УДК 616-053.2:616.716.1-089:617.58

THE MODERN APPROACH TO TREATING FLATFOOT DEFORMITY IN CHILDREN

G.V. Slizovskiy, Y.V. Shikunova, M.A. Fyodorov, Y.V. Yevdokimova, S.S. Tukhvatullin.

Siberian State Medical University, Tomsk, Russian Federation

СОВРЕМЕННЫЙ ПОДХОД К ЛЕЧЕНИЮ ДЕФОРМАЦИИ ПЛОСКОСТОПИЯ У ДЕТЕЙ

Г.В. Слизовский, Ю.В. Шикунова, М.А. Федоров, Ю.В. Евдокимова, С.С. Тухватуллин.

Сибирский государственный медицинский университет, Томск, Российская Федерация

Summary. Degenerative-dystrophic diseases in children occupy an important place in the overall structure of orthopedic disorders, and the problem of their treatment remains relevant. Despite the use of modern therapy methods, children with foot deformities, such as flatfoot deformity, constitute a significant portion of patients in orthopedic practice.

Research objective. Improvement of treatment outcomes for children with valgus deformity of the foot using an implant made of porous titanium nickelide.

Materials and methods. A group of 106 children (138 feet) with valgus deformity of the foot was formed. Clinical studies included children with secondary neuromuscular flatfoot deformity against the background of cerebral palsy (CP). An author's technique of arthroereisis of the subtalar joint with an implant made of porous titanium nickelide was used for deformity correction.

Results. The author's surgical method using porous titanium nickelide showed 99% effectiveness. The positive aspects of this method included deformity correction, high strength, hypo allergenicity, and absence of implant migration in the future.

Conclusions. The conducted study demonstrated a pronounced positive dynamic after surgical treatment of children with valgus deformity of the foot using titanium nickelide implants. The advantages of this method include the possibility of complete deformity correction, absence of age restrictions, and faster recovery of foot functions.

Keywords: *titanium nickelide, biocomposite, flatfoot deformity, degenerative-dystrophic diseases.*

Резюме. Дегенеративно-дистрофические заболевания у детей занимают важное место в общей структуре ортопедических нарушений, и проблема их лечения остается актуальной. Несмотря на использование современных методов лечения, дети с деформациями стопы, такими как плоскостопие, составляют значительную часть пациентов в ортопедической практике.

Цель исследования. Улучшение результатов лечения детей с вальгусной деформацией стопы с использованием имплантата из пористого никелида титана.

Материалы и методы. Была сформирована группа из 106 детей (138 стоп) с вальгусной деформацией стопы. В клинические исследования были включены дети с вторичным нервно-мышечным плоскостопием на фоне детского церебрального паралича (ДЦП). Для коррекции деформации была использована авторская методика артроэрезиса подтаранного сустава с использованием имплантата из пористого никелида титана.

Результаты. Авторский хирургический метод с использованием пористого никелида титана показал эффективность 99%. К положительным моментам этого метода можно отнести коррекцию деформации, высокую прочность, гипоаллергенность и отсутствие миграции имплантата в будущем.

Выводы. Проведенное исследование продемонстрировало выраженную положительную динамику после хирургического лечения детей с вальгусной деформацией стопы с использованием имплантатов из никелида титана. К преимуществам данного метода можно отнести возможность полной коррекции деформации, отсутствие возрастных ограничений и более быстрое восстановление функций стопы.

Ключевые слова: *никелид титана, биокомпозит, плоскостопие, дегенеративно-дистрофические заболевания.*

For citation: *G.V. Slizovskiy, Y.V. Shikunova, M.A. Fyodorov, Y.V. Yevdokimova, S.S. Tukhvatullin.* THE MODERN APPROACH TO TREATING FLATFOOT DEFORMITY IN CHILDREN. INNOVATIVE SURGERY ON THE SILK ROAD. 2024. 1.

Для цитирования: Г.В. Слизовский, Ю.В. Шикунова, М.А. Федоров, Ю.В. Евдокимова, С.С. Тухватуллин. СОВРЕМЕННЫЙ ПОДХОД К ЛЕЧЕНИЮ ДЕФОРМАЦИИ ПЛОСКОСТОПИЯ У ДЕТЕЙ. INNOVATIVE SURGERY ON THE SILK ROAD. 2024. 1.

Introduction. There is a problem in treating flatfoot deformity in children with cerebral palsy (CP). The incidence of CP has significantly increased over the last decades, reaching over 15 cases per 10,000 population. Surgeons' opinions on the necessity of surgical intervention vary. Some believe that conservative treatment is ineffective, but if conservative therapy is considered as preparatory measures before the surgical stage of treatment, it is generally recognized in the literature that they are necessary to improve the results of surgical treatment. Preoperative conservative treatment should be comprehensive and comprehensive, including therapeutic exercises, massage, electromyostimulation, staged casting, redressing, and other orthopedic measures.

Indications for surgical treatment include: presence of deformity, pain syndrome, impaired foot function, difficulty wearing shoes, cosmetic defect, and failure of conservative therapy.

Surgical treatment of flatfoot deformity in children with CP has its peculiarities. A review of the literature revealed a large number of applied techniques. According to several authors, the most common techniques have a high percentage of unsatisfactory results, suggesting their low effectiveness. The reason for such results primarily lies in the complexity of maintaining the achieved correction in the postoperative period when the patient begins to load the limb.

Postoperative complications included avascular necrosis of the tarsal bone, growth plate injury, incorrect fixation period, suppuration, ischemic disorders, scarring, and foot growth restriction. Treatment of flatfoot deformity in children with CP requires a comprehensive approach to correcting neuro-degenerative damage to ligaments and joints. Currently, there are numerous surgical treatment methods aimed at eliminating various aspects of the pathology, which is explained by different views on the pathogenesis of deformities and anatomical features of the joints.

In the 1930s, P.N. Napalkov proposed a classification of methods for surgical correction of foot arches. He distinguished 4 groups:

1. Calcaneal osteotomy by elevating the posterior part.
2. Osteotomy of the leg bones above the ankle to correct flatfoot deformity.
3. Correction of the deformity of the forefoot by remodeling the contour of the inner part of the foot and abducting the anterior part
4. Correction of the inner edge of the foot by elevating its inner edge.

Based on the sources of modern literature, all surgical methods used in the treatment of flatfoot deformity in children can be conventionally divided into three groups: surgeries involving tendon-muscle components (muscle-ligament transpositions and fixations), bone-joint surgeries, and combined operations (osteotomies, arthrodeses, arthrolyses), as well as surgeries using external fixation devices (Ilizarov, Kostyuk, Hofmann, Vidal).

Materials and Methods. The clinical part of our study was conducted at the Department of Pediatric Surgery of the Siberian State Medical University of the Ministry of Health of Russia (Rector: Professor E.S. Kulikov, Head of the Department: Professor G.V. Slizovskiy) and at the City Clinical Hospital No. 2 in Tomsk (Chief Physician: A.V. Karavaev). It was a fragment of comprehensive research carried out on the problem of "Treatment of degenerative-dystrophic diseases of the musculoskeletal system in children" by the hospital staff and the Department of Pediatric Surgery of the Siberian State Medical University.

In our study, we analyzed the surgical correction of flatfoot deformity in 106 children (138 feet) hospitalized according to the referral from the outpatient clinic. The clinical research included children with secondary neuromuscular flatfoot deformity associated with cerebral palsy (CP).

To solve the tasks of this study, all patients were divided into the main group (treatment using porous titanium nickelide implants) and the comparison group (surgical treatment by the Grice method without the use of titanium nickelide materials).

In our research, we took into account the strategy of import substitution in Russian medical technologies, giving preference to domestic manufacturers that are not inferior to foreign analogs, as confirmed by Russian patent No. 2601658 dated 13.11.2016 "Method of Surgical Treatment of Flatfoot Deformity in Children Using Titanium Nickelide Implants" (authors: Slizovskiy G.V., Kuzhelivskiy I.I., Fedorov M.A.).

In addition to dividing patients into comparison groups, all children were divided into two main age categories: 8–10 and 11–14 years old. The reason for this division lies in the more conservative approach to the younger age group due to less pronounced rigid changes in the developing neuromuscular deformity of the feet and the possibility of compensation in the absence of irreversible degenerative-dystrophic processes, which significantly affect the weight-bearing capacity of the limb. On the other hand, disease progression in the older age group dictates a more radical approach, with surgical interventions involving tenotomies and/or relocations (Tab.1).

Table 1

Distribution of patients into clinical groups and comparative assessment of group homogeneity according to criteria of statistical significance

Orthopedic Pathology	Comparison group (treatment according to Grice from 2016 to 2023)					Main group (treatment by the author's method from 2016 to 2023)					p_{1-2}		
	gender		age, years		In total:	gender		age, years		In total:	gender	age, years	In total
	m	f	8-10	11-14		m	f	8-10	11-14				
Children with neuro-muscular foot deformity	26	29	37 (47)	18 (23)	55 (70 feet)	28	23	16 (28)	35 (40)	51 (68 feet)	0,555	0,001	0,680

Note: Statistical analysis of the data presented in the table indicates that there were significant differences between the main group and the comparison group based on the age criterion. The groups were homogeneous in terms of gender, but there were differences in age composition. When comparing clinical groups, it can be concluded that the comparison group is homogeneous in terms of gender, but there are significant differences in age.

From a clinical point of view, Table 1 shows that the study included 106 patients (100%) with acquired neuromuscular flatfoot deformity.

In the main group, there were 51 patients (48.1%) (68 feet) who received treatment from 2016 to 2023 (prospective study). In this group, there were 16 patients (15.1%) aged 8–10 years (9 girls and 7 boys) and 35 patients (33%) aged 11–14 years (18 girls and 17 boys).

In the comparison group, a retrospective study was conducted on patients who received treatment from 2016 to 2023 using the Grice method without the use of titanium nickelide materials. In this group, there were 55 patients (51.9%) (70 feet), with 18 children (17%) aged 8–10 years, including 12 girls and 6 boys, and 37 children (34.9%) aged 11–14 years, including 15 girls and 22 boys.

The distribution of patients with neuro-muscular flatfoot deformity in the main group and the comparison group according to age criteria is presented in Table 2.

Table 2

Distribution of patients in clinical groups by age criterion.

	8 years	9 years	10 years	11 years	12 years	13 years	14 years	In total
Main group	3	5	8	18	9	4	4	51
Comparison group	7	13	17	10	4	2	2	55

From the data provided in Table 2, it can be concluded that the majority of patients in the main group were aged 11 years (18 patients - 35.3%) and 10 and 12 years old (8 (15.7%) and 9 (17.6%) patients respectively). In the comparison group, the maximum number of patients was at the age of 10 (17 (30.9%) individuals), with 13 (23.6%) and 10 (18.2%) patients at the ages of 9 and 11 respectively. The age criteria in the present study do not differ significantly between the groups and generally align with the findings of other researchers [4, 10].

During the clinical work, criteria for inclusion and exclusion in the clinical study were established. Inclusion criteria: age from 8 to 14 years; children with acquired neuromuscular foot deformities due to cerebral palsy (CP) who were indicated for surgical treatment; integrity of the talocalcaneal and calcaneocuboid joints of the foot; no history of previous triple arthrodesis foot surgery; no history of previous surgery in the subtalar space.

Exclusion criteria: age younger than 8 years and older than 14 years; children with foot deformities without CP as the main condition, genetically associated degenerative diseases of the foot; mixed systemic dysplasias and other dysplastic diseases of the musculoskeletal system; children with foot deformities for whom conservative treatment was indicated; history of triple arthrodesis foot surgery; history of surgery in the subtalar space.

Upon admission for planned hospitalization, all patients underwent clinical, radiological, and functional (objective and subjective) examinations, as well as consultation with specialists in related fields (neurologist, pediatrician) in accordance with the standards for traumatology and orthopedic care, approved by orders "On Standards of Medical Care for Patients with Foot Deformities" (Ministry of Health of the Russian Federation dated August 11, 2005, No. 508, 510, and 516).

The clinical examination began with a detailed analysis of the medical history, describing the development of the pathology and its transition to a decompensated stage under the influence of etiological factors. Information about concomitant diseases helped determine the individual tactics of preoperative preparation and postoperative management. Attention was also paid to etiological factors that influenced the risk of recurrence of foot pathology and determined the rehabilitation strategy.

During the clinical examination, the type and degree of foot deformity were determined, as well as the presence of skin changes (calluses) due to pathologically altered limb support, or the presence of hyperemia in the area of the metatarsophalangeal joints and swelling due to loading synovitis and/or bursitis. The prolapse of the medial arch of the foot and the degree of valgus deviation of the calcaneus bone were assessed.

Functional tests were conducted through palpation and manipulation. The stiffness of the foot, the presence of subluxation, and pain during gentle manipulation were assessed. Additionally, points of maximum tenderness during examination of joint range of motion in the affected foot were determined. The following tests were conducted: Silverside test – degree of dorsal flexion of the foot (<90°, >90°, =90°); toe raise test (fixed or non-fixed valgus deviation of the calcaneus bone); degree of flexibility or rigidity of the foot; Jack's sign (drawer sign) – dorsal flexion of the first toe of the foot; Coleman's reverse test – neutral position or valgus deviation of the rearfoot when the heel is lifted 2 cm off the ground was considered a positive sign, while the absence of correction or reduction of varus compared to the initial level, not achieving complete elimination, was considered a negative sign.

Since weight-bearing capacity of the foot is an important socially significant aspect affecting the patient's quality of life and social integration, we proposed adapted scales for anatomical and functional treatment outcomes. In our opinion, the most informative scales are the Luboschitz-Matthes-Schwartzberg scale and the GMFCS scale.

Assessment of anatomical and functional treatment outcomes according to the Luboschitz-Matthes-Schwartzberg scale

Evaluation of anatomical and functional treatment outcomes was conducted using the adapted Luboschitz-Matthes-Schwartzberg scale before treatment and no earlier than 180 days after discharge from the hospital, during the course of rehabilitation treatment. Treatment outcomes were characterized by: absence of recurrence, dynamics of pain syndrome, restoration of limb weight-bearing function and range of motion in the joints, absence of neurological and vascular disorders, presence of complications after surgical treatment, vocational and social rehabilitation of patients, and the number of bed-days.

Treatment outcomes, taking into account anatomical and functional clinical data, were assessed using a scoring system and expressed as a percentage for good, satisfactory, and unsatisfactory results. A good outcome was considered with an index fluctuating within 3.5–4.0 points; satisfactory – 2.6–3.4 points; unsatisfactory – less than 2.5 points.

Evaluation of static-dynamic characteristics using the GMFCS scale

Evaluation of static-dynamic characteristics (body position in space and motor stereotypes) was conducted using the GMFCS (Gross Motor Function Classification System) scale. This scale provides the most comprehensive description of posture and movement pathology and is most in demand among orthopedic clinicians.

According to this classification scale, there are 5 levels of changes in the main static-dynamic characteristics and body stereotypes. The main principles for classifying patients into one of the GMFCS levels are presented below:

Level 1 - independent walking without limitations;
Level 2 - independent walking with limitations;
Level 3 - walking with assistive devices;
Level 4 - independent mobility in a wheelchair;
Level 5 - mobility only with assistance

We deemed it appropriate to divide the GMFCS levels into two clinical groups: 8–10 years old and 11–14 years old (Tab.3).

When assessing the static-dynamic characteristics of a patient using the GMFCS scale, the clinical (neurological) form of cerebral palsy (CP) is not taken into account. Therefore, the system described above allows tracking treatment dynamics regardless of the primary and concomitant conditions. The GMFCS scale reflects changes in static-dynamic characteristics in patients before treatment and after completing a course of rehabilitation and restorative therapy.

Table 3

Characteristics of GMFCS levels for two clinical groups of patients

Степень	8–10 years	11–14 years
1	The patient can: Sit; Squat; Stand; Walk.	The patient can: Walk. Run; Jump; Participate in sports activities
2	The patient can: Sit; Squat with support; Get up on all fours; Stand up with support	The patient can: Walk. Use assistive devices for support; Climb stairs
3	The patient can: Sit with support Lower themselves onto all fours with support; Crawl on their stomach	The patient can: Walk with assistive devices Use a wheelchair; Climb stairs with assistance
4	The patient can: Sit with support Roll over	The patient can: Permanently use a wheelchair Move with assistance
5	The patient can: Controls their head; Cannot maintain a position; Can roll over with assistance.	The patient can: Can only move in an adapted motorized wheelchair; Requires assistance from 2 people to move

Instrumental examination of the orthopedic status in patients with acquired neuromuscular deformities of the feet

After comprehensive clinical examination, patients underwent instrumental diagnostic methods according to the standard scheme for orthopedic patients. The examination scheme included:

- Photographing the posture and local status of the patient;
- Pedography;
- X-ray of the feet (lateral and anteroposterior projections);
- Computed tomography;
- Electromyography;
- Gait biomechanics analysis

Photographing of the patient's posture and local status with neuromuscular planovalgus foot deformity was performed using a digital camera from the front, back, and side (fig.1).

Pedography was performed in 47 patients (92.2%). This method of clinical examination is the most informative and decisive in establishing an accurate diagnosis and planning surgical treatment strategy.

Using this method, the main anatomo-podometric parameters were examined: foot shape, width in all sections (splaying and flattening), deviation of the first toe, angles of the main joints and bone elements of the foot, as well as the main support points of the planovalgus foot.

a ***b*** ***c***

Figure 1 - Photographs of the feet in frontal (a), rear (b), and lateral (c) views in a patient with neuromuscular planovalgus foot deformity

Radiographic examination was performed using the PHILIPS apparatus with image digitization by Villa Sistemi Medicali 2012 Buccinasco (MI) Italy, Apollo. The studies were conducted jointly with the head of the X-ray department of the City Clinical Hospital No. 2 of Tomsk, L.A. Mayer, and on the "DIAGNOST" apparatus (Philips) of the clinical base of the orthopedic department of the Sever Clinical Hospital (head of the department, M.A. Fedorov) of the FMBA of the Federal Research Center "Institute of Clinical and Experimental Lymphology" of the Siberian Branch of the Russian Academy of Sciences (director, Ph.D. V.A. Vorobyov).

Analysis of the radiographs was carried out according to the scheme of anatomo-functional relationships of the elements of the ankle joint. X-ray of the feet was performed in two projections for all patients in the main group – direct and lateral, with load (standing) and without load (sitting).

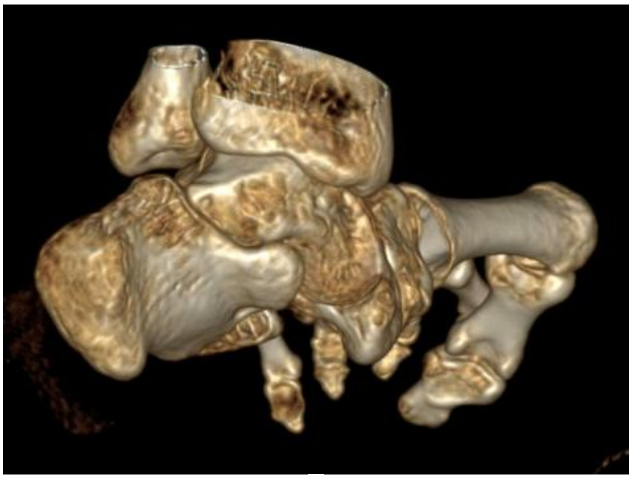
If necessary, in complex clinical cases with a significant degree of foot deformity, to clarify the anatomical relationships of the joint elements before and after surgical intervention, computed tomography (CT) was performed in 27.4% of cases using the Somatom Emotion Siemens apparatus, Germany, with spatial 3D remodeling in computer software.

a *b*

Figure 2 - X-ray of the feet in a patient with neuromuscular planovalgus deformity: a - in the lateral projection; b - in the frontal projection.

a

b



c

Figure 3 - Computer tomography of the feet with 3D modeling in anterior (a), lateral (b), and posterior (c) projections.

These images were used to determine quantitative and qualitative parameters of the foot condition, as well as approximate sizes of implants for insertion into the subtalar space during surgical intervention. Analysis of the X-ray images was conducted using commonly accepted radiological parameters, based on the main signs of functional X-ray diagnostics according to Sadoev V.I. (1986):

- Sagittal section examination of the ankle joint revealed calcaneal, equinus deviations and subluxations, tibiocalcaneal angle (TCA), talocalcaneal angle (TCA), longitudinal arch angle (LAA), Meary angle;
- Examination of the displacement of anatomical components of the ankle joint in width;
- Examination of the subtalar joint in the sagittal plane revealed depression (dropping) of the talus bone;
- Examination of the talonavicular joint in the sagittal plane revealed displacement and subluxation of the anatomical components of the joint;
- Examination of the talonavicular joint in the frontal plane also revealed displacement and subluxation of the anatomical components of the joint;
- Examination of the ankle joint in the horizontal plane revealed the tibiocalcaneal angle and talonavicular angle.

Electromyography was performed on 10 patients (19.6%). This method was used to assess the functional status of the foot: recording of bioelectrical potentials of the main leg muscles. The MG45 myograph produced by "Medicolor" (Russia) was used in the study. The frequency of oscillations, action potential amplitudes, and muscle status integral (product of frequency of oscillations by integral) were examined. Electromyography and description were carried out with the participation of the head of the functional diagnostics department of City Clinical Hospital No. 2, Marczul S.A.

Electromyography was used by us to assess the effectiveness of surgical correction and rehabilitation of patients with flatfoot deformity. The main criterion confirming the change in neurophysiological processes after rehabilitative treatment is the reciprocity coefficient (balance of work between antagonist muscles, restoration of efferent connections after rehabilitative kinesiotherapy). After rehabilitation of statodynamic skills in the patient, the aforementioned coefficient was calculated and compared with the indicators of the control group (patients of the planned surgery department who agreed to undergo a course of rehabilitative kinesiotherapy). The obtained data are presented in Table 4.

Based on the data presented in the provided table, it can be concluded that during rehabilitative kinesiotherapy in the main group, the reciprocity coefficient decreased from 326.3 to 43.2, demonstrating a tendency towards normal values (the norm of the coefficient is 27.5). It can be inferred that there is a restoration of the statodynamic stereotype of muscle activity in the main group.

Table 4

Comparative dynamics of the reciprocity coefficient in patients of the main group and the control group

Group	Coefficient of reciprocity			
	before treatment	10 days	20 days	30 days
Main group	326,3	195,5	91,3	43,2
Comparison group	128,5	107,1	66,3	28,5

The provided tabular data demonstrates the effectiveness of the proposed rehabilitation methods using restorative kinesiological treatment. Therapy efficacy is achieved through the restoration of afferent-efferent relationships, proprioceptive activity, and antagonistic muscle function. The statodynamic stereotype is restored, correcting the faulty posture and pathological weight bearing, and with the motivation of both parents and the patient towards rehabilitative treatment, the motor status of operated patients with neuromuscular planovalgus foot deformity due to cerebral palsy can be significantly improved.

Electromyography was conducted only on every fifth patient, as it is not part of the obligatory examination for orthopedic patients and is not a direct objective of this study; hence, it is provided in this chapter. Information obtained from examining 10 children with neuromuscular planovalgus foot deformity allows us to conclude that electromyographic study parameters showed considerable variation, yet the main indicators demonstrated a clinical variant of spastic cerebral palsy. Additionally, the study confirmed fundamental knowledge about central paretic disorders in patients with cerebral palsy and associated orthopedic changes, as well as the restoration of key indicators of neuromuscular activity and statodynamic status during kinesiological rehabilitation.

Implants for Surgical Correction of Planovalgus Foot Deformity

During the surgical treatment of children in the main group, implants of Russian production made of medium-porous titanium nickelide (grade TN10) with 81% porosity and an average pore size (permeability) of 420 μm were used. These physico-technical parameters are most similar to cancellous bone tissue, optimizing the process of osseointegration of the metal-bone biocomposite. Upon implantation, the implant is rigidly fixed due to the roughness of the material, and migration in the subtalar space is eliminated due to the geometric shape of the truncated cone. Implants made of porous titanium nickelide (conical, with heights/diameters ranging from 5/5.5 to 9/9.5 mm) were manufactured to individual order at the Scientific and Production Enterprise "MIC", Research Institute of Medical Materials and Implants with Shape Memory, Tomsk (Director: Dr. Eng., Professor V.E. Gunter).

The shape of the implant corresponds to the geometric figure of the truncated cone, as described in the method. Previously, conical implants were used by us and proved to be inconvenient due to the need for adjustment to the required size during the operation. To optimize this procedure, standard implants of five sizes were created (Fig.4).

In addition to standard sizes of implants made of porous titanium nickelide, custom implants of non-standard shapes and/or sizes were manufactured, if necessary, based on the degree of pathological changes in the foot (Figure 6).

Figure 4 - Porous composite implants made of titanium nickelide for surgical treatment of flatfoot deformity in children of standard shape and sizes.

Five sizes of truncated cone-shaped implants were used (Fig. 5).

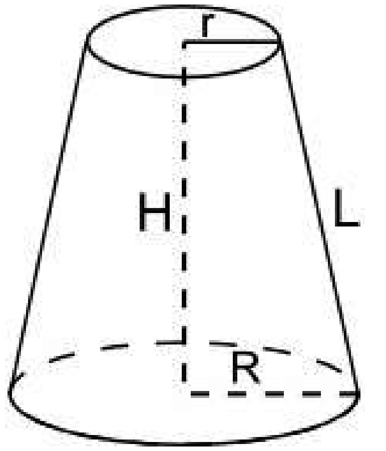


Figure 5 - Geometric parameters of the implant sizes in the form of a truncated cone:

R= 5mm, r= 4mm, H=8mm
R= 6mm, r= 5mm, H=10mm
R= 7mm, r= 6mm, H=12mm
R= 8mm, r= 7mm, H=14mm
R= 9mm, r= 8mm, H=16mm

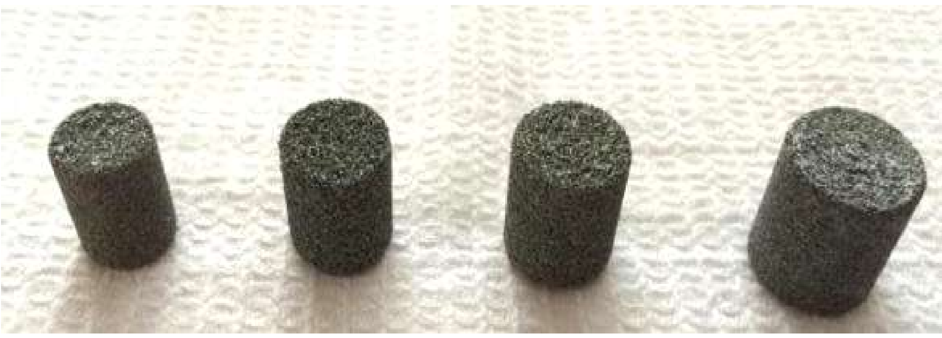


Figure 6 **- Porous composite implants made of nickel-titanium for surgical treatment of planovalgus foot deformity in children of non-standard shape and sizes**

Thus, in cooperation with the Scientific Production Enterprise "MIC", Research Institute of Medical Materials and Shape Memory Implants in Tomsk (Director D.Sc., Professor V.E. Gunter), implants made of porous nickel-titanium alloy of standard and non-standard shapes were created by us.

Author's method of surgical correction of planovalgus foot deformity in children using implants made of porous nickel-titanium

During surgical correction of planovalgus deformity, the most optimal and modern approach involves operations in the sinus tarsi. The essence of the surgical treatment lies in correcting the configuration of the talonavicular joint by implant placement, forming an anatomically correct arch of the foot in the precise position, and securely fixing it in hypercorrection or normocorrection using a "boot" plaster cast.

We proposed a method of surgical correction of planovalgus foot deformity in children using implants made of porous nickel-titanium alloy, which is illustrated by the following clinical example, supplemented by photographs of the main stages on a skeleton model.

Clinical example 1. Patient R., 13 years old, admitted to the clinic with a diagnosis of: congenital bilateral paralytic planovalgus deformity of both feet, grade 3 severity against the background of cerebral palsy. He underwent conservative treatment since the age of 6 months: massage, therapeutic corrective foot exercises, rhythmic galvanization of the leg muscles, staged foot repositions with application of plaster casts. He used orthopedic shoes for 3 years. There was no pronounced effect from conservative treatment, and the deformity progressed. Upon external examination, muscle atrophy of the legs was noted. The foot is splayed. Both arches are practically absent. The bones of the forefoot are sharply contoured on the inner and anterior aspects, with deviation of the anterior part outward. The prominence of the navicular bone is located low. The valgus of the calcaneus bone is 15°. Clinically, splaying of the left and right feet is determined, confirming the third degree of deformity (Fig. 7 a,b).

a ***b***

Figure 7 - Planovalgus deformity of the left (a) and right (b) foot of patient R. before treatment

Electromyograms of the muscles of the leg and foot reveal a sharp decrease in the bioelectrical activity of the tibialis anterior muscle group, predominantly the anterior tibial muscle, with reduced bioelectric potentials of the calf muscle, short and long extensor muscles of the toes, confirming the necessity of surgical correction.

Radiographic examination of the feet in the anteroposterior and lateral projections without load, performed upon admission of the patient to the clinic before surgical correction, is presented in Figure 8.

After comprehensive examination and preoperative preparation, the patient underwent an arthrodesis surgery of the subtalar joint using an implant made of porous nickel-titanium alloy.

To perform the method, cone-shaped porous composite implants made of nickel-titanium alloy, with a diameter of the working part ranging from 10 mm to 18 mm, developed based on the Research Institute of Medical Materials and Implants with Shape Memory in Tomsk, are used.

By order No. 1027 of the USSR Ministry of Health dated August 5, 1986, the use of constructions made of nickel-titanium alloy in clinical practice was approved.

In recent times, the gold standard for correcting flat-valgus deformity of the feet in children has been surgeries in the subtalar sinus. The essence of surgical treatment lies in correcting the configuration of the subtalar joint by implanting the implant, forming an anatomically correct arch of the foot in the exact position, and reliably fixing it in normal correction using a plaster cast of the "boot" type and orthoses.

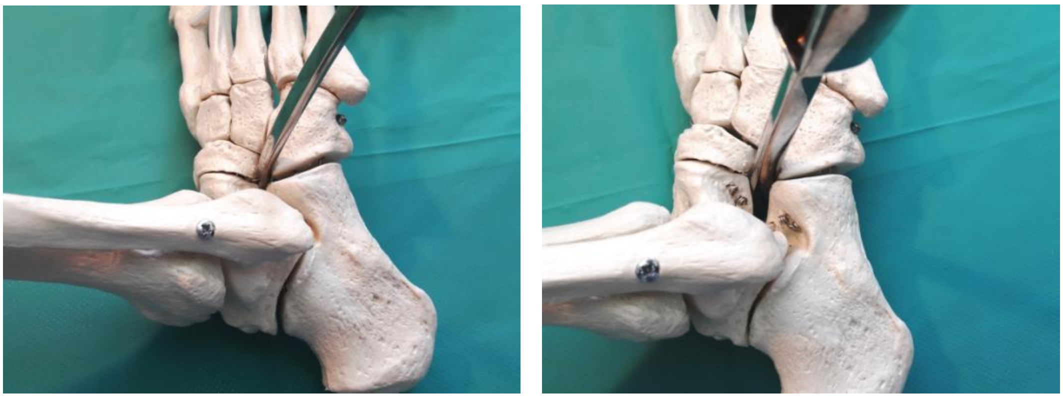
a *b*

Figure 8 - Radiographic examination of patient R's feet before operative treatment (a - direct projection, b - lateral projection)

Surgical correction is performed under spinal anesthesia in the operating room. The patient lies on their back. A pneumatic tourniquet is applied to the mid-thigh area. The operated lower limb is pre-treated by applying elastic bandage pressure and inflating the pneumatic tourniquet. The lower limb is treated three times with an antiseptic solution. A skin incision is made slightly anterior and distal to the outer ankle, up to 2 cm in length, in order to avoid damage to the cutaneous nerve, in an oblique direction (Fig.9).

Figure 9 - Skin incision in the projection of the subtalar sinus during operative correction of flat-valgus deformity of the foot by the author's method.

Next, a layered approach to the subtalar sinus is performed, and using a retractor, the collapse of the talus bone is eliminated (Fig.10).



a *b*

Figure 10 - Introduction of the retractor into the subtalar space (a) and elimination of talus bone collapse by rotating the retractor 90 degrees clockwise (b).

Next, scar tissue and ligaments filling the subtalar joint are removed using a Luer's forceps and an electric drill (Fig. 11).

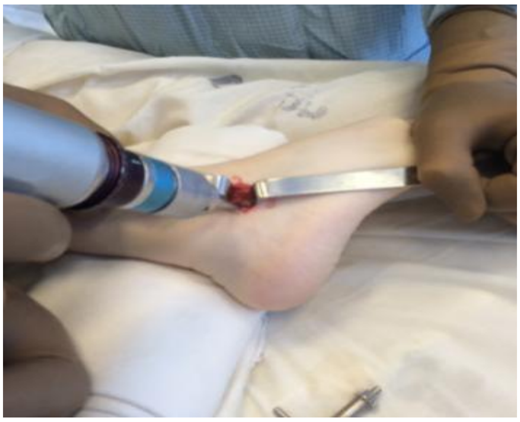


Figure 11 - Processing of the subtalar sinus with an electric drill before implant placement.

The articular surface of the talus bone and the middle and anterior facets of the calcaneus are cleaned of cartilage tissue using a Folkmann spoon. The cartilage tissue is completely removed until bleeding occurs, forming a bed for implant placement made of porous nickel-titanium alloy (Fig.12).

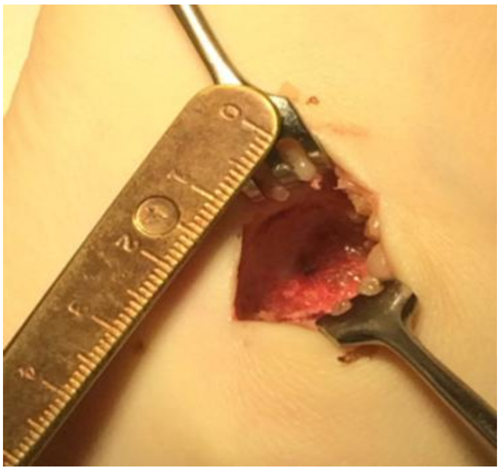


Figure 12 - Implant bed formed in the subtalar space

The foot is positioned in a normal corrected position. With the aid of a special instrument (probe), the appropriate size of the implant is selected and fitted into the prepared implant bed (Fig.13).

Figure 13 - Selection of the implant size in the formed bed of the subtalar space

Next, a trial of the probe is performed to choose the required size of the implant (Fig.14).

Figure 14 - Implant fitting using a probe

After selecting the optimal size implant with the maximum possible degree of foot deformity correction, a conical-shaped implant made of porous nickel-titanium is installed into the subtalar joint cavity with its base facing outward from the foot at an angle of 10-15 degrees to the frontal plane. Subsequently, it is additionally secured in the joint using a Kocher clamp with a mallet. Finally, the implant is firmly placed into the formed bed (Fig.15).

Figure 15 - Implanted porous nickel-titanium implant in the subtalar space bed.

Subsequently, provisional rocking and rotational movements of the foot are performed to ensure that the implant is firmly seated in the joint and there is no tendency for migration (Fig.16)

Figure 16 - Foot movements after the implantation of the porous nickel-titanium implant

The wound is closed layer by layer, tightly sutured with Vicryl, without leaving a drainage. Separate sutures with Vicryl are applied to the skin (Fig.17).

Figure 17 - Suture in the projection of the subtalar sinus after the installation of the porous nickel-titanium implant

An aseptic dressing is applied to the area of the postoperative suture. The pneumatic tourniquet is released. A splint is applied to the lower limb, followed by a circular plaster-polyurethane dressing, known as a "boot," which fixes the foot at a 90-degree angle from the upper third of the leg to the tips of the toes.

A similar operation was performed on the contralateral limb six months later.

Control X-rays were taken 3-5 days after the operation in the direct and lateral projections with the "boot" plaster cast (Fig.18, a and b).

The patient remains in the plaster-polyurethane dressing for 8-12 weeks post-operation. Control X-rays are taken at 6- and 8-weeks post-operation. The "boot" plaster cast is removed if a bone block has formed around the titanium-nickel implant, and if there are no pain or discomfort sensations in the subtalar sinus area of the foot. After removing the plaster cast, the patient is prescribed mandatory wear of orthopedic shoes with a fixed heel, a high stiff counter, and an insole with an elevated inner edge to unload the medial part of the foot. The patient should wear this footwear for 6 months post-operation.

a

b

Figure 18 - X-ray examination of the feet of patient R. after surgical treatment (a - lateral projection; b - direct projection)

Control X-rays of the feet in the direct and lateral projections are performed at 6- and 12-months post-operation to monitor the patient's progress.

After follow-up examination one year after the operation on the right foot and one and a half years after the operation on the left foot, it was found that foot function is satisfactory, gait is stable and free, and static-dynamic stereotypes are close to normal anatomical and physiological parameters. Podographic examination reveals restoration of gait components, increased bioelectrical activity of the tibialis anterior muscle group, long and short toe flexors, and a reduction in foot imprint diameter close to normal. The clinical result after treatment is presented in Figure 19.

a

b

Figure 19 - Appearance (a - left; b - right) of the feet of patient R. after surgical treatment and rehabilitation.

Upon examination using the Harris scale before and after treatment, the scores obtained were 61 and 90, respectively. The clinical outcome according to the Luboshits-Matis-Schwartzberg scale was 4.3 out of 5 possible points, indicating a good result. The GMFCS level improved from level III to level II within 1 to 2 years post-operation, with a dynamic coefficient indicating improvement. The patient is recommended for dynamic observation by a pediatric surgeon at the local clinic.

CONCLUSIONS

The proposed method of surgical correction of flat valgus deformity of the feet using porous nickel-titanium restores the anatomical relationship of the joint and prevents implant displacement by promoting bone tissue ingrowth into its pores, making its structure stronger and preventing its destruction or rejection. The implant does not require removal during the child's growth process as it complements the bone structure and maximizes contact with surrounding tissues, blocking pathological joint movements. This method also reduces the risk of vascular disturbances, which can lead to impaired bone tissue remodeling and recurrence of foot deformity.

Operative correction and comprehensive rehabilitation of patients with flat valgus foot deformity, including the author's method of sub-talar arthrodesis using porous permeable nickel-titanium of Russian production, wearing orthopedic footwear such as "bercs", massage, and physical therapy, allow restoration of the tone of the calf-foot joint muscles and foot arch, which positively affects the static-dynamic function of the lower limbs, thus increasing treatment effectiveness as evidenced by GMFCS outcomes: in 23.6% of cases, level 1 was achieved in the 8–10 age group and in 60.8% in the 11–14 age group. Level 2 according to GMFCS was achieved in 7.8% in both age groups. Surgical treatment outcomes in the main group according to the Luboshits-Matis-Schwartzberg scale depending on age indicate good outcomes in 29.4% of cases in the 8–10 age group and in 58.8% of cases in the 11–14 age group; satisfactory outcomes were observed in 1.9% of cases in the 8–11 age group and in 5.9% of cases in the 11–14 age group. Unsatisfactory results were encountered in only 3.9% of cases.

References:

1. Aliev, R.N. Taranno-ladevidny arthrodesis in the complex treatment of flat valgus foot deformity: [dissertation] / Rasul Nikolaevich Aliev. - Moscow, 2014. - 131 p.
2. Berezhnoy, S.Y. Subcutaneous operations in the treatment of static deformities of the anterior part of the foot: [doctoral dissertation] / Sergey Yurievich Berezhnoy. - Moscow, 2014. - 299 p.
3. Belousova, E.D. Dysport in the treatment of equinovarus foot deformity in cerebral palsy / E.D. Belousova // Neurological Journal. - 2001. - Vol. 6, No. 6. - P. 44.
4. Bolotov, A.V. Complex treatment of flat valgus foot deformity in children and adolescents taking into account the condition of the neuromuscular apparatus of the lower limbs: [dissertation] / Alexey Viktorovich Bolotov. - Moscow, 2014. - 145 p.
5. Bosykh, V.G. Dangers and mistakes in the treatment of equinus foot deformity in cerebral palsy / V.G. Bosykh [et al.] // Materials of the symposium of pediatric traumatologists and orthopedists of Russia. - St. Petersburg, 2003. - P. 314.
6. Vavilov, M.A. System of treatment of equinovarus foot deformities in children: [doctoral dissertation] / Maxim Alexandrovich Vavilov. - Yaroslavl, 2016. - 332 p.
7. Kenis, V.M. Orthopedic treatment of foot deformities in children with cerebral palsy: [doctoral dissertation] / Vladimir Markovich Kenis. - St. Petersburg, 2014. - 314 p.
8. Yezhov, M.Y. Arch index of the foot / M.Y. Yezhov // Modern technologies in traumatology and orthopedics: materials of the anniversary scientific conference. - St. Petersburg, 2010. - P. 413–414.
9. Kopyssova, V.A. Surgical treatment of static foot deformities using nickel-titanium implants (porous and shape memory) // Actual issues of implantology and osteosynthesis. - Novokuznetsk, 2003. - P. 41–45.
10. Kutuzov, A.P. The use of bone-plastic operations for the correction of foot deformities in children with cerebral palsy: clinical-radiological justification and analysis of results / A.P. Kutuzov, V.M. Kenis, V.I. Sadofyeva // Herald of Traumatology and Orthopedics named after N.N. Priorov. - 2001. - No. 4. - P. 54–57.
11. Tamoev, S.K. Analysis of complications after sub-talar arthrodesis in patients with flat valgus foot deformity / S.K. Tamoev, N.V. Zagorodniy, V.G. Protsko // Traumatology in Russia. - 2011. - No. 4 (62). - P. 37–43.
12. Arangio, G.A. Radiographic comparison of standing medial cuneiform arch height in adults with and without acquired flatfoot deformity / G.A. Arangio, T. Wasser, A. Rogman // Foot Ankle Int. - 2006. - Vol. 27(8). - P. 636–638.
13. Chen, J.P. Flatfoot prevalence and foot dimensions of 5- to 13-year-old children in Taiwan / J.P. Chen, M.J. Chung, M.J. Wang // Foot Ankle Int. - 2009. - Vol. 30. - P. 326–332.
14. Desmarchelier R. Scarf osteotomy versus metatarsophalangeal arthrodesis in forefoot first ray disorders: comparison of functional outcomes / R. Desmarchelier, J.-L. Besse, M. Fessy // Orthopaedics & Traumatology: Surgery Research. - 2012. - N 98. - P. 77–84.
15. Thomason, P. Single-event multilevel surgery in children with spastic diplegia: a pilot randomized controlled trial / P. Thomason [et al.] // J. Bone Joint Surg. American volume. - 2011. - Vol. 93, N 5. - P. 451-60.