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Method of two-stage treatment of total and subtotal defects of the foot in Charcot neuroosteoarthropathy

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Abstract

Introduction One of the complications of diabetes mellitus is Charcot's osteoarthropathy, associated with the development of angio-neuropathic and metabolic disorders in the foot and loss of limb weight-bearing. Its association with purulent infection not only worsens the quality of life of patients, but also poses a threat to life. The literature reports very conflicting information about the choice of reconstruction technologies and methods of foot fixation. The lack of unified approaches and generally recognized protocols indicates the dissatisfaction of orthopedists with the results achieved and the imperfection of the technologies used. **The aim of the work** is to evaluate the effectiveness of the combined use of the Masquelet technology and Ilizarov transosseous osteosynthesis in Charcot osteoarthropathy in conditions of purulent infection. **Material and methods** The authors present an original approach to foot reconstruction in 8 patients, based on the combined use of the Masquelet technology and Ilizarov transosseous osteosynthesis. The follow-up period ranged from 1 to 11 months from the date of the primary operation. **Results** In all patients treated by this technique, the limb support was restored. Nonunion, loss of correction, and late infection complications were not detected. **Discussion** The combined use of transosseous osteosynthesis allows discrete correction of multicomponent foot deformities without creating additional angiotrophic disorders, and the use of Masquelet bone grafting to sanitize pathologically altered tissues with the formation of an induced membrane that produces growth factors and has antimicrobial activity. Choosing the tactics of treatment for preservation of the foot as an organ in patients with severe condition of the feet with Charcot osteoarthropathy, the method of two-stage surgical treatment is justified and provides length compensation of the segments, limb support even in cases where, at first glance, amputation has relative indications. **Conclusion** Differentiated application of the Ilizarov and Masquelet technologies is effective and justified in conditions of Charcot's arthropathy.

Keywords: diabetic foot syndrome, Charcot foot, Ilizarov apparatus, antibacterial spacer, Rimmer Irrigator Aspirator Synthes

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INTRODUCTION

Charcot's diabetic osteoarthropathy is a complication of diabetes mellitus with sensorimotor and autonomic neuropathy triggered by trauma and metabolic bone disorders [1]. The presence of subtotal and total foot defects in Charcot osteoarthropathy leads to impaired support function. The unstable nature of the deformity prevents the successful use of therapeutic shoes or orthoses, while the addition of an infection process poses a threat to life. In some cases, only reconstructive surgery may be the only way to avoid limb amputation [2–6].

The methods of treatment are resection arthrodeses of the middle and hind foot (types 3–4–5 according to the Sanders & Frykberg classification) with internal fixators for Charcot arthropathy. At the same time, the authors themselves state a high level of complications which are recurrence of ulcers, migration of fixators, nonunion, loss of the achieved correction [7].

The literature reports very conflicting information about the choice of foot fixation technologies. Thus, some experts have abandoned internal fixators for arthrodesis of the ankle joint in favor of the Ilizarov apparatus to salvage the segment previously operated in Charcot arthropathy [8–29].

However, according to the literature, a number of researchers are skeptical about the possibilities of external fixation in the rehabilitation treatment of patients with Charcot osteoarthropathy and prefer the use of internal metal fixators [30].

Supporters of external fixation in the treatment of patients with Charcot osteoarthropathy note many advantages of using transosseous osteosynthesis in severe osteoporosis, purulent complications, osteomyelitis, and soft tissue defects [13]. The choice of osteosynthesis technology may depend on many factors. Therefore, information about the advantages and disadvantages of various fixation options is crucial for achieving the best results [31].

In resection arthrodesis with internal fixators for stage 2 according to the Eichenholtz classification, the

risk of nonunion, secondary displacement of fragments, bone loss, and secondary amputation increases.

The disadvantage of the methods of arthrodesis with both internal and extrafocal fixators is the need to shorten the segments, bringing the foot in a forced position, followed by the fabrication and permanent use of customized orthopedic shoes. Bone ankylosis is not always achieved due to incongruence and insufficient contact area of the arthrodized fragments.

Management of the talus with simultaneous filling of the defect with trabecular metal implants and autografts combined with intramedullary fixation and the use of Rimmer Irrigator Aspirator Synthes was described by foreign authors in two patients with Charcot's arthropathy. However, the replacement stage was acute what significantly reduces the possibilities of the regenerate for organotypic rearrangement [32].

The Masquelet method of managing extensive defects of long bones in two stages has been actively used and was shown in detail in many clinical studies. The method leads to the formation of an osteoinductive membrane in bone defect that provides a complete organotypic restructuring of the graft material [33–35].

According to the current literature, there is experience of successful management of bone defects with the combined use of the Ilizarov non-free bone grafting and the Masquelet technique in the rehabilitation of patients with acquired bone defects and pseudarthrosis [36].

In Masquelet bone grafting, surgeons gave priority to external fixation, while evaluating the transosseous osteosynthesis from the standpoint of long-term rigid fixation of bone fragments and impairment of patients' quality of life [36, 37].

Management of partial midfoot defects in two stages in Charcot arthropathy was described in a case report [38]. Despite a good clinical result, the only case described leaves open the question of its possibilities for total and subtotal foot defects.

The process of collecting an autograft from the iliac crest has a number of disadvantages. There is a cosmetic defect, high trauma, risk of damage to the cutaneous femoral nerve, and damage to the parietal peritoneum [39]. The anatomical features of the iliac wing do not allow obtaining a large amount of spongy bone. To graft extensive bone defects, bilateral collection from the iliac crests is used. It is accompanied by extensive damage to the soft tissues and the cortical layer of the bone over a large area.

The goal of surgical treatment of patients with complicated diabetic neuroosteoarthropathy is to radically eliminate the nidus of bone tissue destruction and restore the functionality of the foot by reconstructing its anatomy, restoring the length of the segment and its biomechanics.

The technical result achieved with the proposed technique is the elimination of a purulent destructive focus and the defect gap in the foot compartments, the restoration of the support ability of the foot, its length, and the preservation of its functionality due to producing bone ankylosis.

Thus, at present, we have a wide variety of applied surgical technologies and methods of fixation for reconstructive and restorative operations in patients with Charcot's arthropathy. At the same time, the lack of unified approaches and generally recognized protocols dissatisfies the orthopedists with the results achieved and the imperfection of the technologies used. The analytical review of the literature did not find any publications on the possibility of surgical rehabilitation of patients with Charcot arthropathy using transosseous osteosynthesis and the Masquelet technique.

Purpose of the study was to evaluate the clinical efficacy and prospects for the outcomes of surgical treatment of patients with diabetic Charcot foot with destruction of the middle and hind foot in remission and active purulent infection using a combination of the Masquelet technology and Ilizarov transosseous osteosynthesis.

MATERIALS AND METHODS

The location of the destruction focus with or without infection was determined by clinical and radiological pictures and interpreted according to the anatomical classification of Sanders & Frykberg (1991) [40]. The classification of Chantelau & Grützner (2014) for the interpretation of the clinical and radiographic picture, proposed by the RF recommendations [41, 42], was not used due to the impossibility of an objective description of the processes occurring in the focus, which can affect the tactics of orthopedic treatment. The authors used the pathophysiological classification of Eichenholtz (1966) [43]. In the presence of ulcerative defects of the foot, the Wagner classification [44] was used, which characterizes the depth of the ulceration of one or another part of the foot. Given the preservation of the main distal blood flow in this cohort of patients, the WIFI classification [45] was not used in this study.

The earlier idea of combining these classifications into one for simplicity and a more complete characterization of the true local status of SERW patients [46] was changed. Instead of the Rogers classification [1], which describes the deformity of the foot without specifying its type, the type of deformity was indicated with a description: VL – valgus, VR – varus, QU – equinus, PP – press-papie; the proposed classification has been renamed SEDW accordingly.

The results of treatment of 6 patients with type 2 diabetes mellitus and 2 patients with type 1 diabetes mellitus with main or main-altered peripheral blood flow (according to ultrasound angioscanning and/or CT

angiography), with Charcot's foot and location of the pathological process in the middle and hindfoot (type 2-5 according to the Sanders & Frykberg classification), who were treated in the Department of Purulent Surgery of the City Clinical Hospital No. 13 and the Center for Foot and Diabetic Foot Surgery of the Yudin City Clinical Hospital in 2020-2021. Two patients had defects of the talus accompanied by defects of the bones of the midfoot; two patients had defects of the Chopart and Lisfranc joints; two patients had isolated defects of the medial column of the foot, and two patients had isolated defects of the neck and head of the talus. One patient was operated on at the stage of exacerbation of the fistulous type of chronic osteomyelitis, and three patients were operated on immediately after wound healing after previously opened phlegmons. The authors believe that the reason for the formation of phlegmon is secondary infection of hematomas, which are formed during pathological fractures of the bones of the hind and middle foot and maintaining the full load of the involved foot by the patient.

All patients were provided with limb unloading, glycemic control and correction, neuroprotective therapy and, if indicated, systemic antibiotic therapy.

At the first stage of the two-stage method, the parts of the deformed and affected bones, scar tissues and pathological granulations were removed, the cartilage of the articular surfaces of the bones was resected and synovectomy was done under spinal anesthesia in aseptic conditions under a pneumatic tourniquet through the approach performed regarding the type and location of the deformity. In the presence of an ulcer, it was excised with the formation of skin and fascial flaps for subsequent plastic closure of the wound defect.

The foot was brought by skeletal traction to a functionally correct position with diafixing pins while maintaining the defect gap, the correct ratio and length of the segments (foot and/or lower leg). A polymethyl methacrylate cement spacer was implanted into the gap that was made from medium-viscosity revision bone cement and containing 1 gram of gentamicin. Up to 2–4 grams of vancomycin were added to the cement independently during the formation of the spacer. The volume of the integrated spacer depended on the volume of the defect gap. With a shortage of one dose of bone cement (40 g), two doses were used. The dimensions of the implanted spacer were 6 × 4 × 2 (± 1) cm with the filling of the resulting defects from 30 to 80 cm3. The spacer had a similar diameter in relation to the adjacent bone, and its volume corresponded to the volume of the formed gap. Wounds on the foot were sutured tightly in layers without drainage.

Then, extrafocal osteosynthesis was performed using a compression-distraction external fixation apparatus, consisting of two rings fixed on the lower leg in case of damage to the ankle and subtalar joints or one ring on the lower leg in case of damage to the midfoot. Two half rings were on the foot: one half-ring was installed in the hind foot and one on the forefoot. In the projection of the rings and half rings, the wires were drilled in the oblique frontal plane, the wires were fixed in the plane of the rings and tightened with a wire tensioner. The half-rings were interconnected by threaded rods and one- or two-plane hinges.

At the second stage, after 6–8 weeks (according to the Masquelet technology), the cement spacer was removed without damaging the resulting inductive membrane, and the diastasis defect was filled with a combined graft.

The autograft was taken from the femoral canal. Previously, the diameter of the femoral canal was measured in the transverse direction in the narrowest part using the C-arm, and the size of the cutter head was selected based on 1–1.5 mm wider than the diameter of the medullary canal of the femur. The approach to the femoral canal was made under aseptic conditions from the standard lateral approach to the proximal femur. The point of entry of the wire into the channel was determined under the control of a mobile image intensifier tube (C-arm). A guide wire was inserted into the formed point in the projection of the greater trochanter of the femur; next, a cannulated awl was inserted along the guide. Under the C-arm control, autologous bone was harvested in the femoral canal, using the Rimmer Irrigator Aspirator Synthes system. The wound on the thigh was tightly sutured with layered stitches without drainage.

The collected autologous biomaterial was mixed under aseptic conditions with the allograft in the form of demineralized spongy bone crumbs in a one-to-one ratio; the combined graft was integrated into the wound cavity. The wound on the foot was sutured tightly by layers without drainage. The fragments were stabilized in an external fixator.

The sutures were removed 2–4 weeks after the operation. Radiographic checking was carried out every 1–1.5 months. The external fixator was dismantled when obvious radiological signs of consolidation were detected and after the clinical test was carried out. Hardware fixation of the foot was replaced by fixation with a posterior plaster splint for a period of 2–3 weeks, until the wounds in the places of the removed fixing elements healed. Subsequently, the patient continued to fix the foot with an individual Total Contact Cast bandage, followed by recommendations for wearing customized orthopedic shoes.

The control group of the study included patients who had previously been operated on using standard methods of resection arthrodesis with an external fixation device or screws.

The results of the study were evaluated by the method of descriptive statistics.

The work was performed in accordance with the ethical standards of the Declaration of Helsinki of

the World Medical Association "Ethical principles for medical research involving human subjects" as amended in 2013 and "Rules of Clinical Practice in the Russian Federation", approved by order of the Ministry of Health of the Russian Federation dated June 19, 2003 No. 266. Patients signed an informed consent for the surgical intervention and the publication of the data obtained without identification.

RESULTS

Arthrodesis of the hind foot was performed in 16 patients. Eight cases underwent Ilizarov extrafocal osteosynthesis, and the other eight had internal fixation with screws (Table 1).

In the early stages (up to 1 month after the operation), no complications were detected. Complications developed later in 4 patients: three with internal fixation and one with external fixation.

In one patient with morbid obesity (BMI = 44), a combined lesion and osteomyelitis, a tactical mistake was made. Internal fixation with screws was performed, which, against the background of non-compliance with the unloading regimen, led to instability of fixation, secondary infection with the development of systemic inflammatory response two months after surgery. The removal of implants and the use of an individual removable immobilizing bandage did not cope with the purulent inflammatory process, and the case ended in amputation at the level of the upper third of the leg.

Two more patients with internal fixation developed fistulas and septic instability of the implants at 9 and 13 months. The fixators were removed followed by reaming of the canals and sealing with a collagen sponge impregnated with gentamicin without loss of foot correction and without recurrence within a period of up to one year in one patient. One case of nonunion and instability at 9 months required the use of external fixation.

One patient with external fixation was diagnosed with pin osteomyelitis in the middle third of the leg after 12 months; sequestrectomy was performed without recurrence at the follow-up (1.5 years).

Arthrodesis of the midfoot was performed in 76 patients with internal fixation with screws (Table 2).

One case (1.3 %) of an early postoperative complication (< 1 month) was identified: wound suppuration and septic instability of the screw, which required its removal, surgical debridement and fixation in plaster – no recurrence, stable foot; 5 (6.6 %) cases of late septic instability of the screws (from 2 to 37 months) – the screws were removed without loss of foot correction; 1 case (1.3 %) of opposite screw break after more than one year without loss of foot correction and without the need to remove screws. The main cause of complications was non-compliance with limb unloading by the patients.

There were two cases (2.6 %) of foot ulcer recurrence, but of a different localization, which required planar exostosis resection by lateral access without intervention on the ulcer; later by wearing an unloading orthosis, the ulcers healed; one case (1.3 %) of recurrence of ulceration in case of non-compliance with the unloading regimen of the foot by a patient with morbid obesity, which required the involvement of a psychologist and relatives, the use of immobilization of the limb in an individual unloading bandage - the ulcer healed.

So, in total, 9.2 % of cases of early and late complications and 3.9 % of cases of recurrence of ulcer formation were noted in the period from 1 to 5 years.

Table 1

Distribution of patients in the control group and identified complications according to the SEDW classification. Hind foot

Classification, stage	Number of patients	Complications	
		Number	%
Pathological process location			
Sanders 3–4: tarsal joints and ankle joint	4	1	25
Sanders 4: ankle joint	5	1	20
Sanders 4–5: ankle and subtalar joints	1	0	0
Sanders 3–4–5: combined lesion	6	2	33.3
Stage of the pathological process			
Eichenholtz 1: fragmentation	10	3	30
Eichenholtz 2: coalescence	4	0	
Eichenholtz 3: consolidation	2	1	50
Deformity and complications			
Deformity and wound (VR)	4	0	0
Deformity and osteomyelitis (VR – 9, VL – 2, QU – 1)	12	4	33.3
Deepness of tissue involvement			
Wagner 2: deep infected ulcer without bone involvement	4	0	0
Wagner 3: deep infected ulcer and osteomyelitis	12	4	33.3

Table 2

Distribution of patients in the control group and identified complications according to the SEDW classification. Midfoot

Classification, stage	Number of patients	Complications	
		Number	%
Pathological process location			
anders 3: tarsal joints	76	7	9.2
Stage of the pathological process			
Eichenholtz 1: fragmentation	17	2	2.6
Eichenholtz 2: coalescence	14	1	1.3
Eichenholtz 3: consolidation	45	4	5.3
Deformity and complications			
Deformity and wound (PP – 31, VR – 3)	34	0	0
Deformity and osteomyelitis (PP – 36, VR – 4, VL – 2)	42	7	9.2
Deepness of tissue involvement			
Wagner 2: deep infected ulcer without bone involvement	34	0	0
Wagner 3: deep infected ulcer with osteomyelitis	42	7	9.2

Despite the good results of reconstructive interventions and the restoration of limb support, a relative shortening of the limb length in the hindfoot and a relative shortening of the foot were observed in all patients of the control group: from 1–4 cm in the hindfoot lesion and 1–5 cm after a midfoot reconstruction. The preservation of this shortening required repeated surgical interventions to restore the length of the limb, but the issue of compensation for the length of the midfoot remained unresolved. All patients needed complex orthopedic appliances and their permanent wearing.

Patients of the study group are at different stages of the treatment process. So, three patients who completed the treatment (the follow-up period was 10 and 9 months from the moment of the primary surgical intervention) actively walk in customized orthopedic shoes; arthrodesis completed. In those patients, in the early postoperative period after the second stage, there was a preservation of sanious wound discharge for up to two weeks without subsequent suppuration. The authors attribute this to the error in graft placement, insufficient compaction of the latter in the defect cavity, and osteoperforation of the bone ends, which could lead to additional hematoma accumulation and its removal through the wound. Nonunion, loss of correction and late purulent inflammatory complications were not revealed.

Four patients who underwent both stages of the surgical treatment are at the final stage of fixation by transosseous osteosynthesis (follow-up period from 4 to 6 months from the date of the primary operation). One patient had suppuration around the wires in the lower third of the leg that was arrested upon frame rearrangement and wire reinsertion. In another patient, due to low compliance and continued full load on the foot, the apparatus instability developed after the first stage, the installation of a spacer, which required dismantling the apparatus and replacing the spacer with transosseous reosteosynthesis. There were no other complications in those four patients.

Two patients underwent the first stage of surgical treatment: bone resection, spacer placement and limb fixation in the Ilizarov apparatus. No complications were detected in the observation period, and the second stage of treatment is planned in the near future.

Case presentation

Male patient Sh., 58 years old: type 2 diabetes mellitus, insulin-dependent, first diagnosed in 2012. In 2015, he noted the appearance of foot deformity and an ulcer. On examination, he was diagnosed with diabetic foot syndrome, neuropathic type, Charcot osteoarthropathy with damage to the Lisfranc and Chopart joints, type 2–3 according to the Sanders & Frykberg classification, stage 1 according to Eichenholtz, stage D according to the Rogers classification, and stage 3 according to Wagner (Fig. 1).

In 2015, osteonecrectomy was performed with the filling of the defect in the middle foot with a collagen sponge impregnated with gentamicin and fixation of the foot and lower leg in the Ilizarov apparatus (Fig. 2); the period of fixation in the apparatus was 6 months.

The wounds healed, the flotation of the foot in the midfoot was preserved, which did not prevent the patient from moving freely in orthopedic shoes.

In 2017, the patient presented with a picture of plantar ulcer, stage 2 according to Wagner. Correction of unloading shoes and conservative therapy led to the healing of the defect.

Referral in February 2021 revealed deformity in the ankle joint, fistula with scanty purulent discharge in this area. Radiological study determined total lysis of the talus, destructive changes in the contact surfaces of the tibia and calcaneus (Fig. 3).

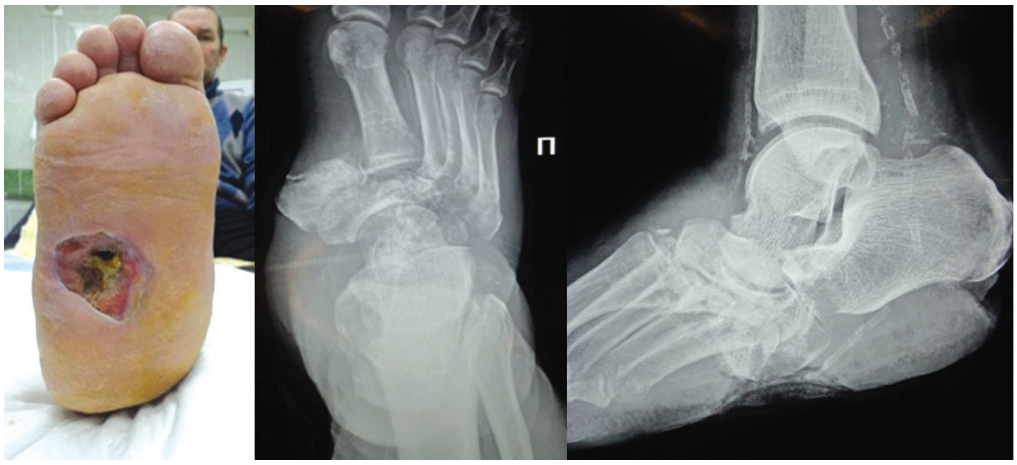

Fig. 1 photo and radiographs of the foot in both projections before treatment

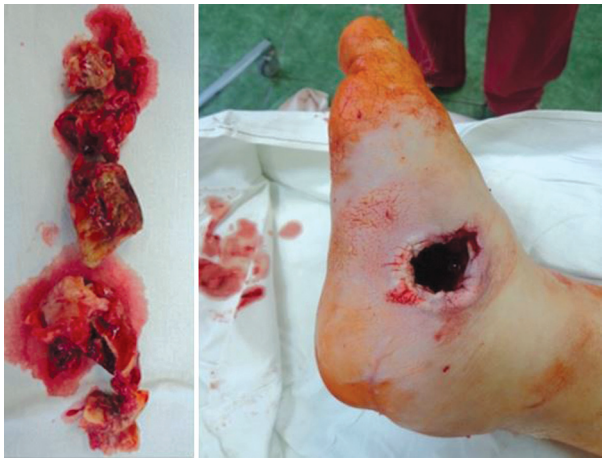

Fig. 2 Intraoperative photo of the foot and resected tissues after sequesternecroectomy

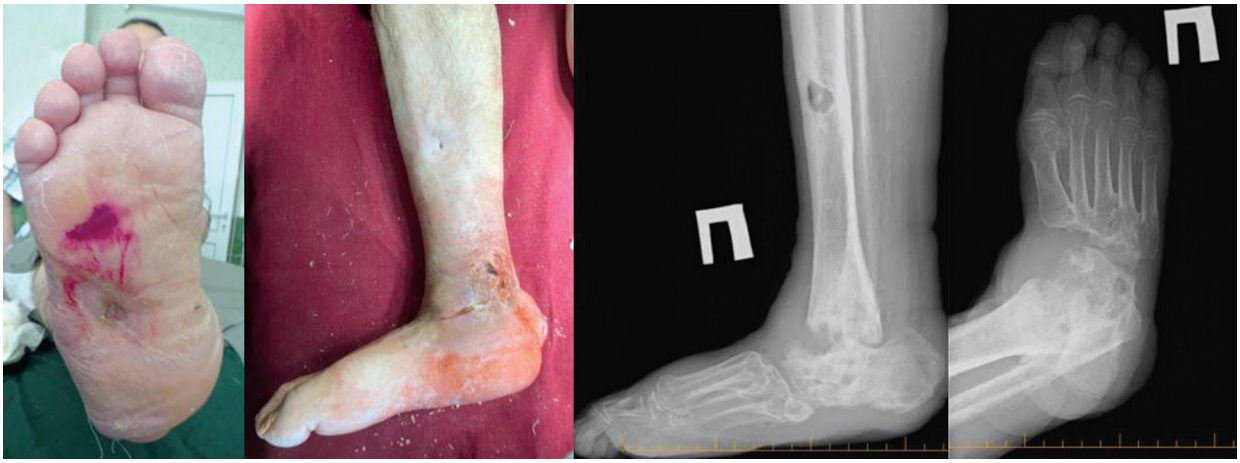

Fig. 3 Photo and radiographs of the foot before the first stage of reconstructive intervention

At the first stage, under spinal anesthesia and a pneumatic tourniquet, osteonecrectomy of the area of the calcaneo-tibial neoarthrosis was performed, and the osteomyelitic cavity of the tibia was opened. The resection gap zone of the midfoot was revised, the bone ends were made congruent, followed by filling of the diastasis zones with two cement spacers and osteosynthesis of the foot and lower leg with an external fixation device (Fig. 4) with primary sutures.

Six weeks later, the second stage was performed, removal of spacers and bone grafting of the gaps with combined bone grafts (RIA plus allobone) with primary sutures. Within two weeks, a bloody discharge remained in the area of the sutures, which stopped on its own.

After another six months, a dense bone regenerate with the formation of ankylosis in the projections of the ankle joint and the midfoot was radiologically confirmed; after the clinical test, the external fixator was dismantled (Fig. 5, 6).

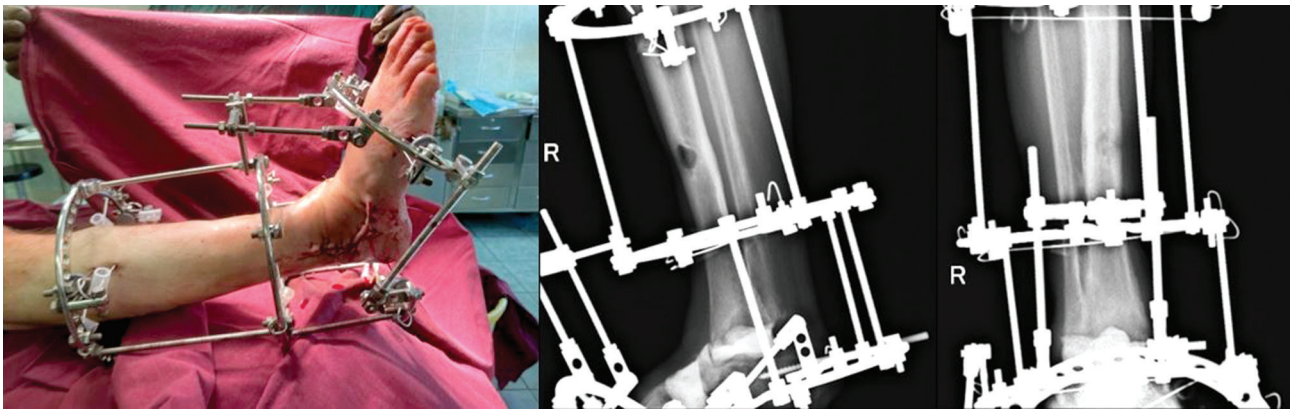

Fig. 4 Photo and radiographs capturing the tibia and foot after the first stage

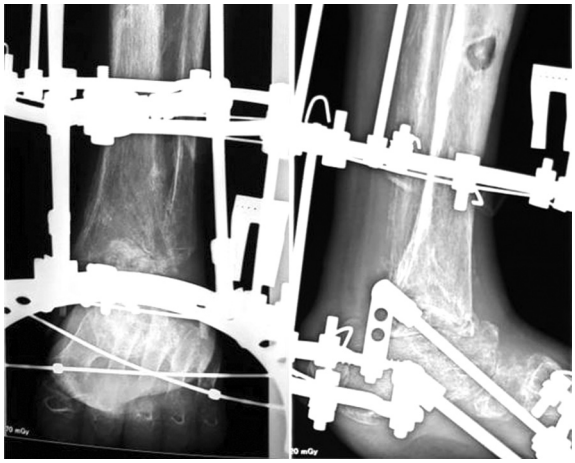

Fig. 5 Radiographs of the foot after 6 months

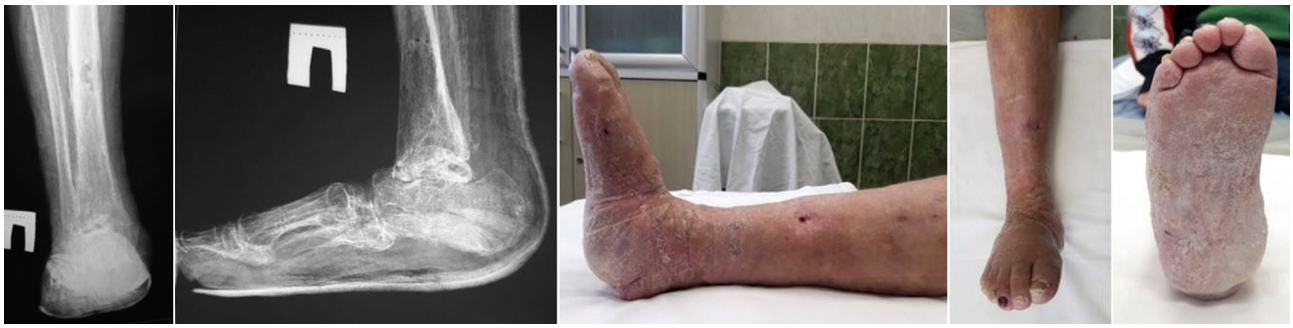

Fig. 6 Radiograps and photos of the foot; outcome of treatment

The patient passed through the stages of unloading in a plaster splint and Total Contact Cast, activated in orthopedic shoes. For a period of 11 months from the moment of the first stage of surgical treatment according to the proposed method, nonunion, loss of correction and late pyoinflammatory complications were not detected.

DISCUSSION

Currently, publications have appeared on the effective combined use of the Ilizarov non-free bone plasty and the Masquelet technique in the rehabilitation of patients with heterogeneous bone defects and nonunion [36, 47].

The concept of the combined application of the Ilizarov non-free bone grafting and the Masquelet technique is based on the idea of using the known advantages of the two technologies. According to authoritative authors, Ilizarov non-free bone plasty is an ideal form of bone grafting, when a vascularized autograft with a preserved soft tissue cover is moved into the problem area in a dosed and directed manner. Theoretically, it enables to create a tubular bone of any length and shape in the defect [48].

According to the literature, the induced membrane formed around the spacer is well vascularized and produces growth factors (VEGF, TGF-beta1) and morphogenetic proteins BMP-2 and BMP-7 [37]. The induced membrane also has antimicrobial activity [49].

The use of transosseous osteosynthesis enables to correct multicomponent foot deformities without creating additional angiotrophic disorders, and the combined use of Masquelet bone grafting allows sanitizing pathologically altered tissues with the formation of an induced membrane that produces growth factors and has antimicrobial activity.

In our opinion, when choosing the tactics of treatment and preservation of the foot as an organ in patients with severe lesions of the feet with Charcot osteoarthropathy, the method of two-stage surgical treatment is justified and restores the length of the segments, limb support even in cases where, at first glance, amputation is indicated. Undoubtedly, the use of this technique requires a cognitive balance and the patient's adherence to the treatment, compliance with the prescribed regimens of immobilization, unloading, activation and rehabilitation.

CONCLUSION

Thus, the differentiated application of the Ilizarov and Masquelet technologies according to their advantages can be used for Charcot's neuroosteoarthropathy. The preliminary results of their clinical application in two-stage surgical treatment of patients with total and subtotal foot defects for Charcot osteoarthropathy prove the validity, effectiveness and prospects of the technology.

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