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Correction of Foot Deformities Using Triple Arthrodesis and Its Effect on Soft Tissue Blood Supply at Surgical Site in Patients with Cerebral Palsy

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Abstract

The aim of the study is to evaluate the efficiency of triple arthrodesis of foot and its effect on soft tissues blood supply at the surgical site during simultaneous correction of segment deformity in patients with cerebral palsy. ***Materials and Methods.*** The present study reflects the authors' experience of triple arthrodesis for correction and stabilization of foot multicomponent deformities of varying severity in 75 patients (136 feet) with cerebral palsy (II-IV level by Gross Motor Function Classification System (GMFCS)) treated in the Ilizarov center in the period from April 2012 to December 2016. The average age of the patients was 16.4±4.3 years (from 11 years 8 months to 43 years 3 months). All patients included into the study had severe arthrosis of hind and midfoot. The main option of foot fixation in this group of patients was internal fixation (elastic threaded wires, compression screws) together with plaster cast immobilization for 6–8 weeks. All patients underwent average of 4.59 surgical elements during a procedure as part of simultaneous multilevel interventions. The blood supply at the surgical site was evaluated by laser and high-frequency Doppler flowmetry before and after all stages of the surgery. ***Results.*** Long-term outcomes were evaluated at the average of 19 months after the surgery in 56 (74.7%) patients. 37 patients (66.1%) demonstrated good treatment outcomes and 19 patients (33.9%) — satisfactory outcomes. No unsatisfactory outcomes were observed. The clinical outcome of foot surgery was evaluated using the Angus-Cowell criteria. The obtained significant x-ray enhancement was maintained at the control stages of the follow up. Despite large simultaneous correction of foot deformity, there was no decrease in the parameters of microcirculatory blood supply of the skin, muscles and subcutaneous fat of the foot. The authors observed a stabilized or an increased perfusion of soft tissues. ***Conclusion.*** Triple arthrodesis for correction of foot deformities in patients with cerebral palsy and severe arthrosis in hind and midfoot is an efficient method which allows to correct and stabilize gained position of segments. The data of physiological research testify the sparing approach of such procedure and a possibility of an earlier weight-bearing on operated limb.

Keywords: foot deformity, triple arthrodesis, internal fixation, cerebral palsy, soft tissue blood supply.

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Introduction

Foot deformities are the most common orthopaedic pathology in patients with neurological diseases. In preschool children with cerebral palsy (CP), the equinus component of deformity prevails [1]. However, in older children, adolescents and adults with this disease, flat-valgus foot deformity is more common, which is one of the main causes of instability in verticalization [2-7].

Deformities of feet in adolescents and adults manifest by pain, changes in soft tissues (hyperkeratosis) at the pressure site of bone elements (for example. the head of the talus) and are one of the reasons for loss of active independent movement. Patients often experience difficulties in the selection of shoes, orthosis. Flat-valgus foot deformity is an important element in the formation and preservation of pathological crouch gait [8].

Older children and adults with deformities of the feet are recommended to undergo corrective osteotomies of the foot bones, arthroeresis, stabilizing operations [2-4, 9-13]. However, reconstructive intervention on the foot using osteotomy in severe bone deformities and changes in articular cartilage (osteoarthritis 2-3 degree) is doubtful. Irrational interventions and osteosynthesis on the foot without taking into account the age characteristics of the segment skeleton, neurological disease of the patient often do not give the desired result; there are cases of relapse of deformity, non-union of the bones, pain [10, 13-17]. Positive reports on the use of triple arthrodesis for correction of foot deformity and stabilization of the result are described in many works [3, 6, 9, 10, 18].

Undoubtedly, with acute correction of complex deformities of the foot, it is important to control the soft tissue trophic in the postoperative wound and the segment. Methods of laser and high-frequency Doppler flowmetry make it possible to determine early signs of circulatory disorders in various types of anesthesia [19], to study and control changes in tissue microcirculation during combined reconstructive plastic surgeries [20].

The aim of the study was to assess the clinical and radiological results of the use of triple arthrodesis of the foot and to determine its effect on the blood supply of soft tissues in the surgical site with simultaneous correction of segment deformity in patients with cerebral palsy.

Materials and methods

From January 2012 to December 2016, 75 patients (136 feet) with foot deformities were treated in our clinic using triple arthrodesis, in the framework of acute multilevel orthopaedic interventions. Patients belonged to II-IV functional level according to Gross Motor Function Classification System (GMFCS) [21]. The average age of patients was 16.4±4.3 years (from 11 years 8 months to 43 years 3 months.). There were 61 children in the study and 14 adults; there were 46 male patients and 29 — female patients. All patients had severe degenerative changes in the middle and posterior parts of the feet. Patients with spastic diplegia prevailed — 61 (81.3%), there were 14 (18.7%) patients with spastic hemiplegia. Foot deformities with valgus deviation 119 (87.5 %) prevailed. The structure of foot deformities in patients before treatment is presented in table 1.

Patients underwent radiography of the feet in lateral and AP views with loading.

Table 1

Structure of foot deformities before treatment

Type of deformity	Quantity
Equino-cavo-varus	14 (10.3%)
Cavo-varus	3 (2.2%)
Plano-valgus	62 (45.6%)
Equino-plano-valgus	43 (31.6%)
Calcaneal valgus	14 (10.3%)

In addition to clinical and radiological methods of study, quantitative assessment of some parameters of walking using the Edinburgh Gait Score was made [22]. The classification of gait types in patients capable of independent vertical movement was carried out using the scale of J. Rodda et al [8]. The level of motor activity was assessed by GMFCS and FMS (Functional Mobility Scale).

All patients underwent simultaneous multilevel interventions on the operated limb in combination with corrective and stabilizing foot surgery in the amount of triple arthrodesis. Multilevel orthopaedic interventions were performed in accordance with the algorithm adopted in our clinic [23. 24]. In this series, an average of 4.6 surgical elements were performed per operation. Variants of interventions on the tendon-muscular apparatus of the tibia and foot with triple arthrodesis are presented in table 2.

Triple arthrodesis was performed through classical lateral approach in the posterior foot [25]. However, in our work, soft tissue dissection was performed in a special way to reduce its tension during the subsequent suturing of the wound after acute correction of severe foot deformity (Fig. 1):

1) the skin incision was not straight, but arched;

2) *retinaculum mm. extensorum inferius* is mobilized from a short extensor of the toes and dissected not H-shaped, but U-shaped with the base facing posteriorly (a non-free displaced flap with a wide base is formed);

3) *m. extensor digitorum brevis* is also U-shaped mobilized and separated from the surface of the calcaneus, with the base of this muscle flap being distal. Both of these flaps are easily approximated and connected edge-to-edge with no tension, filling the space of the surgical wound.

After cutting the articular cartilage, subchondral bone elements were shaped taking into account the deformity of the foot (Fig. 2).

Table 2

Surgeries on the tendon-muscular apparatus of the tibia and foot with triple arthrodesis

Procedure	Number of feet
Aponeurotomy of gastrocnemius muscles. Achilles tendon plasty, plantotomy	48
Release, lengthening of peroneal tendons	22
Release of posterior tibial muscle, capsulotomy of talus-navicular joint	10
Lengthening of tendons of flexors or extensors of toes	42
Transfer of the short peroneal muscle to the calcaneus	14

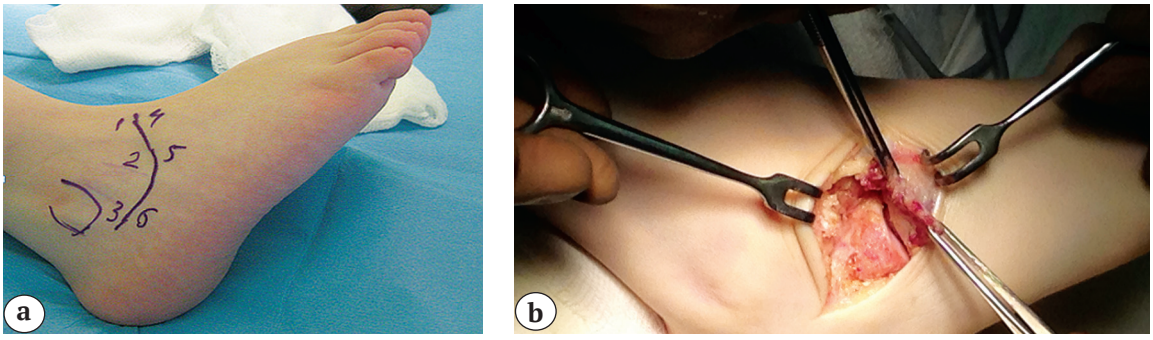

Fig. 1. Approach and dissection of soft tissues during triple arthrodesis in patients with CP: a — incision, marking of the measurement area; b — wound during dissection

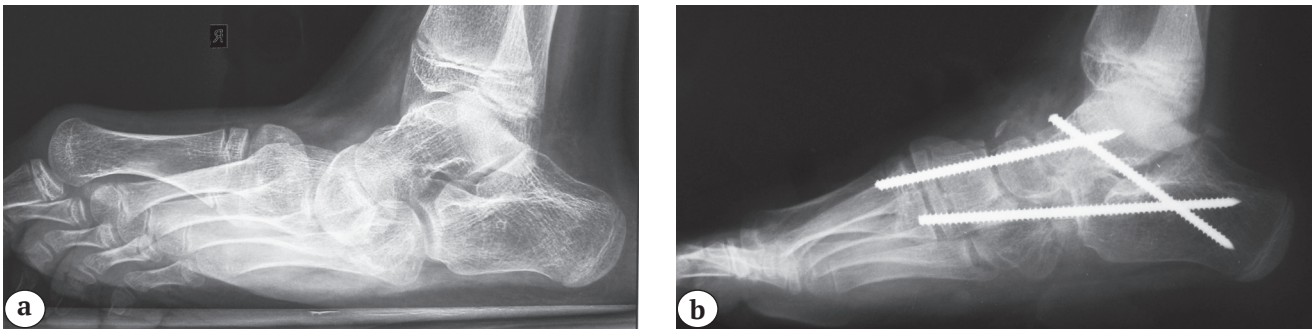

Fig. 2. X-ray images of patient 13 y.o.:
a — before treatment (complex foot deformity with talus verticalization);
b — thrifty resection of bones and creation of contact between bone fragments

The main option for fixation of the foot bones in question was internal fixation: elastic threaded wires with a diameter of 3.0 and 4.0 mm, compression screws 4.0 and 6.5 mm in diameter, the material of osteosynthesis was titanium. Threaded wires, fixing the middle part of the foot, were placed through open approaches in the first and fourth interdigital spaces.

To assess the possible negative impact of these manipulations on the soft tissues of the foot, a study of blood supply of the soft tissues at the surgical site using laser and high-frequency Doppler flowmetry was performed before and after all stages of the surgery.

In the operating room, microcirculation of foot tissues was studied: skin, subcutaneous tissue, muscle tissue in 21 patients with CP with foot deformity at the age of 13 to 23 years (15.4±1.0 years). Capillary skin blood flow (ml/min 100 g of tissue) was assessed by laser Doppler flowmetry (BLF-21, transonic Systems, USA) using a skin sensor. Blood flow registration (three measurements at each point) was performed before the operation, after marking the measurement areas (1-6 points) (see Fig. 1a) and after all stages of the operation, removal of the tourniquet and suturing (in 15.3±1.7 min, 8 to 25 minutes after removal of the tourniquet).

In addition, the study area included subcutaneous tissue, retinaculum mm. extensorum inferior, m. extensor digitorum brevis. Registration of microcirculatory blood flow of these structures was performed using high-frequency Doppler ultrasound (Doppler «Minimax-Doppler-K» (Minimax, St. Petersburg) using an intraoperative sensor 20 mHz in the mode of study of microcirculation and perfusion of small blood vessels.

After the surgery for 2-3 days the operated limb was fixed with a semi-circular plaster cast, change of bandages and wound examination were performed. Then circular plaster cast immobilization of the limb was performed from the middle third of the femur to the toes for 6-8 weeks depending on the amount of the entire multi-level intervention. Gradually increasing weightbearing on the operated limb was allowed in 2 weeks after the surgery. Surgeries on each limb were performed with an interval of 3-4 weeks (on average 25.4±3.1 days).

Efficacy of the treatment was determined by results of orthopaedic and neurological examinations of the patient. The ability to move was evaluated using Gillette questionnaire [26]. Evaluation of clinical outcome of the intervention on the foot was performed using the criteria proposed by P.D. Angus and H.R. Cowell [27].

Statistical analysis

Statistical processing was performed in Microsoft Office Excel (2010) with the AtteStat and SPSS 18.0 add-in. To assess the significance of mean differences, we used paired Student and Mann — Whitney criteria.

Results

Long-term results of treatment were evaluated after an average of 19 months (from 15 to 42 months) in 57 patients (76.0%). According to the criteria of P. D. Angus and H.R. Cowell (1986), long-term follow-up evaluation showed good results of treatment in 38 patients (66.7%), satisfactory — in 19 patients (33.3%) who regularly complained of moderate pain in the feet after a long walk. There were no poor results. The analysis of gait at the long-term follow-up showed improvement of the majority of parameters of the supporting and non-supporting step phases in patients who used and did not use assistive devices to walk. The dynamics of x-ray parameters of multi-component foot deformity with supination component is shown in table 3.

Changes of radiographic parameters in valgus foot deformity are presented in table 4.

Table 3

Dynamics of radiological changes of feet with varus component (*n* = 17)

Studied angle between foot bones	Before treatment, degrees	After treatment, degrees	Changes		Norm. degrees
			Abs., degrees	rel. %	
AP view					
Talus-calcaneus	34.5	15.9	18.6	53.9	15–25
Total adduction	66.74	15.3	51.44	77.1	28–30
Angle between I and V metatarsals	31.76	20.4	11.36	35.8	28–30
Metatarsophalangeal	10.9	3.9	7.0	64.2	10–15
Lateral view					
Tibia-talus	116.55	103.5	13.05	11.2	100–105
Tibia-calcaneus	67.41	76.7	9.29	12.1	75–80
Talus-calcaneus	35.49	30.5	4.99	14.1	20–30
Foot arch angle	119.2	125.78	6.58	5.2	125–130
Meary angle (between talus and the I metatarsal)	33.58	4.33	29.25	87.11	0–5

Table 4

Dynamics of radiological parameters of foot with valgus component of foot deformity (*n* = 119)

Studied angle between axis of shadows of foot bones	Before treatment, degrees	After treatment, degrees	Changes		Norm. degrees
			Abs., degrees	rel. %	
AP view					
Talus-calcaneus	27.6	17.3	10.3	37.32	15–25
Total adduction	15.3	5.1	10.2	66.7	0–7
Angle between I and V metatarsals	24.6	25.19	0.59	2.34	28–30
Metatarsophalangeal	33.4	11.02	22.38	66.5	10–15
Lateral view					
Tibia-talus	122.9	106.71	16.19	13.17	100–105
Tibia-calcaneus	67.17	73.1	5.93	8.11	75–80
Talus-calcaneus	56.52	28.96	27.56	48.76	20–30
Foot arch angle	168.4	136.47	31.93	18.96	125–130
Meary angle (between talus and the I metatarsal)	38.59	2.43	36.16	93.7	0–5

According to Gillette questionnaire, the functional abilities improved by one level in 29 patients (50.9%), by 2 levels — in 2 patients (3.5%), there was no increase of functional abilities — in 26 patients (45.6%).

Clinical case

The patient is 15 years old, GMFCS III, MACS I, FMS 5,2,2, IV type of gait by Rodda. A multi-level surgical intervention was performed, including lengthening of the hamstring group, lowering of the patella and the triple arthrodesis of the feet using elastic threaded wires (Fig. 3). In 20 months at the control outpatient examination, the patient did not complain; the range of motions in the knees and ankles was complete; the presence of foreign bodies in the feet did not cause discomfort. During prolonged walking, the patient observed minor pain in the feet, tension in the gastrocnemius muscles. According to Gillette's questionnaire, the patient's functional abilities increased by one level.

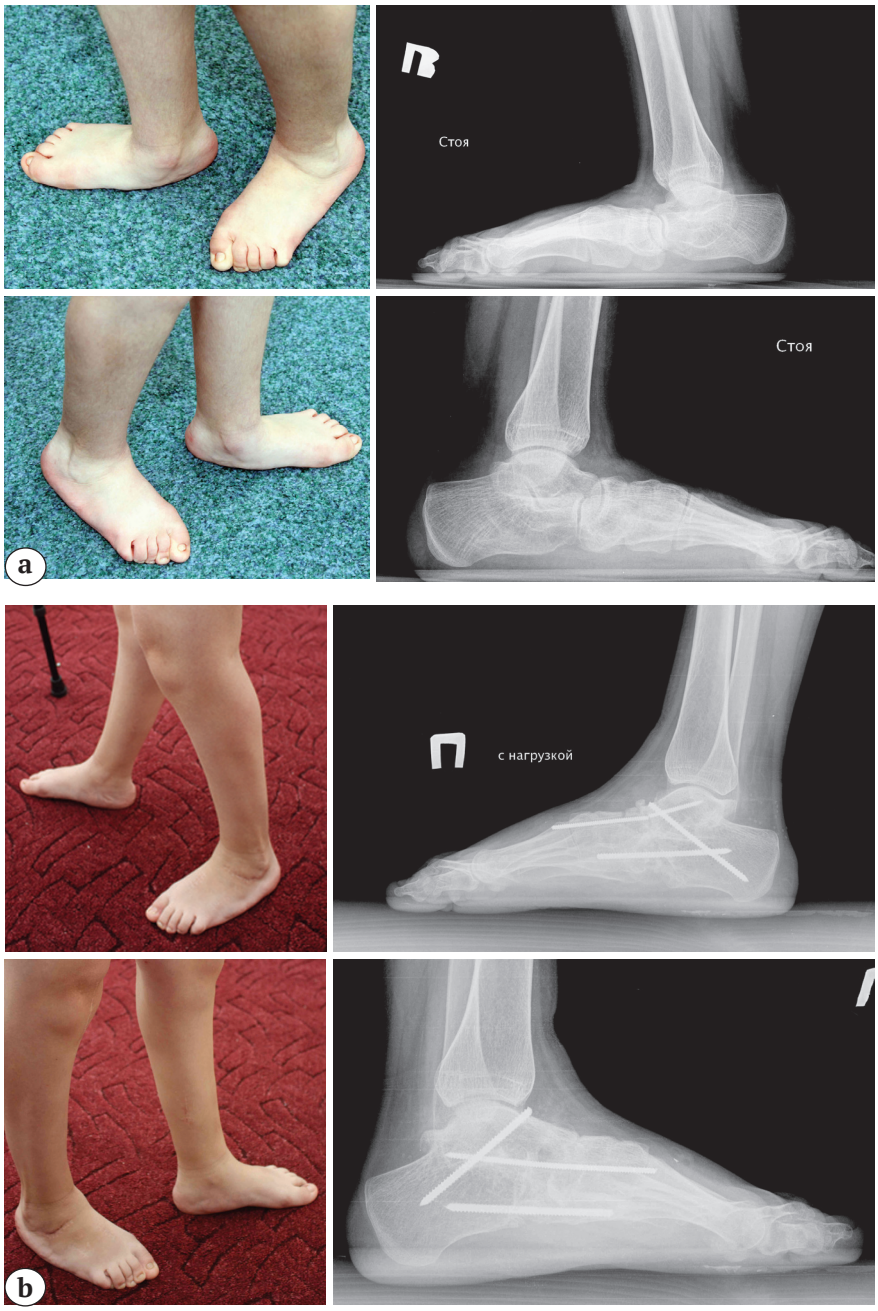

Fig. 3. Image and X-ray of patient of 15 y.o.:
a — planovalgus feet deformity before treatment;
b — follow-up in 20 months after surgery (normal feet position, contact between bones of subtalar and Chopart joint, internal fixation with threaded wires)

Postoperative complications were observed in 15 patients (20%). 5 patients had a poorly granulating wound. It was 6.7% of the total number of patients in this group. This complication was eliminated during treatment (appropriate change of dressings) and did not affect the final result. In 10 patients (13.3%) breakage of threaded wires was observed.

Outpatient examination was performed in 6 months. Consolidation and remodeling of the relevant bones was observed in all the patients. There were no cases of non-union. Removal of threaded wires and screws was performed as planned in 48 (64%) patients. This was done due to both the desire of the patient (or the child's parents) to remove the hardware and pain at the site of the threaded wire as a result of breakage and mobility of its distal fragment outside the area of arthrodesis in 10 (13.3%) patients, which we also attributed to complications of the primary intervention. In case of wire breakage, only its distal fragment was removed. Signs of osteoarthritis (especially in adult patients) of the adjacent joints of the foot in this series of patients remained at the initial level, and we did not observe its progression in the observation period.

The study of soft tissue microcirculation at the surgical site before the surgery showed no statistically significant difference of the indicators of skin capillary blood flow in various measuring points. After performing all stages of the surgery, removing the tourniquet and suturing the skin capillary blood flow tended to increase in all measuring zones (table 5).

Individual approach to analysis of blood flow reactions showed that in various measuring points there was a significant increase of blood flow in 45.5-72.7% of cases. In points 1, 4 and 5 the blood flow increased 4-6 times (p<0.05).

Study of microcirculatory blood flow of the subcutaneous tissue and muscular tissue determined absence of directed dynamics or tendency (table 6).

There was no significant difference from preoperative level in indicators of blood flow after performing all stages of the surgery and removing the tourniquet.

Individual approach to analysis of results of study of microcirculatory blood flow of these structures showed that in different points of measurement there was increase of blood flow in 18-55% of cases. Significant growth by 40-80% (p<0.05) was observed in points 1, 5 and 6 (table 7).

Table 5

Indicators of skin capillary blood flow of the foot before and after all stages of the surgery (M±m, *n* = 21)

Area of study	Capillary skin blood flow (ml/min 100g)					
	before surgery			after performing all stages of the surgery, removing the tourniquet and suturing		
	measurement 1	measurement 2	measurement 3	measurement 1	measurement 2	measurement 3
Point 1	7.7±2.9	7.7±2.9	7.7±3.1	11.9±2.7	11.8±2.7	11.6±2.6
Point 2	6.3±1.5	6.1±1.4	6.3±1.5	8.1±2.7	7.7±2.4	8.2±2.7
Point 3	7.4±2.5	7.3±2.5	7.4±2.5	10.1±4.9	10.3±5.0	10.3±5.1
Point 4	7.4±3.2	7.4±3.2	6.8±2.5	12.2±3.7	12.1±3.9	11.6±3.4
Point 5	7.0±1.9	6.9±1.9	6.9±1.9	11.2±3.4	11.6±3.5	11.2±3.4
Point 6	9.0±1.9	9.1±2.0	9.1±2.0	14.0±4.0	14.4±4.0	13.7±3.7

Table 6

Indicators of microcirculatory blood flow of the foot tissues before and after all stages of the surgery (M±m, *n* = 21)

Area of study	Indicators of blood flow							
	before all stages of the surgery				after performing all stages of the surgery and removing the tourniquet			
	Vs (cm/sec)	Vm (cm/sec)	Vd (cm/sec)	Qs (ml/min)	Vs (cm/sec)	Vm (cm/sec)	Vd (cm/sec)	Qs (ml/min)
Point 1 (subcutaneous tissue)	8.8±0.7	4.5±0.4	1.8±0.3	4.2±0.3	9.5±0.9	4.6±0.6	1.9±0.3	4.2±0.3
Point 2 (subcutaneous tissue)	9.5±0.9	5.0±0.6	1.7±0.2	4.1±0.5	8.1±0.8	3.7±0.4	1.4±0.3	3.8±0.4
Point 2 (subcutaneous tissue)	8.2±0.9	3.9±0.5	1.4±0.2	3.9±0.4	7.7±0.8	3.6±0.6	1.6±0.5	3.6±0.4
Point 4 (muscular tissue)	8.0±0.6	4.4±0.4	1.9±0.3	4.0±0.3	8.4±0.7	4.7±0.4	2.1±0.4	4.1±0.3
Point 5 (muscular tissue)	8.7±1.0	4.8±0.7	2.1±0.5	4.2±0.5	9.0±0.8	4.4±0.6	1.9±0.3	4.3±0.4
Point 6 (muscular tissue)	7.6±0.9	4.0±0.7	1.8±0.5	3.6±0.5	8.0±0.8	3.3±0.6	1.4±0.4	3.8±0.3

Vs — maximum systolic velocity; Qs — volume velocity; Vm — average velocity); PI — pulsatility index); RI — resistivity index.

Table 7

Indicators of microcirculatory blood flow of the foot tissues in positive dynamics (M±m)

Area of study	Indicators of blood flow							
	before all stages of the surgery				after performing all stages of the surgery and removing the tourniquet			
	Vs (cm/sec)	Vm (cm/sec)	Vd (cm/sec)	Qs (ml/min)	Vs (cm/sec)	Vm (cm/sec)	Vd (cm/sec)	Qs (ml/min)
Point 1 (subcutaneous tissue)	7.6±0.7	4.1±0.5	1.3±0.2	3.6±0.3	10.6±1.2*	6.9±0.7*	2.8±0.5*	4.5±0.5
Point 2 (subcutaneous tissue)	6.4±1.0	3.1±0.5	1.2±0.3	2.5±0.6	8.0±0.5	4.1±0.6	2.4±0.3	4.1±0.3
Point 2 (subcutaneous tissue)	6.7±0.5	3.2±1.0	–	2.7±0.3	6.8±0.8	4.9±1.1	–	3.3±0.8
Point 4 (muscular tissue)	6.7±0.8	3.3±0.6	1.2±0.2	3.3±0.5	9.1±1.1	5.1±0.8	2.8±0.8	4.5±0.6
Point 5 (muscular tissue)	6.7±1.2	3.2±0.4	1.2±0.3	3.4±0.6	9.6±0.7*	4.6 ±1.1	1.96±0.4	4.7±0.4
Point 6 (muscular tissue)	5.0±0.4	2.7±0.6	0.9±0.2	2.4±0.2	7.1±0.9*	3.7±0.8	1.5±0.7	3.6±0.5*

* — statistical significance of difference from the initial level, $p<0,05$.

Discussion

The approach to surgical treatment of orthopedic complications of CP is to perform multi-level single-stage surgical interventions [1, 8, 14, 23, 24, 29, 30]. In our series 119 (87.5%) feet had valgus deviation.

In the literature there are known publications that describe the long-term results (over 25 years) of various methods of correction of valgus and flat-valgus foot deformity [4, 5, 13, 31-34]. Some authors describe recurrences of deformity up to 25% after the surgery [13,14]. We believe that in patients older than 12 years with CP and rigid painful multi-component foot deformities and osteoarthrosis of 2-3 degree it is more rational to perform triple arthrodesis. Some of our colleagues believe the same and their patients are satisfied with the result of treatment in 79-95% of cases [6, 9-11, 18, 28 35].

Deformities of the feet in adolescents and adults manifest in pain, changes in soft tissues in the sites of pressure of bone elements and are one of the reasons for the loss of active independent motion. Undoubtedly, with the acute correction of complex deformities of the foot there is a risk of trophic disorders in the soft tissues of the postoperative wound and the segment in general. In our work, we conducted a study of the microcirculation of soft tissues at the surgical site (skin, subcutaneous tissue, muscle tissue) before and after all stages of the operation and removal of the tourniquet and suturing (the skin). Analysis of results showed that, despite a sufficiently large amount of acute correction of foot deformity, there is no decrease in the microcirculatory blood flow of the skin, muscles and subcutaneous tissues of the foot. There is either stabilization or increase in perfusion of these structures. This fact indicates the sparing nature of the surgical influence and presence of conditions for earlier weightbearing than described by other researchers (2 weeks after surgery with assistive devices) [2, 9, 15].

According to some authors, triple arthrodesis of the foot is especially indicated in neuromuscular imbalance [36]. Arthrodesis operations can be performed after the end of active growth of the foot bones [10, 11, 28]. We performed bilateral corrective triple arthrodesis in a patient with open growth zones (11 years 8 months), but did not receive negative consequences. The surgery in this patient was performed due to the need for correction and stabilization of multicomponent foot deformity.

In comparison with the work of our colleagues, who do not recommend weightbearing on the operated foot with triple arthrodesis for 1.5-2 months [2, 9, 15], which brings a number of inconveniences and limitations, including psychological ones, we recommend verticalization with a gradually increasing weight-bearing on the operated segment with assistive devices in 2 weeks after the surgery. With this approach we did not observe any cases of loss of results, nonunions in the study group of patients.

When performing triple arthrodesis of the foot, the most common complication is absence of union in the site of one or more joints after this operation. Thus, in children, the frequency of non-union occurs in up to 23% [6, 10, 12, 15, 25, 29], in adults — up to 46% [16, 29, 34, 37]. And it manifests in pain in the foot in almost 40% of patients [15]. For example, according to the study of I.B. de Groot et al there were 19% of nonunions, which required subsequent revision [36]. Outpatient examination 6 months later showed consolidation and remodeling of the bones in all cases, both in children and adults. We didn't leave diastasis between the bones. If necessary, we took out a bone fragment from the surgical site on the foot in order to create good contact.

In the study of M. Vlachou *и* D. Dimitriadis there was a deep infection of the foot after the triple arthrodesis in 2 (3,85%) patients. No infectious complications were noted. However, in acute correction of severe deformities in 5 patients we observed poorly granulating wound of the foot that did not

affect the final result of treatment. This fact is associated with some tension of soft tissues during acute correction of severe foot deformity [15].

According to the literature, pain in the postoperative period was observed in 20-57% of cases [6, 15, 17, 28]. In our long-term follow-up study, moderate pain in the feet after walking was observed in 19 (33.3%) patients.

C.L. Salzman and co-authors observed arthrosis of the ankle joint at the long-term follow-up (more than 25 years) in 45% of patients after triple arthrodesis [34], S.K. Trehan — in 11.5% of cases [6], P.D. Angus — in more than 50% [27].

We observed no progress of degenerative processes in the ankle joint in the patients included into this study at the time of the last outpatient examination (42 months).

Conclusion

We believe that the rational approach is to use triple arthrodesis of the foot as a part of multi-level orthopedic treatment of patients with CP, taking into account the age, severity of the main condition of the patient, deformity and degenerative changes of the segment; and it does not cause trophic disorders of soft tissues of the segment. The method of triple arthrodesis of the foot allows for restoration and stabilization of the correct interrelations between the bone elements, restoration the limb supportability, which in combination allows for improvement of functionality and minimization of the risk of deformity recurrence. We recommend this operation to patients older than 12 years with osteoarthritis of the foot 2-3 degree, using our proposed method of soft tissue dissection. Despite the rather large amount of acute correction of foot deformity, there is no decrease in the microcirculatory blood flow of soft tissues in the surgical site (skin, muscles and subcutaneous tissues of the foot) after all stages of the operation.

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