountered in 6.9—70% of the entire population [1,3,4,12].

The human foot has two anatomic column the inner column, which consists of the astragaloid bone, the navicular bone, three sphenoid bones and the 1-2-3 metatarsal bones; and the outer column, which is presented by the calcaneum, the cuboid and the 4-5 metatarsal bones [10]. The column in question functionally intersect at the level of the talocalcaneonavicular articulation and the subtalar articulation.

The talocalcaneonavicular articulation, due to its shape, has been named acetabulum pedis. The term acetabulum pedis has been proposed in the works of A. Scarpa, S.K. Sarrafian, V.J. Turco, and the modern topographic-anatomical features and concept of the given formation have been described and formulated in 1995 in the works of T. Epeldegui и E. Delgado [10]. According to this concept, the head of the astragaloid bone is compared to the head of the femur, and the naviculocalcanear foot cavity, formed by the proximal articular surface of the navicular bone, the front and medial articular facets of the calcaneum and a well-defined capsular-ligamentous apparatus, above all the spring ligament – is compared to the cotyloid cavity.

The naviculocalcanear foot cavity has an ellipsoidal shape with the front, lower, lateral, medial and upper walls.

The front wall is formed by the proximal articular surface of the navicular bone, the lower – by the plantar calcaneonavicular ligament and the articular facets of the calcaneum (front and medial). The lower wall – by part of the bifurcational ligament and the outer calcaneonavicular capsule, the medial – by the upper-medial calcaneonavicular ligament. The upper wall consists of the upper talonavicular ligament and the upper part of the talonavicular capsule [10]. The most vulnerable part of the aforementioned anatomical complex is the lower-medial part, formed predominantly by soft-tissue elements.

The centering of the head of the astragaloid bone in the given cavity is given the same significance as the centering of the head of the thigh-bone in the cotyloid cavity.

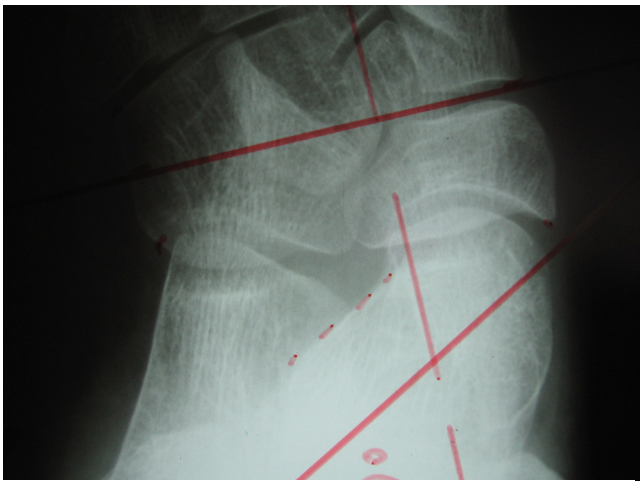

Fig. 1. Decentered position of the head of the astragaloid bone in the case of pes plano-valgus with alteration of its shape and the direction of oseeus trabeculae.
(Patient B. Age 11)

In the work of F. Pauwels [29] it is signified that in physiological interactions in the structures of the hip joint the maximum pressure on the head of the thigh-bone amounts 18,0 kg/cm², while during the decentration with subluxation it increases to 225 kg/cm². In the same way the decentered position of the head of the astragaloid bone is accompanied by overload of all elements of acetabulum pedis with subsequent Dysplastic alterations of adjacent joints, development of arthroses and pain syndrome. During observation clinical cases with well-defined indications of deforming arthrosis of the talonavicular joint even in teenage children.

Fig. 2. Deforming arthrosis of the talonavicular joint in pes plano-valgus with well-defined regional osseous accretions and deformity of the head of the astragaloid bone (Patient B. Age 11)

From the start of a child's walking the prerequisites for pressure on the foot in a functionally inconvenient position are formed. It is due to the fact that, in order to maintain balance, a child spreads his or her legs widely, leans on the inner section of the foot, the knees shift inward, creating a valgoid, functionally inconvenient arrangement of the whole limb. In this position of the lower limb the medial shift of the head of the astragaloid bone occurs, the bone strives to shift downward and inward in respect to sustentaculum tali. This leads to decentration of the head and superdistension of the most vulnerable part of acetabulum pedis – its lower-medial part.

Thus, the prerequisites for the formation of pes plano-valgus appear.

In cases of pes plano-valgus the biomechanics of the foot itself and the superincumbent structures of the musculoskeletal system tend to be impaired [22].

Within the cycle of a step in phase of support, when the heel touches upon the surface, from the outside of the axis of the subtalar joint there appears the force of the reaction of the support, which generates the pronating moment on the level of the subtalar joint. It leads to the pathological inward rotation of the talus around the calcaneum. The astragaloid bone tends to bend towards the heel, and moves and rotates inward in the horizontal plane while the calcaneum performs outward rotation and occupies the valgus position. The center of gravity gets displaced that results in even stronger reinforcement of the pronating effect of the static load upon the calcaneum. Increase in pronation displacement on the level of the subtalar joint tends to be limited due to exertion of the posterior group of muscles of the shin (presumably of the posterior shin-bone muscle and a long flexor of the right toe); in case power of muscles is insufficient it gets blocked by exertion of ligaments and capsules of joints.

If in phase of support the valgus deviation of the calcaneum from the vertical axis exceeds 6°, then the power of muscles of instep / arch supporters happens to be insufficient to overcome the pronating moment on the level of the subtalar joint and, prior to separation of the heel from the surface, it fails to switch to the supinating position which is so important for the next movement. Thus, in its turn, results in decrease of rigidity rate of the power lever of the foot as well as leads to the overexertion of ligaments, shin and foot muscles, and overload of joints of the medium part. Overstretching of soft-tissue foot structures and their aseptic inflammation as well as arthrosis-induced changes in subtalar and subtalar-navicular joints result in appearance of a pain syndrome [22].

The above specified biomechanical disturbances result in changes of location and shift of the vector of the general center of body weight of a patient upon walking.

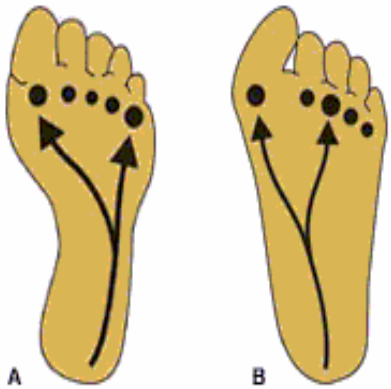

Fig. 3. The vector of shift of the general center of body weight (A— normal condition, B— the formation of pes plano-valgus)

In cases of normal development of the foot the major load is distributed onto the sole surface in the direction from the calcaneal tubor along the external edge down to the basis of the fourth metatarsal bone. Then the vector is divided into the two components leading to the heads of the first and the fifth metatarsal bones. In cases of pes plano-valgus deformity the supporting vector shifts medially that results in changes of the nature of walking and causes increase of dynamic load upon the whole musculoskeletal system, i.e. beginning with the foot and

the ankle-joint and ending up with the cervical part of spinal cord [22].

In the works of V. Mosca the author points out that in cases of flat foot, due to close interrelation of all three anatomico-functional sections of the foot, alterations cannot occur only in one of them, the deformity is always of a complex nature [26]. Such a situation is always observed in cases of flat foot, even in minor deviations, clinically defined as reduction of the longitudinal arch. Therefore local pressure only on one component of the deformity does not lead to success.

The principal pathological components of pes plano-valgus, which alter the biomechanics, are the following [19, 25]:

1. excessive pronation in the subtalar joint accompanied by valgus and external (outward) rotational deviation of the calcaneum; plantar flexion of talus, calcaneum, and, in some cases, of the navicular bone;
2. inward horizontal displacement of the head of the astragaloid bone and vertical downward displacement with respect to the navicular bone;
3. the shortening of the external as well as lengthening of the internal foot column;
4. supination of the anterior section of the foot vs. the posterior one accompanied by the rear flexion of the first instep (metatarsal) bone;
5. overdistension of tendon of the posterior tibial muscle and its functional insufficiency;
6. the shortening of Achilles' tendon.

Modern orthopedic surgery comes up with numerous operative techniques aimed to correct severe forms of pes plano-valgus foot deformity. They can be relatively divided into several major groups, i.e.:

1. surgical correction aimed to block or limit excessive multi-planar flexibility of the subtalar joint and to create a more functionally favorable position of the astragaloid bone (subtalar arthrodesis) [11], arthrorisis of the subtalar joint [7, 21, 33];
2. operations performed on the medial column of the foot and comprising shift and grafting of tendons, various types of capsuloplasty, arthrodesis, corrective osteotomy of sphenoid and talar bones [13, 14, 16, 17, 20, 23, 24, 30, 32];
3. various types of osteotomy of the calcaneum, i.e. a) the extraarticular ones on the level of the posterior upper part of the calcaneum, aimed to limit pronation on the level of the subtalar joint on analogy with the extraarticular arthrorisis [6, 7, 31]; b) osteotomy of the body of the calcaneum backward of the subtalar joint aimed to achieve a varus location of the distal fragment of the bone [9, 15, 18, 27, 28]; c) extraarticular extending osteotomy of the anterior part of the calcaneum [25] and the extending calcaneocuboid arthrodesis [5, 8];
4. combined operations on the osseous structures, joints and soft tissues [27, 28];
5. deformity correction by means of application of apparatuses of external fixation [2].

The bulk of the proposed surgical techniques, aimed at surgical correction, are based on the principle of local effect upon the main pathogenetic link. At the same no consideration is taken into account that changes in a single part of the foot or a separate foot joint happen to occur extremely seldom.

Procedures on soft tissues make a positive change in the muscular balance, but do not influence the skeleton of the foot, which is the basis of its stability. Local arthrodesis-performing procedures are accompanied by an overload of the adjacent joints and lead to development of early arthroses. Isolated osteotomies of the calcaneum also in many cases do not lead to full elimination of the deformity and recovery of the anatomico-functional condition of the foot. Devices for external fixation pose are difficult to endure for patients and require a lengthy correction process.

The aim of this research was the development and theoretical grounding of a new approach to surgical treatment of non-fixed pes plano-valgus with single-stage elimination of all principal components of the deformity.

Materials and methods

40 children (27 males (67.5%) and 13 females (32.5%)) who underwent surgical correction of non-fixed pes plano-valgus foot deformity (total 55 feet) have been followed up at our clinic. All pre-operated children were diagnosed to have a bilateral deformity. 18 patients (36 feet; 65.45%) have been operated on both feet.

For single-stage elimination of all principal components of the deformity the following procedure is proposed. The principal stages of the procedure and their grounding:

1 – due to the fact, that modern biomechanical research has shown that 63% of foot stability is provided by the configuration of the bones of the foot and their short ligaments, and 37%— by the spring ligament complex, transverse osteotomy of the front section of the calcaneum with its lengthening is performed. At that, it is necessary to apply two instruments, proposed by the author, which allow to perform an osteotomy of the front section of the calcaneum, which is visually controlled for the whole duration of the procedure, a single-stage distraction of the osteotomized parts and implantation of osseous autotransplant from the wing of ilium or allotransplant with demineralized bone matrix between the osteotomized parts of the calcaneum. This stage of the procedure lengthens the eouter column of the foot, turns the medial section of the foot inward, leads to tension of the capsular-ligamentous apparatus of the plantar surface of the foot. At the same time the centering of the head of the astragaloid bone with respect to acetabulum pedis occurs.

2 – For varisation of the calcaneum a Z-shaped extension of the Achilles tendon at the level of the subtalar articulation in the sagittal plane with medialization of the attachment point is performed.

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3 – For the purpose of strengthening of the capsule of the talonavicular joint along the lower-inner surface (including the spring ligament) the superdistnded capsule of the joint is excised along lower-inner surface within 6-10 mm with subsequent capsuloplasty.

4 – Transference of half or the whole ligament of the front shin muscle to the lower-lateral surface of the navicular bone at the level of the plantar surface of the navicular bone, the 1st sphenoid and the 1st metatarsal bone. This leads to strengthening of the foot arch at its top and formation of an additional ligament on the plantar surface of the foot, which eliminates supination of the first metatarsal bone.

5 – For the elimination of superdistension and functional insufficiency of the ligament of the posterior shin muscle, after the Z-shaped intersection of the aforementioned ligament, its shortening on a supinated foot is carried out.

Results and discussion

The course of the post-operative follow-up of all the children under study lasted from one to seven years. Clinically, the patients demonstrated disappearance of pain syndrome upon long walks, their gait improved; restoration of the longitudinal arch favorably improved the cosmetic outlook of the operated feet.

Fig. 4, 5. Pes plano-valgus of the left foot before and after surgery

Post-operative X-ray studies confirmed lengthening of the calcaneum by 5-6 cm, increase in the angle of the calcaneum slope on average by 12 degrees, decrease of the angle of the longitudinal arch by 18-38 degrees, and increase of the height of the longitudinal arch by 10-24 mm. At the same time, talocalcaneal angle before and after the operation remained practically the same and, therefore, it can not serve as a parameter used for description of such type of deformity. X-ray evaluation of the ratio between the angle of the longitudinal arch of the talus and the medium part of the foot served as a very informative finding in this study. After surgical correction it ranged from 0 to 10 degrees and matched the normal values.

Complications within the post-operative period comprised as follows: the upward subluxation of the distal fragment of the calcaneum (in 5 cases;), local marginal necrosis of skin within the area of maximal tension of skin along the dorso-external surface of the foot (in 6 cases;). The above complications did not affect the results of surgical treatment.

Conclusions

1. The above proposed technique for surgical correction enables to simultaneously remove all the components of deformity of posterior, medium and anterior parts of the foot.
2. This operative technique tends to preserve mobility in the subtalar joint, in the joints of the medium and anterior fragments of the foot as well as to prevent development of early degenerative arthrosis.
3. In cases of inefficient complex conservative therapy children over 4-6 years of age with severe forms of pes valgus foot deformity should be administered surgical correction of this deformity.

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