



Comparative analysis of the clinical efficiency of the combined Ilizarov – Masquelet technology and non-free Ilizarov bone grafting in patients with segmental tibial defects in the conditions of active purulent infection and its remission

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Abstract

Introduction There is currently no consensus on the effectiveness of the Ilizarov Masquelet technologies, and their combination in long bone defect management. The greatest challenge is restorative treatment for patients with bone defects accompanied by purulent infection, both during remission and exacerbation of the inflammatory process.

The **aim** of the work is a comparative analysis of the effectiveness of the combined use of the Ilizarov non-free bone grafting and the Masquelet technique versus the classical Ilizarov bone transport in patients with bone defects of the tibia in the conditions of active purulent infection and its remission.

Materials and Methods This study is based on the analysis of the results of a multicenter study of the restorative treatment of 56 patients who underwent a combination of the Ilizarov non-free bone grafting and the Masquelet technique for tibia defects in the presence of osteomyelitis remission (Group 1, $n = 33$) and active infection (Group 2, $n = 10$), as well as the classical Ilizarov bone transport technique in the presence of active infection (Group 3, $n = 13$).

Results The conditions for bone transport predetermined different durations of the transosseous osteosynthesis stages for filling similar-sized defects in the tibia. In Groups 1 and 2 (combined technology), the duration of the osteosynthesis stages was quite comparable. In the patients of Group 1, the transport of the fragments continued for (62.4 ± 10.4) days, the fixation stage was (163.4 ± 5.6) days. The duration of distraction in patients of Group 2 was (63.9 ± 15.2) days, the fixation period was (150.5 ± 19.4) days. Surgical rehabilitation of the patients in Group 3 took a longer time: distraction was performed for (115.3 ± 37.5) days, and additional (331.9 ± 122.9) days were required for restoration of the bone skeleton of the tibia. In two patients in Group 1 (7.4 %) and two individuals in Group 2 (20 %), wounds healed by secondary intention, with fistula formation. A recurrence of purulent infection was noted within one year after dismantling of the fixator and removal of the transosseous fixation elements, requiring minor surgical debridement and antibacterial therapy. Complete suppression and eradication of purulent infection was not achieved in one patient in Group 2. No recurrence of purulent infection was observed in Group 3 patients during follow-up.

Discussion The combination of the Masquelet technique and Ilizarov non-free bone grafting, despite the implantation of spacers with a prophylactic dose of antibiotics and empirical antibacterial therapy, does not guarantee the elimination of the risk of purulent recurrence if debridement of infected areas is not complete. However, combining the Masquelet technique and Ilizarov non-free bone grafting, the formation of an induced membrane creates favorable conditions for Ilizarov bone transport during the second stage of surgical treatment.

Conclusion A comparative analysis of surgical rehabilitation of patients using the Ilizarov non-free bone grafting and the combined use of Ilizarov bone transport and the Masquelet technique in patients with bone defects of the tibia with active purulent infection and its remission showed that the treatment period in the classical Ilizarov bone transport method was longer, but it did not result in recurrence of the purulent process. Guaranteed arrest of purulent infection is only possible after radical surgical debridement and debridement of the purulent bone wound.

Keywords: combination of techniques, Masquelet technique, Ilizarov bone transport, induced membrane

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INTRODUCTION

Currently, there is no doubt or active discussion about the statement that effective technologies for managing extensive defects of long bones are Ilizarov bone transport, the Masquelet technique and the use of free vascularized autografts [1, 2, 3, 4].

However, despite the successes in bone plasty surgery, the search for new technological approaches and the development of innovative bone plasty materials, orthopedists do not have alternative surgical technologies and ideal implants [5].

While recognizing the effectiveness and efficiency of vascularized autografts, it is necessary to note its certain problems and disadvantages: surgical intervention is two-stage and time-consuming, requires the use of microsurgical techniques, the volume of bone-plastic material is limited, negative consequences are possible in the donor area, such as the formation of a bone-and-soft tissue defect and the appearance of phantom pain; a implanted massive bone fragment has a high risk of thrombosis of the arteriovenous shunts [1, 2, 6].

Mi et al. published a meta-analysis of comparative results of restorative treatment of patients using the Ilizarov fragment lengthening technology (37 articles were included) and the outcomes of treatment using the Masquelet technique (41 sources), which revealed that the achieved results did not have statistically significant and reliable advantages in restoring the anatomical and functional integrity of the limb, fragment consolidation, or the risk of developing postoperative complications [4]. In the meta-analysis of Shen et al., which included 23 studies (three randomized controlled and 20 observational) with a total of 930 participants [7], the effectiveness of various treatment methods was ranked: Ilizarov non-free bone grafting, the Masquelet technique, vascularized and non-vascularized autografts, and bone tissue engineering. The results of that meta-analysis indicate no statistically significant differences in the bone union rate between the Ilizarov and Masquelet methods, which confirms the findings of Mi et al. [4]. Moreover, the authors of the publication highlight stratification by defect size: for defects from 4 to 8 cm, the best results were achieved by vascularized autografts (SUCRA value of 80.4 %), and for defects larger than 8 cm, Ilizarov non-free bone grafting (SUCRA value of 76.2 %) became the method of choice, since it ensures more predictable bone formation over a greater extent of the defect. The Masquelet technique in those groups was inferior in effectiveness to both methods [7].

Several authors report long-term adverse outcomes of surgical rehabilitation using the Ilizarov bone transport and the Masquelet method. According to published data, amputation was performed in five patients out of 38 that were treated with the Masquelet method, whereas amputation was performed in only one patient in an attempt to compensate the defect with the Ilizarov fragment lengthening method [8, 9, 10].

According to various authors, the Ilizarov non-free bone grafting has a higher risk of purulent complications. In the case of transosseous osteosynthesis, superficial soft tissue inflammation is more frequently detected during the external fixation stages than with the Masquelet technique. However, those studies provide more optimistic data on the incidence of deep purulent infection with Ilizarov defect repair, which is significantly lower than with the Masquelet technique [8, 9, 10, 11, 12, 13, 14].

The authors of other studies found superficial infection at wire insertion sites in 48 cases out of 199 (61.3 %), deep infection was detected in three patients (1.5 %), delayed consolidation in 50 (25.13 %) patients, and deformations of bone segments in 86 cases (43.2 %) [15].

Complications of the Ilizarov non-free bone grafting in the treatment of patients with lower limb bone defects are also presented in large meta-analyses. Burianov et al. found that the most common

shortcomings and complications of Ilizarov grafting are: infection in the area of wire/pin insertion (65.96 % of cases); development of deformities (40.78 %); contractures of adjacent joints (stiffness) (23.76 %) and delayed consolidation in the area of fragment contact (13.48 %) [16]. The authors note that, despite the higher frequency of some complications compared to the Masquelet method, positive results of the Ilizarov grafting were achieved in 95 % of clinical cases.

Opponents of transosseous osteosynthesis cite data on the worsening in the quality of life of patients, long duration and multi-stage nature of transosseous osteosynthesis, the risks of inflammation of soft tissues in the area of transosseous fixation elements and the development of pin-tract osteomyelitis, and contractures of adjacent joints, etc. [17].

The Masquelet technology is not without problems of free bone grafting, associated with long-term and incomplete organotypic reconstruction of massive replants, risks of pathological fractures and infection around implants, donor-site problems, bone nonunion and resorption of bone plasty materials [18, 19, 20].

To date, there is no consolidated opinion on the effectiveness of using the Ilizarov, Masquelet, or their combination technologies in long bone defect management.

No doubt, the greatest difficulty is the restorative treatment of patients with bone defects and pseudoarthrosis of long bones in conditions of purulent infection during remission and exacerbation of the inflammatory process.

Considering the effectiveness and limitations of Ilizarov and Masquelet bone grafting procedures, our team of authors came up with the idea of using them in combination. To date, we have gained positive experience in reconstructing lower leg bones using non-free Ilizarov bone grafting and the Masquelet technique, as well as their combined use in repairing acquired and congenital tibial defects [21, 22].

The effectiveness of the Masquelet technique and Ilizarov non-free bone grafting for surgical rehabilitation of patients with acquired bone defects and pseudoarthroses has been recognized, but ideal bone grafting materials and flawless reconstructive surgical procedures do not exist. Based on an assessment of the challenges and effectiveness of induced membrane and bone transport, the authors proposed a new design for technological solutions based on the original Masquelet and Ilizarov methods for the restorative treatment of patients with bone defects and pseudoarthroses [21, 22].

The outcome of our research work was this study.

The **aim** of the work is a comparative analysis of the effectiveness of the combined use of the Ilizarov non-free bone grafting and the Masquelet technique and classical Ilizarov bone transport in patients with bone defects of the tibia in conditions of active purulent infection and remission.

MATERIALS AND METHODS

The work is based on a retrospective and prospective multicenter study of the results of restorative treatment of 56 patients who underwent bone transport and a combination of the Ilizarov non-free bone grafting and the Masquelet technique to compensate tibial defects.

The results of the analysis of the scientific and clinical study are based on the interaction and coordination of the work of surgical teams and research by employees of the National Ilizarov Medical Research Center (Kurgan), a branch of the Republican Specialized Scientific and Practical Medical Center for Traumatology and Orthopedics (Samarkand, Uzbekistan) and Central City Clinical Hospital No. 23 (Ekaterinburg).

Inclusion criteria: adult patients with post-resection segmental defects of the tibia associated with active osteomyelitic process or its remission.

The patients were three groups:

- Group 1 patients ($n = 33$) were treated with a combination of the Ilizarov non-free bone grafting and the Masquelet technique to manage tibial defects in osteomyelitis remission at the specialized department of the Ilizarov Center from 2016 to 2025;
- Group 2 patients ($n = 10$) had bone defects and active manifestations of the osteomyelitic process and were treated with the combined Ilizarov-Masquelet technology at Central City Clinical Hospital No. 23 from 2020 to 2025;
- Group 3 patients ($n = 13$) with tibial defects in conditions of active purulent infection were treated using the classical Ilizarov bone transport technology at the Samarkand branch of the RSPC TD from 2019 to 2025.

In the analyzed groups, post-resection segmental defects of the tibia, type “C” defects (according to the universal classification of defects of long bones [23]) were formed.

All patients in Group 1 were of working age, ranging from 18 to 65 years (34.6 ± 15.1); there were 24 females and 9 males. Post-resection defects in the infection remission were repaired using a sequential combination of Masquelet and Ilizarov bone grafting techniques. All patients had acquired etiology of pseudoarthrosis and defects, with the majority resulting from road traffic accidents. The injury duration ranged from one to seven years (3.7 ± 1.5). All patients had previous surgical failures to manage the defects. Anamnesis collection and review of medical records revealed that intramedullary locked osteosynthesis, external osteosynthesis, and transosseous osteosynthesis were used at different stages of treatment (Table 1). Due to injuries, repeated surgeries, and inflammatory processes, the soft tissues in all patients were cicatricial, atrophic, and fused with bone fragments. Patients with an active purulent process were not included in this group. The identified nonunions were characteristic of pseudoarthrosis defects with anatomical shortening in 18 patients (66.7 %), gap defects with anatomical shortening of the segment were detected in eight patients (29.6 %), and one patient (3.7 %) had no anatomical shortening (classification by Shevtsov et al. [24]). The defects were also classified according to Karger et al. [12] (Table 1).

In Group 2, there were nine male patients and one female, aged from 21 to 66 years (46.5 ± 16.1) years. All defects of the tibia were post-resection. Post-resection defects in the of active purulent infection were managed by sequential combination of bone grafting technologies according to Ilizarov and Masquelet. Post-resection defects of the tibia measured from 3.0 to 13 cm (5.7 ± 2.9) cm, in 40 % of cases ($n = 4$) the defects of the tibia were more than 5.0 cm. Seven patients in Group 2 were found to have gap defects without anatomical shortening of the limb, three patients had defects of the tibia with anatomical shortening of the tibia (classification of V.I. Shevtsov et al. [24]). Defects of the tibia of classes II and III (according to Karger et al. [12]) were identified in nine patients, an extensive defect of the tibia of class IV (> 10 cm) in one case (Table 1). From the anamnesis, it was found that all patients in Group 2 had undergone surgical failures. Some patients did not have primary medical documentation and there was no data on the number and nature of the previous surgical interventions. It was known that patients in Group 2 had underwent external osteosynthesis, transosseous osteosynthesis, locked osteosynthesis of the tibial bones (Table 1). Before admission to the hospital, internal metal constructs were removed in five patients, but the arrest of the active purulent process was not achieved.

Group 3 included 13 patients aged 16 to 57 years (34.2 ± 14.6 years), 11 males and two females. Post-resection defects of the tibia measured from 3.0 to 13 cm. All patients in Group 3 underwent classical non-free bone grafting techniques with tibial defect repair by fragment lengthening

under the conditions of active purulent infection. The time since injury ranged from three months to three years; the injuries were sustained in road traffic accidents and at home (Table 1). According to the anamnesis, 11 patients in this group had undergone multiple unsuccessful surgeries; two patients had no previous surgery and were admitted to the hospital after ineffective conservative treatment complicated by an osteomyelitic process. Patients in Group 3 had previously undergone external osteosynthesis, transosseous osteosynthesis, and locked osteosynthesis of the tibia bones (Table 1). Before admission to the hospital, internal metal structures were removed in six patients, but the active purulent process persisted. In all patients in Group 3, after sequester necroectomies and segmental resections of the tibia, gap defects without anatomical shortening of the limb were formed (classification by Shevtsov et al. [24]). Defects of classes II, III, and IV were revealed (according to Karger et al. [12]), and a class IV defect was verified in two patients (Table 1).

All patients in Groups 2 and 3 had an active purulent infection, classified by us according to Cierny – Mader as type IV (diffuse osteomyelitis) with loss of segment stability and entire bone diameter involvement [25].

Table 1

Characteristics of patients

Parameters	Group 1 (<i>n</i> = 33)		Group 2 (<i>n</i> = 10)		Group 3 (<i>n</i> = 13)	
	<i>n</i>	%	<i>n</i>	%	<i>n</i>	%
Males	9	27.3	9	90	11	84.6
Females	24	72.7	1	10	2	15.4
Road traffic injury	21	63.6	6	60	6	46.2
Household injury	9	27.3	2	20	7	53.8
Production site injury	2	6.1	–		–	
Gunshot injury	–		2	20	–	
Postresection defect	1	3.0	10	100	13	100.0
Previous treatments						
Intramedullary locked nailing	13	39.4	3	30	1	7.7
Plating	13	39.4	8	80	9	69.2
Transosseous osteosynthesis	7	21.2	7	70	3	23.1
History of osteomyelitis	33	100.0	10	100	13	100.0
Active infection	–	–	10	100	13	100.0
Class I defects (> 2 cm)	4	12.1	0	0.0		
Class II defects (2–5 cm)	19	57.6	5	50	1	7.7
Class III defects (5–10 cm)	9	27.3	4	40	10	76.9
Class IV defects (> 10 cm)	1	3.0	1	10	2	15.4

In patients in Groups 1 and 2, a sequential combination of Masquelet and Ilizarov non-free bone grafting techniques was used in the conditions of osteomyelitic remission (Group 1, *n* = 33) and active purulent infection (Group 2, *n* = 10). Surgical interventions were performed in two stages. The first stage of treatment involved segmental resection of the defect area and pseudoarthrosis, followed by transosseous fixation of the segment with the Ilizarov apparatus. Depending on the pathogen identified intraoperatively from the source of infection, etiotropic antibiotic therapy was prescribed. In patients in Groups 1 and 2, the apparatus configuration allowed for osteotomies (corticotomies) of fragments after spacer removal to fill the post-resection defect using the Ilizarov bone transport. In patients in Group 1, a preformed polymethyl methacrylate cement spacer, ranging in length from 3.0 to 11.0 cm (5.4 ± 1.3 cm) was implanted intraoperatively into the interfragmentary gap. In half of the cases, bone cement mixed in the factory with an antibiotic (gentamicin) was used; the remaining spacers were made from cement with the addition of antibiotics (gentamicin, vancomycin) in the operating room.

In patients of Group 3, the classical Ilizarov technology of lengthening the proximal or distal fragments of the tibia was used to compensate post-resection bone defects.

The work used methods of descriptive statistics (mean value and its standard deviation).

The ethical principles of the World Medical Association's Declaration of Helsinki (2024 amendments) were observed in the study. All patients were informed on the treatment and diagnostic procedures being performed and provided written consent for publication of the study results.

RESULTS

During the two-stage treatment, spacers were removed in patients in Group 1 after three to six weeks. Spacer implantation lasted from 24 to 46 days (38.3 ± 3.8). The time between surgical stages was determined by a combination of factors (organizational, logistical, etc.) independent of the department's medical staff. The second surgical stage included spacer removal with minimally invasive trauma to the biomembrane, wound suturing, osteotomy (corticotomy) of the tibia fragments, osteotomy of the fibula for possible correction of segmental deformity, rearrangement of the Ilizarov apparatus, and, if necessary, re-insertion and additional insertion of transosseous fixation elements.

To manage acquired defects in this group of patients, we limited ourselves to single-level fragment lengthening. Distraction began on the fifth to seventh postoperative day at a rate of 0.5–1.0 mm per day, depending on the activity of distraction osteogenesis, monitored radiographically. The duration of distraction for tibial fragment transport was 62.4 ± 10.4 days. Compression along the tibial axis was maintained at the fragment junction at a rate of 1 mm once every two weeks until fragment consolidation was achieved, verified radiographically and clinically. The average duration of tibial fixation in the apparatus was 163.4 ± 5.6 days. After apparatus removal, all patients were recommended to immobilize the operated tibia with a splint or orthosis for up to six weeks, followed by physical therapy. Residual anatomical shortening of the tibia, ranging from 1.0 to 6.0 cm (3.6 ± 1.2 cm), was detected in five patients within 8–10 months of device removal, following complete organotypic remodeling of the reconstructed bone. In two cases (7.4 %), recurrence of the purulent process was observed within one year of device removal and removal of the transosseous fixation elements, requiring minor surgical procedures and medication therapy.

A clinical case treated with a combination of Masquelet and Ilizarov non-free bone grafting technologies in the conditions of osteomyelitis remission (Group 1)

A 50-year-old female patient sustained an open fracture of her right tibia in a traffic accident one year prior to surgery. Her medical history included osteosynthesis of the right tibia with an external fixator, but union was not achieved.

Diagnosis at admission: Post-traumatic deformity of the right tibia, pseudoarthrosis of the right tibia. Combined contracture of the knee and ankle joints. Shortening of the right lower limb by 2.0 cm. Chronic post-traumatic osteomyelitis of the right tibia, in the remission phase (Fig. 1 a).

The first stage of osteosynthesis involved resection of the right tibia fragment ends, implantation of a cement spacer, and osteosynthesis of the tibia using the Ilizarov apparatus. The resulting post-resection defect (gap) of the tibia was 3.0 cm (Fig. 1 b). Intraoperative wound cultures revealed a *Staphylococcus capitis* microflora growth of 10^3 CFU/ml. The duration of fixation in the Ilizarov apparatus at the first stage of surgical treatment was 44 days. The postoperative wound healed by primary intention.

During the second surgical stage, the following procedures were performed: removal of the cement spacer, corticotomy of the proximal fragment of the right tibia, placement of additional transosseous

fixation elements, and rearrangement of the Ilizarov apparatus. Intraoperative cultures were taken from the wound and the spacer surface; no microflora growth was observed. Postoperatively, on the fifth day, distraction was initiated using the apparatus to move the osteotomized fragment of the right tibia into the defect area to the junction with the opposing fragment at a rate of 1 mm per day in four steps. The distraction duration was 30 days (Fig. 1 b, c). After distraction, the patient was discharged for outpatient stay at her place of residence. Recommendations were given to maintain compression at the junction of the tibial fragments using the apparatus at a rate of 1 mm once every two weeks. The duration of fixation in the apparatus was 218 days. Union was achieved, the tibial defect was repaired, the axis, length, and function of the right lower extremity were restored, and no recurrence of the purulent process was recorded (Fig. 1 g). The fixator was removed, and the lower leg and adjacent joints were immobilized with a brace for four weeks. The patient did not return to repeat surgery.

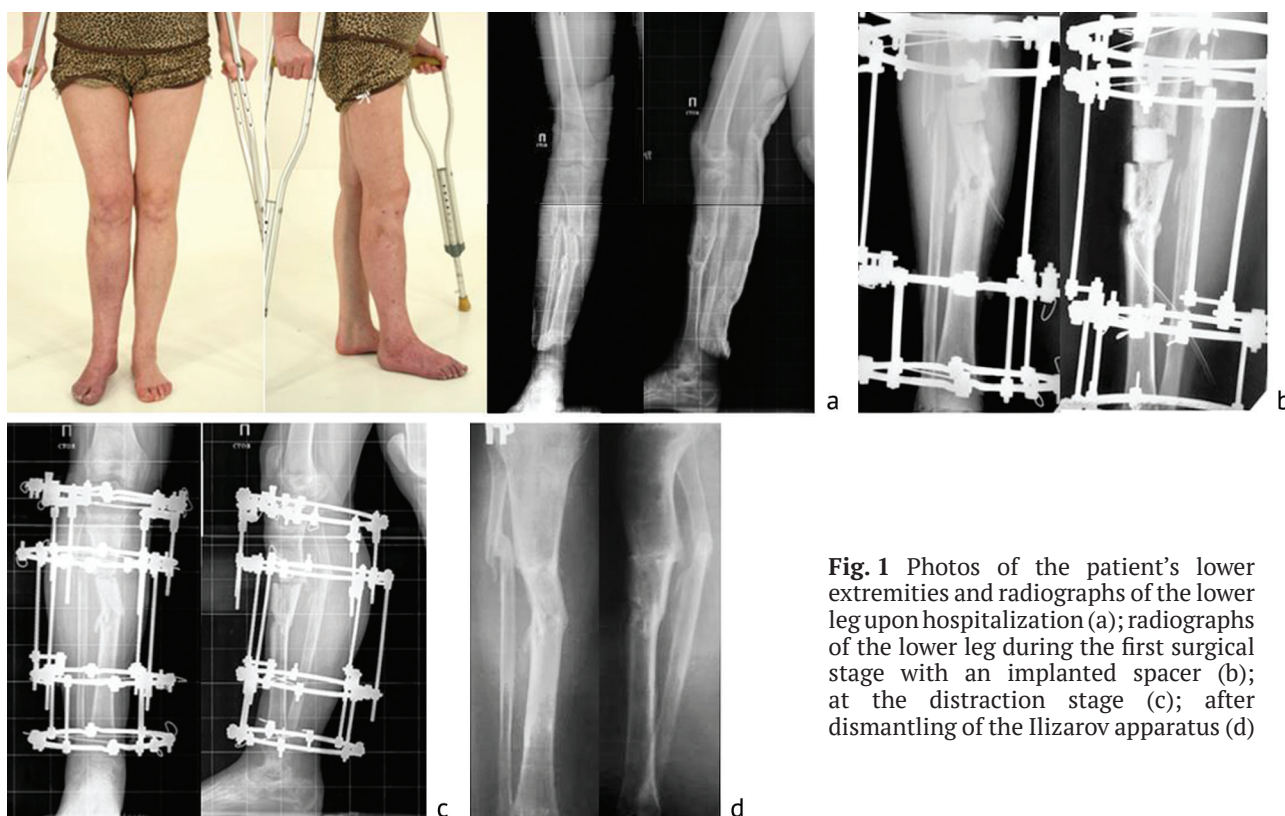


Fig. 1 Photos of the patient's lower extremities and radiographs of the lower leg upon hospitalization (a); radiographs of the lower leg during the first surgical stage with an implanted spacer (b); at the distraction stage (c); after dismantling of the Ilizarov apparatus (d)

In patients in Group 2, intraoperatively fabricated polymethyl methacrylate cement spacers were implanted into the resulting post-resection defects. The spacers were shaped to the desired cylindrical size to accommodate the interfragmentary gap, with a prophylactic dose of gentamicin or vancomycin added to the cement. According to the literature, intraoperatively fabricated spacers are weaker than commercially manufactured spacers, and mixing the polymethyl methacrylate cement with an antibiotic also reduces the mechanical strength of the implant [26]. Therefore, spacers longer than 5 cm were additionally reinforced (Fig. 2).

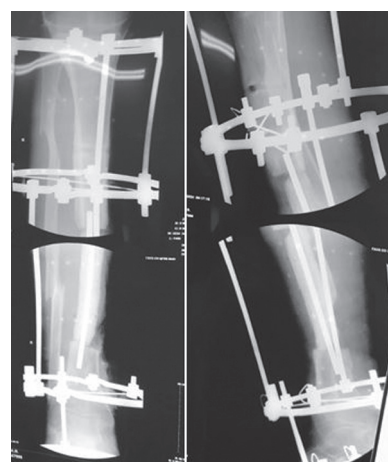


Fig. 2 Radiographs of the lower leg in two projections with a reinforced implanted spacer

In two patients (20 %) in Group 2, wounds healed by secondary intention at the time of spacer removal, with persistent purulent fistulas. In one case, the wound initially healed by primary intention, but the fistula reopened during outpatient treatment, six weeks after spacer implantation. Wound cultures were positive for *S. aureus* (MRSA) and *Enterobacter* spp. Following spacer removal and repeated radical debridement, the postoperative wound healed by primary intention. The patient was scheduled for a follow-up appointment and hospitalization for further leg reconstruction four to five weeks after spacer implantation, but he failed to present on time.

In eight patients of Group 2, post-resection defects were compensated by lengthening the proximal tibial fragment using the Ilizarov method. In two clinical observations, tibial defects were compensated by lengthening the opposing fragments towards each other with polylocal formation of distraction regenerates [27]. Transport of bone fragments took (63.9 ± 15.15) days. By the time the transported fragments contacted with the opposing fragments, the endplates at the ends of the fragments were not formed in the majority of clinical cases. After removal of spacers, the ends of the fragments were additionally sparingly treated, and in the presence of fistulas, in two clinical observations, they were additionally processed radically. The absence of endplates allowed for closed reduction and co-adaptation of bone fragments ends in eight patients. In two clinical cases, the ends of the tibial fragments were openly adapted. Compression of 1.0 mm was maintained at the fragments junction every 10–14 days until fragment consolidation was achieved. The duration of segment fixation with the apparatus in Group 2 was 150.5 ± 19.4 days. Complete suppression and elimination of the purulent process was not achieved in one clinical case.

It is necessary to underline the radical approach to the debridement of the purulent infection focus in patients of Group 3. As a result of radical sequester necroectomies, post-resection defects of the tibia ranged from 3.0 to 13.0 cm (7.8 ± 2.8) in size. Relapses of the purulent process were not detected during the observation stages. The terms of the treatment process were long, distraction was performed for (115.3 ± 37.5) days. Post-resection defects were filled by lengthening of the proximal tibial fragment in 11 clinical observations; in two patients, the bone defect was compensated for by lengthening of the distal tibial fragment. Due to segmental resections of the tibia, defects of the tibia with congruent ends of the opposing fragments were formed, which enabled to perform closed co-adaptation of the ends of the fragments after bone transport in 11 patients. In two clinical cases, open reduction of the fragment ends was performed with sparing resection of the fragment ends, removal of the endplates, and exposure of the bone marrow canals of the fragments. The time required for fixation of the tibia fragments was also long. Bone union between the ends of the tibia fragments in patients in Group 3 required from 221 to 623 days (331.9 ± 122.9).

Clinical case of a tibial defect managed by lengthening the proximal fragment (Group 3)

A 21-year-old patient was injured in a traffic accident. At the local hospital, transosseous osteosynthesis of the tibia with wire fixation of the fragment ends was performed. Postoperatively, an infected skin defect developed at the fracture level, with bone fragments forming the wound bottom, and the wires securing the fragment ends were visible (Fig. 3 a). The patient underwent radical sequester necroectomy, resulting in a 10-cm post-resection defect (Fig. 3 b). Fifty days after the radical sequester necroectomy, an osteotomy was performed to fill the post-resection defect by lengthening the proximal tibial fragment (Fig. 3 c). Distraction was continued for 177 days. After transport of the non-free autograft, the tibial fragments were adapted in a closed manner (Fig. 3 d). Consolidation of the tibial fragments was achieved (Fig. 3 e).



Fig. 3 Photo of the limb and radiographs of the patient's lower leg before admission (a); photo of the limb after sequester necrotomy (b); radiographs of the lower leg after osteotomy of the proximal fragment during the displacement of the formed fragment (c); radiographs of the lower leg after closed co-aptation of the ends of the fragments (d); photo of the limb and radiographs of the patient's lower leg at long-term follow-up (e)

A clinical case of filling a tibial defect by lengthening the distal fragment (Group 3)

A 19-year-old patient sustained an open fracture of the right tibia diaphysis in a traffic accident. The patient underwent external fixation with the Ilizarov apparatus using a combination of pins and wires for tibial osteosynthesis. The postoperative period was complicated by an osteomyelitic process; an infected wound with a soft tissue defect formed in the diaphyseal region of the tibia, the wound bottom being fragments of the tibia (Fig. 4 a). Sequesterectomy, removal of infected metal structures, pins and wires (Fig. 4 b) resulted in a post-resection segmental defect measuring 10 cm (Fig. 5 a).



Fig. 4 Photos and radiographs of the patient's lower leg upon admission (a); photo of the limb and intraoperative biopsy material after sequesterectomy (b)

Once the postoperative wound healed by secondary intention (Fig. 5 b), osteotomy of the distal tibial fragment was performed to fill the resulting postoperative defect. Retrograde transport of the tibial fragment to the junction with the opposing proximal fragment was performed for 147 days. Given the location of the post-resection defect and damage to the intraosseous artery, retrograde transport of the fragment was performed at a rate of 0.5–0.75 mm per day in two to three steps (Fig. 5 c). Due to the formed endplates at the fragment ends and closure of the medullary canals, open coaptation of the tibial fragment ends was required. Formation of a bone union between the fragment ends lasted 329 days. The treatment resulted in restoration of the integrity of the bone skeleton of the limb and elimination of the purulent inflammatory focus (Fig. 5 d, e).

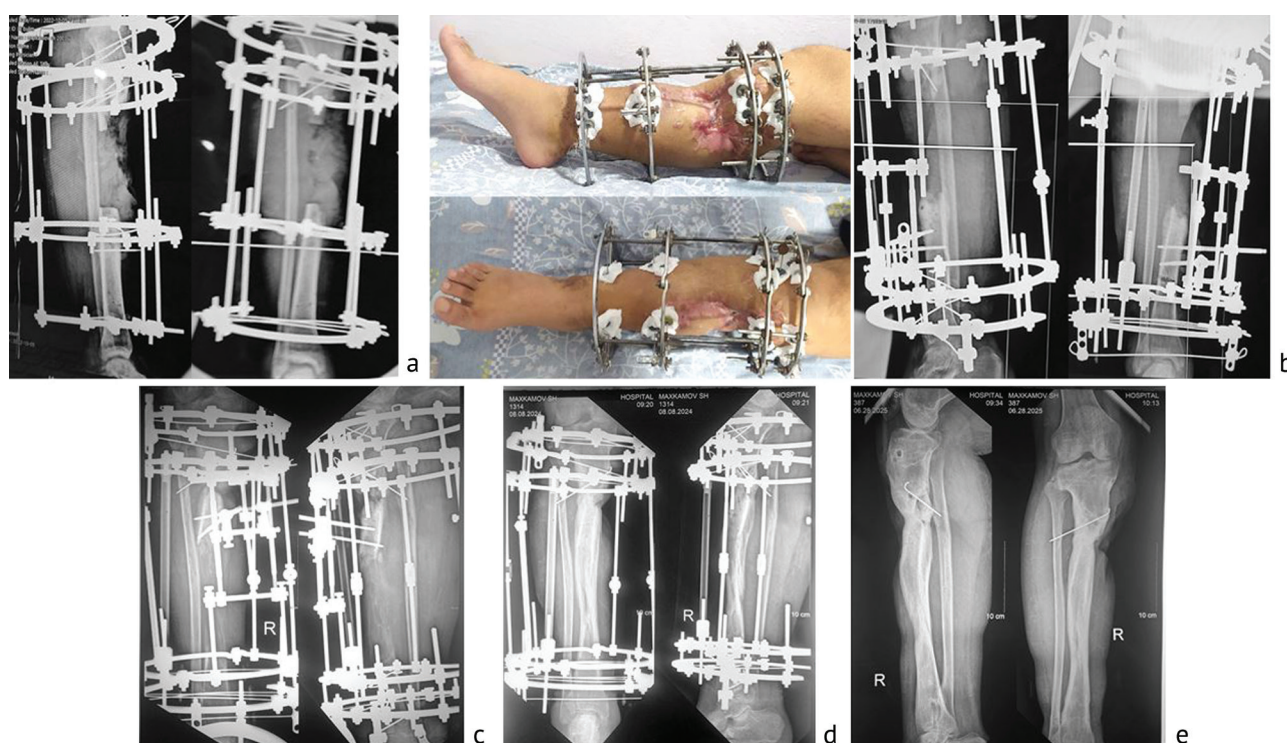


Fig. 5 Radiographs of the lower leg after sequester necrosectomy (a); photo and radiographs of the patient after osteotomy of the distal tibial fragment (b); radiographs of the lower leg at the bone transport stage (c); radiographs of the lower leg, achieved treatment result (d); radiographs at the long-term follow-up period (e)

DISCUSSION

According to the literature, the newly formed membrane around the spacer is vascularized and contains mesenchymal stem and epithelial-like cells, fibroblasts, myofibroblasts, growth factors, and morphogenetic proteins [28, 29, 30]. The secretion of membrane-induced growth factors reaches its peak between the fourth and sixth weeks after spacer implantation [31]. The formed induced membrane has antimicrobial activity, which is associated with the presence of antioxidant chemicals locally secreted with growth factors [32]. The antimicrobial activity and resistance of newly formed tissues to purulent infection are entirely consistent with the concept of Ilizarov and Paevsky on the bactericidal activity of tissues and the sanitizing effect of purulent wounds under conditions of dosed and discrete stretching. According to Masquelet, the formation of an induced membrane, and the use of an antibiotic-saturated spacer without thorough surgical treatment of the wound do not guarantee suppression of purulent infection [33]. Some clinical studies reported that with the use of Masquelet bone grafting alone, the purulent process was not arrested in 8.1–8.8 % of patients [4, 34].

According to a literature review by Minasov et al., custom-made spacers manufactured intraoperatively are less durable than factory-made ones; addition of antibiotics to polymethylmethacrylate cement also leads to a decrease in the mechanical strength of the spacer [26]. In our opinion, reinforcing

the spacer and using external fixation devices in neutral osteosynthesis mode at the first stage of tibia reconstruction in patients in Group 2 is justified and reduces the risk of failure of a massive implant.

It is known that the elution of an antibiotic from a polymethyl methacrylate cement spacer into the surrounding tissues does not exceed 10 % of the initial dose and, of course, depends on the characteristics of the active substance and the structure of the implant, but, as a rule, does not exceed 2–3 mm from the periphery of the spacer [36].

We support the opinion of researchers that suppression of purulent infection is ensured by radical surgical debridement of the lesion and local creation of an antibiotic depot in compromised tissues [4, 37]. The key to the successful solution of the stated therapeutic problems is the rational choice of osteosynthesis options and their possible combined use [21]. We assume that secondary healing of postoperative wounds and the formation of fistulas with purulent discharge in the area of implanted spacers in two clinical cases of Groups 1 and 2 are primarily associated with non-radical surgical debridement of infection foci. It should be noted that with a combination of the Ilizarov non-free bone grafting and the Masquelet technique, fragment elongation occurs under the conditions that are favorable for distraction osteogenesis. The transport of a non-free bone autograft runs without technical problems through sanitized tissues when an induced membrane has formed along the periphery of the transported fragment [21].

The conditions for bone transport predetermined different durations of the transosseous osteosynthesis stages for restoration of similar-size tibial defects. In patients of Groups 1 and 2, the duration of the osteosynthesis stages was quite comparable. In patients of Group 1, the transport of fragments continued (62.4 ± 10.4) days, the fixation stage was (163.4 ± 5.6) days. The duration of distraction in patients of Group 2 was (63.9 ± 15.15) days, the fixation period was (150.5 ± 19.4) days. Surgical rehabilitation of patients of Group 3 took longer: distraction was lasted for (115.3 ± 37.5) days, and additional (331.9 ± 122.9) days were required for the restoration of the bone skeleton of the tibia. However, for an objective assessment of the duration of treatment, it is necessary to take into account the duration of the additional first surgical stage of treatment in Groups 1 and 2, when, before bone transport, patients underwent debridement of the purulent focus under the conditions of transosseous osteosynthesis and implantation of a spacer for four to six weeks.

The main conclusion of the analysis of the surgical rehabilitation results for patients in Group 3 is the recognition of the imperative need for radical debridement of the purulent infection site. The importance of radical surgical debridement for stopping osteomyelitis and reducing the risk of recurrence of the purulent process is not new. The most significant opinion is not that of the surgeon, but of the renowned bacteriologist Fleming: "The severity of the wounds creates an excellent breeding ground for bacteria that the body's natural defenses cannot cope with; and if the surgeon were able to completely remove this dead tissue, then I am absolutely certain that the infection would become completely insignificant" [38].

However, the obtained data indicate that non-radical debridement of infection foci in patients of Groups 1 and 2, including in the remission of the activity of the purulent process with the implantation of massive spacers with a prophylactic dose of antibiotics, does not guarantee persistent suppression of the focus of purulent infection and does not exclude the risks of exacerbation of the osteomyelitic process.

CONCLUSION

In the conditions of combining the Masquelet technique and Ilizarov non-free bone grafting, despite the implantation of spacers with a prophylactic dose of antibiotics and empirical antibacterial therapy, the risk of purulent recurrence remains if debridement of the infection is not radical.

However, by combining the Masquelet technique and Ilizarov non-free bone grafting, the induced membrane during the second stage of surgical treatment is adequately vascularized, contains mesenchymal stem and epithelial-like cells, myoblasts, and fibroblasts, synthesizes growth factors (VEGF, TGF-beta 1), and contains the morphogenetic proteins BMP-2 and BMP-7. This creates favorable conditions for distraction osteogenesis. The formation of an induced membrane and the use of a spacer with antibiotics do not eliminate the risk of exacerbation of the inflammatory process.

Ilizarov fragment lengthening is performed under favorable conditions of external fixation. In combined techniques, no soft tissue inflammation in the area of the wires was observed during bone fragment transport, necessitating their removal and elimination of the pin-tract osteomyelitis. Clinical results of patients in Group 3 indicate that reliable arrest of infection is only possible after radical surgical debridement and sanation of the purulent bone wound.

The result of surgical rehabilitation of patients with segmental post-resection defects of the tibia in the conditions of active purulent infection and its remission is the restoration of the bone framework of the tibia and compensation for the lost bone tissue with distraction regenerates that undergo complete organotypic restructuring with remodeling of newly formed bone and a reduction in the risk of osteomyelitic process recurrence.

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