Subtalar arthroereisis for treatment of children with flexible planovalgus foot deformity and analysis of CT data in long-term period

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ABSTRACT

The aim of the study is to analyze the long-term results of the subtalar arthroereisis of the feet according to Grice in children with flexible symptomatic planovalgus foot deformity.

Methods: 29 children (58 feet) were treated with symptomatic flexible planovalgus foot deformity.

Results: The average value of AOFAS increased from 63 (51–84) to 92 (53–96) points. According to CT size of the bone graft corresponded to 83% of the size of the subtalar sinus.

Conclusion: In compliance with all the technical features of this operation, it is effective for correction of flexible planovalgus foot deformity with pronounced verticalization of talus.

Level of evidence: IV.

1. Introduction

Flattening of the longitudinal arch of the foot of a child is a physiological stage of his development until the age of 3–4 years, due to presence of a fat cushion covering the longitudinal arch of the foot.^{1,2} Flat foot deformity is a frequent disorder and it can be idiopathic, congenital, and often caused by neurological, dystrophic, traumatic conditions^{3,4}; hereditary weakness of the ligamentous apparatus of the foot plays an important role.⁵ For example, congenital planovalgus foot makes up 23.7% in the structure of congenital diseases of the musculoskeletal system.⁶ Conservative treatment of this deformity of feet is not always effective. Wearing orthopaedic shoes does not change the natural history of foot development,⁷ and orthosis is not enough to stop progression of foot deformity.⁴ According to some colleagues, the operation should be performed before the structural changes of the foot bones occur and persistent contractures develop, as it is quite difficult to work with the child's foot when it is formed.^{4,8}

In 1952, Grice D.S. described the operation of subtalar extra-articular arthrodesis to stabilize the posterior part of the foot, which does not violate the active growth of the segment.⁹ Initially, this operation was proposed for paralytic valgus deformity of the foot caused by poliomyelitis. This surgery was recommended for young children who could not

yet undergo triple arthrodesis of the foot, disrupting the natural growth of the segment. Later indications for this technique expanded, and it began to be used in children with congenital vertical position of the talus, talus-heel coalitions, with hypercorrections of congenital equinus-varus deformity of the foot, idiopathic planovalgus deformity, with spina bifida, cerebral palsy, myelodysplasia.^{4,10–13} Chigot P. L. and Sananes P.¹⁴ were the first to suggest using a fibula graft for this operation.

Today there are many variants of the surgery of extra-articular subtalar arthrodesis (arthroereisis) and many of grafts for its implementation, including allo-material and metal.^{4,8,13,15–17} Until present time, the age of the beginning of this operation remains debatable; and also possible complications of the technique with the use of a graft from the own bone restrain its application.

The aim of this work is to analyze the long-term results of application of extra-articular subtalar arthrodesis (arthroereisis) of feet in 5–9 year-old children with flexible symptomatic planovalgus deformity with the use of fibula autograft and its fixation by a Kirschner wire.

2. Methods

From March 2013 until February 2016 52 children were treated

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using the technique of subtalar arthroereisis. However, this case series excludes those that were lost to follow-up prior to 3 years post-surgery. The group included 29 children (58 feet) at the age 5–9 years with flexible symptomatic planovalgus foot deformity. Mean age of children was 6.3 years. There were 20 boys and 9 girls. In this cohort etiology of planovalgus deformity was idiopathic in 9 children, secondary to multiple developmental defects – 1, neurogenic secondary to cerebral palsy of light degree (GMFCS I-II) – 19 children. All patients could walk without personal assistance and without assistive devices. Range of motions in the hips and the knees in all patients was full, contracture of tibial triceps was present in 14 patients. All patients underwent bilateral subtalar arthroereisis using fibula graft with its fixation by a Kirschner wire. 14 patients underwent this orthopaedic surgery in combination with tenodesis of the posterior tibial muscle; 14 patients underwent simultaneous aponeurotomy of the gastrocnemius muscles; 6 – z-shape Achilles tendon tenotomy. The children underwent clinical and radiographic examination (lateral talus-calcaneus, angle Meary, position of the calcaneus, straight talus-calcaneus divergence and talus-1 metatarsal angles) according to modern reference lines and angles.¹⁸ Pre-operative radiographic parameters of feet are in Table 1. It is important to mention that in the AP view of the mid-foot the calcaneus-cuboid angle in all children before and after treatment did not exceed 5°, so this angle was not analyzed deliberately. Functional condition of the feet was evaluated according to scale American Orthopaedic Foot and Ankle Society (AOFAS).¹⁹

Thirteen patients underwent CT of the feet with 3D-reconstruction. Foot examinations were done using computer tomography scanners GE Light Speed VCT (GE Medical Systems, Wisconsin, USA), Toshiba Aquilion-64 (Toshiba Medical Systems corporation, Toshihigi 324–8550, Japan) minimum in 1 year after treatment. The study started from making images of the examined segment in AP view. Technical conditions for spiral scanning: software – LowerExtremity. Technical characteristics: section thickness – 3.0 mm; pitch = 3.0 mm; postprocessor processing with section thickness 0.5 mm, and reconstruction increment 0.3 mm, algorithm – Bonestandard, Highresolution. Processing of axial section was performed in the mode of multiplanar reconstruction in axial, frontal and sagittal planes. Roentgen-morphology was studied and quantitative assessment of density indices of bone autografts was done in Hounsfield units (HU). At the third stage analysis of topographo-anatomic changes was performed in the mode of 3D-reconstructions with application of bone and soft-tissue filters of working stations.

The studies were conducted according to ethical standards described in Declaration of Helsinki of the World Medical Association “Ethical Principles for Medical Research Involving Human Subjects” with amendments of 2013. All participants included into the study gave their informed consent and the study of human subjects was conducted in accordance with rules of clinical practice in Russian Federation (Order of Minzdrav RF No266).

Statistic processing was performed using software Microsoft Office Excel (2010) with add-in AtteStat and SPSS 18.0. To evaluate statistical

significance of the means pair tests were used Student and Mann-Whitney.

2.1. Surgical technique of subtalar arthroereisis

Under tourniquet in the femur 3–4 cm longitudinal skin incision was done in the lower third of the tibia, sub-periosteal using oscillating saw 3–3.5 cm of the fibula bone was harvested. When doing this surgery we harvested the fibula graft from one leg for both feet. The periosteum and the wound was stitched using intradermic suture.

Anterior lateral approach was done above sinus tarsi in oblique direction from the edge of extensor tendons of the toes (from the talus neck) to the level 1–1.5 cm lower and anterior to the apex of lateral malleolus (calcaneal edge of sinus tarsi). As dissecting laterally and downward were moved the tendons of peroneal muscles and n.cutaneus dorsalis lateralis. Partial cleaning of sinus tarsi was done; surfaces of talus and calcaneus not covered with articular cartilage were visualized and exposed using raspator. Then the fibula autograft was placed in sinus tarsi in foot correction position: the foot was moved in supination and adduction manually and using elevator; the graft was oriented in direction from lower surface of talus neck to the bottom of sinus tarsi, with preliminary moving the periosteum and fixing it with a Kirschner wire. The Kirschner wire was inserted from the bottom to the top, from the lateral edge of the calcaneus, moving tendons of peroneal muscles upwards. The wire was inserted through the calcaneus (lateral edge), medullary canal of the graft, talus neck. After radiographic control (image intensifier) of the wire length, position of the auto-graft, sufficient correction of foot deformity the wire was bent and cut. Its end was put inside the soft tissues, having turned the cut and bent end of the wire 2–3 mm in length medially. Then the wound was closed in layers using intradermic suture.

Testing position of the hindfoot, position of the forefoot was done. If in simulation of weightbearing there was a tendency for abduction foot position, then in addition through the medial approach at the site of talus-navicular joint the posterior tibia muscle was shortened by stitching it with overlapping. The distal fragment of the fibula on the side of bone graft harvesting was fixed with and internal Kirschner wire randomly in 5 patients, in the other children this fixation was not performed. Fragments of Kirschner wires were removed from the feet on average after 7 months (from 5 to 24 months) after surgery.

After correction of foot position it was mandatory to check range of motions in the ankle; if it was limited then Achilles tendon plasty was done (Z-shape lengthening in children without spastic syndrome) and aponeurotomy of gastrocnemius muscles by Strayer, Vulpius (in children with cerebral palsy). For fixation plaster cast immobilization was applied.

The initial semi-circular plaster cast was replaced by a circular plaster cast in 2–3 days after the surgery. Walking in a plaster cast with partial weightbearing on the foot was allowed in 2–3 weeks after the surgery. The total period of plaster cast immobilization was 1.5 months, then the patients used orthosis when resting (removable joint immobilizer for the entire limb), and for walking – ankle-foot orthosis (AFO) or orthopaedic shoes.

2.2. Clinical cases

Patient A., 5 years old was admitted to the RISC “RTO” with complaints of foot deformity and periodic pain the feet after long walks (Fig. 1). The patient was followed by an orthopaedic surgeon from the age of 3; during the last 2 years the foot deformity increased. The patient underwent subtalar arthroereisis of the both feet by Grice (Fig. 2). Kirschner wires were removed from the feet at the place of residence in 6 months. In 3 years after our surgical treatment the treatment result remained (Fig. 3), the child and his parents are pleased with the result. Radiographically in 3 years after the surgery there was significant resorption of bone autograft in the sinus of the subtalar joint. Dynamics

Table 1

Radiographic changes (in degrees) before surgery and at final evaluation (M ± m), n = 58.

Radiographic angle	Before surgery	Follow-up	Norm ²⁰
Lateral angle Meary (Shade) talus – 1 metatarsal	32.8 ± 6.3	4.1 ± 1.4*	13
Lateral angle of inclination of calcaneus	8.5 ± 2.3	12.3 ± 2.6*	17
Lateral talus-calcaneus	63.1 ± 3.3	45.7 ± 3.6*	49
Straight talus-calcaneus divergence	28.6 ± 5	20.4 ± 4.3*	20–25
Straight talus-1 metatarsal	26.1 ± 5.2	9.8 ± 3.4*	10

Note * - significance of difference from the preoperative value, p < 0.05.

Fig. 1. Photo (a) and X-rays (AP and lateral views) (b) of tibias and feet of a 5-year-old patient with planovalgus foot deformity.

Fig. 2. X-rays of feet of a 5-year-old patient in operation room.

of indices by AOFAS scale changed from 72 to 94 points.

Patient B., 5 years old, was admitted to the hospital with complaints of planovalgus foot deformity (Fig. 4) and its progression during the child's growth (the child had cerebral palsy of light degree – GMFCS I).

The patient had subtalar arthroereisis of the both feet by Grice in combination with aponeurotomy of gastrocnemius muscles of the tibias and fixation of the lower limbs with casts. In 4 years after surgical intervention the treatment result remained despite resorption of the autograft in the sinus of the subtalar joint of the feet, which is seen of the X-rays and CT (Fig. 5). Functional condition of the feet according to AOFAS scale changed from 55 points before the surgery to 79 points at long-term follow-up.

3. Results

Treatment results were followed for not less than 3 years after surgery (on average, 42 months (from 36 to 53 months)). Treatment results were evaluated by AOFAS ankle and hind foot scale as excellent in 4 (13.8%), good in 21 children (72.4%), satisfactory in 3 (10.3%), poor in 1 (3.4%). Average value by AOFAS increased from 63 (51–84) to 92 (53–96) points. Motions in the ankle joint increased from the initial preoperative level on average by 4.2°. Three children with cerebral palsy after treatment observed spontaneous moderate pain in the feet after long walk, although in general they were satisfied with the treatment.

Radiographic changes in the feet at long-term follow-up were evaluated according to referential data by Davids J.R.²⁰ and were within normal range, which adequately corresponds to clinical data and satisfaction of patients and their parents in the majority of cases (Table 1).

We observed valgus change of joint space of the ankle not more than 5° (14 patients without change of joint space of the ankle – stage 0 by Malhotra D.,²¹ and in 15 children the valgus deformity of the ankle was not more than 5° - stage 1 by Malhotra D.), which did not change at the long-term follow-up.

Complications (Fig. 6) were observed in 2 patients (1 foot in each), which constituted 6.9% of the total number of patients and 3.4% of the total number of operated feet. In 1 case a 9-year old patient, who did not have a follow-up exam for an extended period of time due to family circumstances, and so missed the planned stage of wire removal from the feet, noticed pain in the left foot during movement and weight-bearing at 2 years after our treatment (Fig. 6). The child was admitted to the department for removal of all wire fragments from the feet. The examination showed that the result of our treatment was maintained; he did not need additional reconstructive intervention.

In the second case an 8-year old child with cerebral palsy (GMFCS II) lost the result due to migration of the wire and the corresponding bone graft in the subtalar joint because of disregard of post-operative protocol

Fig. 3. Photo (a) and X-rays (b) of the patient's feet in 3 years after treatment.

Fig. 4. Photo (a) and X-rays (b) of tibias and feet of patient B., 5 y.o. With neurogenic (CP) planovalgus foot deformity.

(the patient started postoperative weight-bearing too early). This complication was observed in 3 months after the surgery during follow-up examination. This patient was admitted to the department to remove the fragments of the wire. 2.5 years later this patient underwent subtalar arthrodesis of the foot.

According to data of CT of the feet the average density of the cortex of the fibula autograft in patients in 1 year after surgical treatment was $1004,28 \pm 136,87$ HU. Length of the implant equaled $1,31 \pm 0,25$ cm, which corresponded to 83% of the size of sinus tarsi. In all the cases interrelations in the joints of the foot were maintained, articular surfaces

Fig. 5. Photo (a), X-rays (b) and CT (c) of feet of patient B. in 4 years after treatment.

were well-defined, even. Weak consolidation in the proximal parts of the implant was observed in 4 feet, weak in the distal parts – in 8 feet, weak both in proximal and distal parts – in 2 feet, good consolidation was observed in 4 feet, absence of consolidation was observed in 6 feet, full bone block – in 2 feet.

In one patient according to CT data in 4 years after surgical treatment the implants dissolved on two sides; in another patient – in 22 months dissolving of the implant on one side was observed.

4. Discussion

Subtalar arthroereisis is a wide-spread surgical method for correction of flexible flat-foot, planovalgus foot deformity in pediatric

population.¹⁵ Nowadays, there are many variations of subtalar arthroereisis and options of transplants for it, including allografts and metal constructions.^{4,8,13,15–17} Arthroereisis according to Grice is an extra-articular intervention and it does not affect bone growth, so it can be applied even in small children.^{4,9,22} Bourelle S.⁴ wrote about good long-term results (from 17 to 22 years) of subtalar arthroereisis according to Grice in 23 children with planovalgus foot deformity in cerebral palsy.

Until present time there is a question about optimal time of application of subtalar arthroereisis of the foot. Some authors believe that the age from 2 to 9 years is optimal for this intervention.²³ Most of authors recommend the surgery of subtalar arthroereisis after reaching the age of 4^{4,12–5} 13,16,24–27 6-year.^{8,22} Volpon J.B. believes that foot print in the

Fig. 6. Complications during out-patient follow-up period: fracture and migration of K-wire in one foot of patient T. with pain, but without losing the result of treatment.

majority of cases corresponds to adult foot at the age of 6.²⁸ Late degenerative changes of adjacent joint of the operated foot this correction were less evident, compared to deformed but not operated foot.^{8,29} In case of failure of arthroereisis later at an older age a stabilizing surgery can be an option (triple arthrodesis) for correction of foot deformity.^{8,30}

Positive results of subtalar arthroereisis of feet by Grice in children with planovalgus foot deformity were described in works of many authors.^{4,8,11,22,27,31} So, by data of Høiness PR²² 83% of treated patients with planovalgus foot deformity secondary to surgical treatment of spinal herniation were satisfied with the conducted treatment and were willing to recommend this intervention. Bourelle S.⁴ described that positive results of subtalar arthroereisis by Grice for planovalgus foot deformity in children with cerebral palsy at long-term follow-up more than 20 years were obtained in most of the cases.

According to literature data lengthening of the posterior muscles of the tibia was done in 30–100% of cases after arthroereisis of the foot.⁴ Simultaneously with subtalar arthroereisis we performed aponeurotomy of gastrocnemius muscles and Achilles tendon tenotomy in 20 patients, which constituted 68.9% of the total number of children.

The most frequently described drawbacks of subtalar arthroereisis are pain, destruction, displacement of the graft, overcorrection and fusion of the joint in varus position, fibula non-union if the graft was harvested from that site or even necrosis of talus.^{11,32–37} Complications described in the literature could be minimized, in our opinion, by precisely following all technical details of the surgery, post-operative protocol and regular follow-up examinations of the treated children. In our study during the average follow-up period of 3.5 years we observed good result in the majority of patients and only 1 child required second surgery in one foot. Three children with planovalgus foot deformity secondary to cerebral palsy after treatment observed spontaneous moderate pain the feet after a long walk, although in general they were satisfied with the treatment.

In our opinion, for this surgery it is very important to perform long-term evaluation of the bone autograft condition. Incidence of autograft resorption in foot arthroereisis according to literature varies from 6 to 33%.^{31,32,38} However, for instance, Lancaster S.J. did not observe graft resorption at all.¹¹ According to Bourelle S. with the average follow-up period of 20 years in 7 out of 26 feet resorption of the fibula graft was observed, however this did not affect the result of treatment.⁴ Absence of union between the bone graft and calcaneus and (or) talus does not necessarily lead to recurrence of deformity, because besides consolidation there is also fibrosis between the involved structures to maintain the hindfoot position.^{4,9,22,31,38} This is confirmed by our CT data: in 1 year the size of the autograft was 83% of the subtalar sinus with maintaining interrelations in the foot joints, and in one patient after 4 years according to CT there was complete dissolving of this bone fragment, however, the achieved clinical result was maintained in the majority of

cases.

It is important to mention condition of adjacent joints after this surgery. In our study with the average follow-up period of 3.5 years condition of adjacent joints remained on the initial level. According to Bourelle S. et al.⁴ in the long-term follow-up (on average 20 years) after subtalar arthroereisis of the feet by Grice degenerative changes of the joints were not observed, and there was no difference in the size of shoes in case of unilateral intervention.

In 23–50% of cases valgus deformity of ankle joint space is considered the reason of poor treatment results.^{4,8,21,27} In our series of patients this deformity was not more than 5° both before treatment and at long-term follow-up.

It should be mentioned that application of special implants and screws is currently very wide-spread for long correction of foot position. However, in this group of patients we used only fibula autograft in combination with a Kirschner wire, which was removed later. Hosny G. A. observed a case of talus avascular necrosis after application of a screw for subtalar extra-articular arthroereisis.³³ Sanchez A.A. described a subsequent revision surgery after subtalar arthroereisis with application of brackets in 16 out of 34 patients.³⁶

Hsu LCS described cases of fibula pseudoarthrosis after harvesting the graft in the distal part of the bone in 71% of the total number of patients.³⁹ In 1 out of 26 cases other colleagues observed fibula pseudoarthrosis at the site of graft harvesting with average follow up of 20 years.⁴ Wiltse L.L.³⁰ and De Leon-Falewski G.⁴⁰ reported that graft harvesting in the distal fibula can stimulate its growth and prevent valgus deformity of the ankle joint.

The question about possibility of weightbearing is also important. Bourelle S. Describes weightbearing on the foot in a cast in 4–8 weeks after surgery using fibula graft and its fixation with the wire with total duration of plaster cast immobilization varying from 6 to 12 weeks.⁴ Høiness P.R. recommends weightbearing on the foot after subtalar arthroereisis using cortical grafts without hardware in 2 months with the total plaster cast immobilization of 3 months.²² De Pellegrin M. Described possibility of gradual weightbearing on the 5 day after arthroereisis of the foot with a screw, full weight bearing on the 11 day, and sports weightbearing in 1 month without any additional fixation.¹³ Other authors describe experience of weightbearing on the foot in case of arthroereisis of the subtalar joint with a screw in 1 month.¹⁶ We started gradual weightbearing on the foot in 3 weeks, full weightbearing was done in 1.5 months after the surgery.

Some authors reported good treatment results due to performing lengthening of the lateral column, midfoot osteotomy,^{41–44} however in children of early age we consider subtalar arthroereisis to be appropriate as the method with the lowest risk of disorders of foot bones growth.

Conclusion. Correction of flexible planovalgus foot deformity with severe verticalization of talus using technique of subtalar arthroereisis by Grice in children 5–9 years, whose foot is in process of active growth and formation is an effective method of treatment. Following post-operative protocol and out-patient control of orthopaedic status of the patient allow us to minimize possible complications. We did not observe principal differences in the treatment process of these foot deformities in the chosen etiological groups of children who walked themselves. In long-term follow-up according to CT data there was no negative influence of this surgical intervention on articular surfaces and development of subtalar joint.

Declaration of competing interest

The Author(s) declare(s) that there is no conflict of interest.

All patients gave informed consent for possibility of publication of treatment process data.

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