ISSN 0030-5987. Orthopaedics, traumatology and prosthetics. 2023. № 4

IN AID OF PRACTING DOCTOR. LECTURES

УДК 617.57/.58-089:616.717/.718-001.45-001.47](045)

DOI: http://dx.doi.org/10.15674/0030-59872023471-78

Experience of the segmental bone defects' treatment for patients with combat trauma using the method of distraction osteogenesis

S. V. Hariyan [1], O. S. Tsybulskyi [1], V. P. Makhovskyi [1], Z. V. Salii [2]

[1] Ternopil Regional Hospital. Ukraine

[2] I. Horbachevsky Ternopil National Medical University. Ukraine

Upper and lower limb injuries resulting from battlefield trauma is a complex multidisciplinary problem. Efficacy of the treatment of segmental bone defects in patients with combat trauma is a subject of analysis for improving its results. Purpose. An analysis of the modern treatment strategies of the segmental bone defects in patients with battlefield trauma under conditions of distraction osteogenesis (based on data available in the literature and own clinical experience). Methods. Analytical review of scientific works and analysis of treatment results of 39 patients with segmental bone defects associated with battlefield trauma and treated using distraction osteogenesis were conducted. Results. Patients with segmental limbs defects require special attention of a multidisciplinary team of specialists to identify reconstructive opportunities to save the limb. Distraction osteogenesis — is an effective method of treating of segmental fractures and shortening of the limbs, infectious complications that led to bone defect formation. Bone transport with ring external fixator (ExFix) is considered as a classical method. Authors analyzed and illustrated with three clinical cases their own results of application of different distraction osteogenesis technique. Conclusions. Different types of ExFix can be applied independently or in combination with internal fixators. The use of an intramedullar nail along which distraction osteogenesis is carried out allows to provide better control of the axis of the limb and transported fragment, reduce the residence time in the ExFix, and, moreover, external fixation devices with a simpler configuration can be used. Transport along the plate allows to maintain proper axial relationships in the presence of short periarticular fragments and improve the quality of fixation but it also increases the risks of FRI and re-operations.

Травми верхніх і нижніх кінцівок, отримані в результаті бойових дій, є складною мультидисциплінарною проблемою. Ефективність методик лікування сегментарних кісткових дефектів у пацієнтів із бойовою травмою — предмет аналізу з метою покращення їхніх результатів. Мета. Проаналізовано сучасні стратегії лікування сегментарних кісткових дефектів у пацієнтів із бойовою травмою за умов використання методики дистракційного остеогенезу. Методи. Проведено аналітичний огляд 165 наукових праць і проаналізовано 39 власних клінічних випадків лікування сегментарних кісткових дефектів у хворих із бойовою травмою з використанням методики дистракційного остеогенезу. Результати. Пацієнти зі сегментарними дефектами кінцівок потребують особливої уваги мультидисциплінарної команди спеціалістів для визначення реконструктивних можливостей порятунку кінцівки. Дистракційний остеогенез — дієвий метод лікування сегментарних переломів і вкорочень кінцівок, інфекційних ускладнень, які призвели до формування дефекту. Класичним методом вважається кістковий транспорт у кільцевому апараті зовнішнього фіксації (АЗФ). Наведено 3 клінічні випадки власних результатів застосування різних технік дистракційного остеогенезу. Висновки. Різні варіації АЗФ можна застосовувати або поєднати методи АЗФ із внутрішніми фіксаторами. Використання інтрамедулярного стрижня, вздовж якого проводиться дистракційний остеогенез, дозволяє краще контролювати вісь кінцівки й транспортного фрагмента, зменшити час перебування в АЗФ, а засоби фіксації можуть бути простішої конфігурації. Виконання транспорту вздовж пластини дозволяє утримати правильні осьові взаємини за наявності коротких навколосуглобових фрагментів і підвищити якість фіксації, проте збільшує ризики FRI та повторних операцій. Ключові слова. Сегментарний кістковий дефект, бойова травма, дистракційний остеогенез.

Keywords. Segmental bone defect, combat trauma, distraction osteogenesis

Introduction

Injuries of the upper and lower extremities, received as a result of hostilities, pose many challenges to the doctor: much more than in the case of high-energy injuries in the civilian population. The large amount of kinetic energy transferred from warheads creates a wide area of soft tissue and bone damage. In addition, the “outside-in” explosion mechanism often leads to significant contamination of the wound with fragments of clothing, shoes, soil, etc. [1]. The morphology of bone fractures is also atypical and uncharacteristic for civilian trauma and cannot be classified in a standard way. This uniqueness of injuries significantly complicates the implementation of a plan to save the limb, requiring careful preoperative planning [2]. Early, aggressive wound dressing and irrigation is the cornerstone in the treatment of severe open fractures [3]. Combat trauma requires careful removal of all non-viable soft tissue. Avascular, extra-articular bony tissue without soft tissue attachment should also be removed, regardless of size. A detailed intraoperative expert evaluation by a traumatologist with subsequent consultation of plastic and vascular surgeons is necessary to save and preserve a functional, non-infected, painless limb [4]. Numerous scoring systems have been developed to predict the ability to salvage mutilated limbs.

Due to the high risk of early or late amputation, special attention should be paid to limbs with a large defect of both soft tissues and bone associated with vascular and nerve bundle injury [5].

Purpose: modern strategies for the treatment of segmental bone defects in patients with combat trauma using the technique of distraction osteogenesis were analyzed.

Material and methods

Literature sources were searched in the PubMed database with a depth of 12 years. 165 publications were selected, which give examples of the treatment of segmental bone defects in patients with combat trauma using the technique of distraction osteogenesis.

The effectiveness of the method was evaluated based on the assessment of treatment outcomes in 39 patients, whose primary injury was the result of a mine-explosive injury, they were treated in the in -patient orthopedic department of Ternopil Regional Hospital, TRH. The study was discussed and approved at a meeting of the Bioethics Committee at I. Ya. Gorbachevskii Ternopil National Medical University of the Ministry of Health of Ukraine (Protocol No. 75 dated 1.11.2023).

Results and their discussion

The most common approach when treating patients with combat trauma is a stepwise one. Thus, according to the concept of the military medical service of France, in the case of a combat injury of the lower limb, it is necessary to observe the principle of preserving life, limb, function [2]. The doctrine of reconstruction is based on the 6/7/8/9 rule, according to which the strategies for restoring soft tissues and lost bone are developed: rehabilitation of the focus within 6 hours, restoration of soft tissues and/or bone coverage within 7 days, osteosynthesis and/or reconstruction of voids in the bone after 8 weeks, in order to achieve functional recovery after 9 months [6].

In most hospitals that provide assistance to the military, early debridement and its subsequent repetition after 48 hours are considered a standard treatment protocol for combat trauma [7].

Cement spacers impregnated with antibiotics [8] are implanted in large bone defects to fill the “dead space” and obtain a local effect of the antimicrobial drug in a high concentration. The authors [8] managed to achieve a significant reduction in the wound cleaning time, a reduction in the number of repeated surgical treatments before wound closure and the duration of antibiotic therapy.

In most cases, it is necessary to apply negative pressure wound therapy (VAC therapy) [9].

As soon as the wound becomes stable and there are no signs of early infection, it is closed. Various techniques are used for this: plastic surgery with a split skin graft or a full-layer skin-fascial or muscle flap [10]. Often, the technique of closing the defect with a vascularized flap is used early to combat infectious complications. A delay in plastic surgery of the wound is allowed for several days or weeks, if there are signs of a severe wound infection.

The transition from a temporary monoplanar external fixation device (EFD) installed in the early stages of care to a more stable annular EFD or to internal fixation is performed on the condition that no further treatment of the wound is necessary. Once the wound has been successfully closed and infection has been avoided, treatment of the bone defect can begin.

Based on the classification of AO fractures, L. Solomin and T. Slongo [11] in 2016 proposed the following systematization of bone defects: cavitary (type A): A1 — diaphyseal, A2 — metaphyseal, A3 — epiphyseal; wedge-shaped, with preserved contact of the main fragments (type B): B1 — full contact of the main fragments, the length of the limb is preserved, B2 — partial contact, the length of the limb is preserved, B3 — partial contact, the limb is shortened; type C — segmental; type D — with a defect of the articular surface (Fig. 1).

A treatment option for type A and B defects is bone grafting with auto-, allografts or bone substitutes.

There are several strategies of bone transplantation: vascularized and nonvascularized autogenous or allogeneic [12]. The most common treatment option for acute and reconstructive defects in traumatology is bone autotransplantation [13]. An autologous bone implant can be used in the form of spongy and cortical bones and bone marrow aspirate. It is collected from the anterior and posterior parts of the pelvis (with the help of an acetabular reamer), from the intramedullary canal of long bones in case of a need for a larger volume of bone mass, or from the proximal part of the tibia or the distal part of the thigh, for example, in the case of interventions on the foot or pylon fractures. Good osteogenetic, osteoinductive and osteoconductive potential make this variant the "gold standard" for the treatment of partial bone defects (types A and B according to the classification of L. Solomin and T. Slongo). However, problems in the area of graft collection (pain, formation of local hematomas, long-term drainage of the wound, repeated operations) and its limited amount lead to complications during the treatment of a certain group of patients. For example, in persons with severe multiple limb injuries and bone defects in several areas and in a group of patients who have a constitutionally smaller bank of bone mass. The frequency of complications after taking a bone graft is 8.6 % [14].

Allograft is an alternative means of treatment of complex bone defects. The absence of pain in the donor area, the potentially "unlimited" quantity and the ready-to-use state make it a desirable alternative to bone graft for surgeons and patients. However, the processing and storage process (freezing and

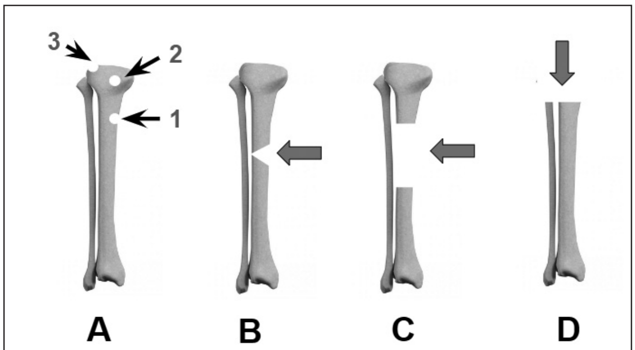

Fig. 1. Types of bone defects

freeze-drying) reduce its osteogenic and osteoconductive potentials [15].

In the literature [16], the prospect of using the strategies of injection engineering of bone tissue and osteogenic cell sheet is quite clearly analyzed, indicating certain limitations, due to the complexity and ineffectiveness of these methods in clinical practice, especially for the restoration of defects of large segmental bone, which bears the load. The experiment demonstrated a good potential of osteoinductive calcium phosphate bioceramics during the regenerative repair of large bone defects that are loaded [17]. Alkindi M. et al. [18] evaluated the effectiveness of controlled bone regeneration of the rat femur using osteoconductive horse bone grafts and beta-tricalcium phosphate without platelet-derived growth factor. In the future, it may be a potential clinical alternative for the reconstruction and regeneration of segmental bone defects. Yingkang Yu. [19] in an experiment on rabbits proved the perspective of combining a matrix obtained from progenitor cells with a hydrogel.

For the treatment of segmental bone defects, the techniques of induced membranes or distraction osteogenesis are used. Shen Z. et al. [20] in experimental models tried to answer the question about the influence of the size of the segmental bone defect on the choice of treatment method. The use of the induced membrane technique had better results for the largest bone defects, and distraction osteogenesis — in the case of small and medium-sized defects. The authors point to the need for further research and emphasize caution and caution in extrapolating these findings to relevant models in humans.

The clinical results of the treatment of segmental bone defects of the lower limbs after post-traumatic osteomyelitis [21] have already demonstrated a better functional effect from the use of the induction membrane technique in the case of femoral bone damage, and distraction osteogenesis in cases of limb deformity and peri-articular bone defects. However, Akgun U. et al. [22] point out the limitations of this study that may distort the results, namely the ratio between patients of 1:4 and the comparison of processes in bones with different vascularization.

The technique of induced membranes is a method of treatment of bone defects that uses cancellous bone autograft shavings. This technique is most effective when treating segmental bone defects, or in the case of necrotic or infected bone tissue. It was initiated by Masquelet [23], it includes two stages. At the first, a radical treatment is carried out with the removal of non-viable or infected bone, then a stable fixation is achieved and a block of cement spacer is placed in the area of the defect. After 4–8 weeks, when a self-induced periosteal membrane is formed, the cement spacer is removed and the defect is replaced with a cancellous bone graft [24]. That is, the probability of graft resorption decreases and the possibility of its revascularization and coagulation increases. Clinical studies prove the effectiveness of this technique without recurrence of infection in septic and aseptic non-unions of the lower leg and diaphyseal bone defects. Also, the effectiveness of the autologous bone graft is increased by increasing the mechanical stability through the cement spacer. Osteogenicity also increases due to significant vascularization of the periosteal membrane caused by the location of the cement spacer [23]. Using this technique, 80–100 % fusion is achieved in the case of long-term follow-up of patients [25]. The most common complication is recurrent infection, which, according to Morelli [26], accounts for about half (49.6 %) of all complications during the treatment of open tibial fractures with segmental defects. The following in frequency are the need for additional bone grafting, repeated fractures of the bone regenerate, and a combination of complications: non-union, resorption of the regenerate, infection that leads to limb amputation.

Considering the risks of infectious complications, the most common method of treatment of segmental bone defects in combat trauma, especially of the lower extremities, is the technique of distraction osteogenesis [13]. This is a biological process of new bone formation between bone segments, which are gradually separated under the influence of increasing gravity. At the same time, there are signs of active histogenesis occurring in the surrounding soft tissues — skin, fascia, muscles, blood vessels, and peripheral nerve fibers, which make it possible to significantly move the bone. From a biological point of view, distraction osteogenesis, starting with a violation of the integrity of the bone and throughout the entire evolutionary process of transforming the regenerate into a full-fledged bone tissue, can be divided into the following stages [27]: osteotomy, induction of inflammation, formation of soft or hard bone callus, remodeling.

Three periods of distraction osteogenesis are distinguished: latent, distraction, and consolidation [28].

Distraction osteogenesis begins with the formation of fibrous tissue — a soft bone callus — along the distraction axis at the osteotomy site [29]. With gradual stretching of the soft bone callus, its fibers are located parallel to the direction of distraction. Between the 3rd and 7th days, capillaries grow into the fibrous tissue, expanding the vascular network not only in the direction of the center of the distraction gap, but also in the medullary canals of both bone fragments. Often, the newly formed vessels in the distraction regenerate have a spiral course and numerous circular folds, as a result of which the speed of their growth significantly exceeds the course of the distraction, and the process of vessel sprouting during normal fracture healing is 10 times higher [30].

During the 2nd week of distraction, primary osteons begin to form, osteogenesis processes are initiated on the existing bone walls and progress towards the center of the distraction gap. At the end of this period, the osteoid begins to mineralize, the distraction regenerate has a specific zonal structure. In the center of the distraction gap, where the influence of stretching forces is maximal, there is a weakly mineralized radiolucent fibrous intermediate area, which is the center of fibroblastic proliferation and the formation of fibrous tissue. On its periphery, there are two areas with longitudinally oriented cylindrical primary osteons, which are covered with a layer of osteoblasts and grow in the direction of each other. This regional distribution of the formed bone tissue is preserved until the end of the distraction period. Two additional areas of primary remodeling of osteons are formed, which are localized at the border of the regenerate and bone fragments. After the end of the distraction period, the fibrous intermediate zone gradually ossifies, and another clearly visible area of coarse-fibrous bone tissue connects the bone fragments with abridge. In the process of maturation of the regenerate, the zone of primary osteons significantly decreases and is completely resorbed. In the following months, the newly formed bone strengthens parallel to the fibers and lamellar bone. The last stage of cortical reconstruction is Haversian reconstruction.

At the end of the distraction period, the first radiological signs of bone tissue regeneration are mostly revealed: the bone regenerate is oriented along the di-

Fig. 2. Radiograph after installation of EFD (direct and lateral projections)

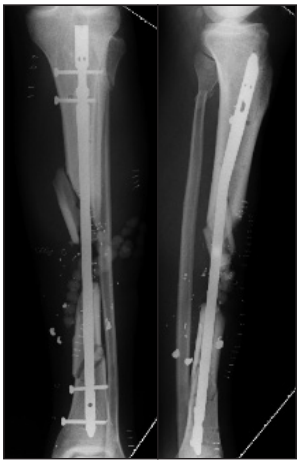

Fig. 3. X-ray (direct and lateral projections). Fixation of the tibia with a rod. Cement “beads” in the area of the defect

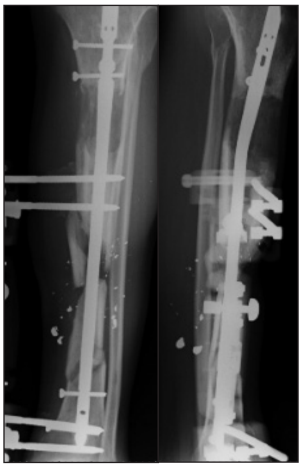

Fig. 4. Radiographs in direct and lateral projections. Distraction is carried out along the IM rod. Bone regenerate is formed

Fig. 5. Consolidated regenerate and the joint area of bone fragments

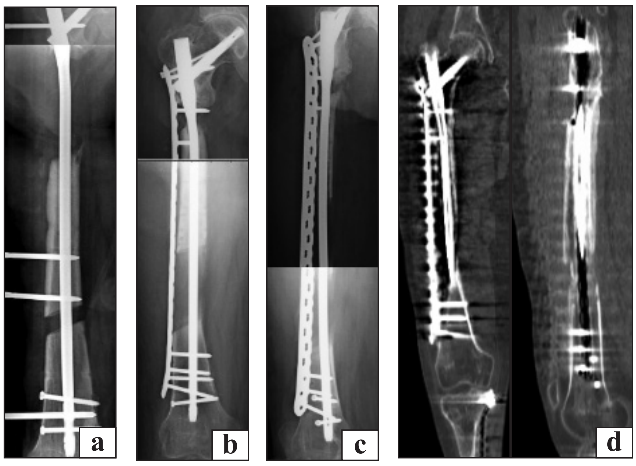

Fig. 6. Treatment of a segmental defect of the upper 1/3 of the thigh with distraction EFD along the PFNA rod: a) first stage; b, c) second stage; d) CT control after 6 months.

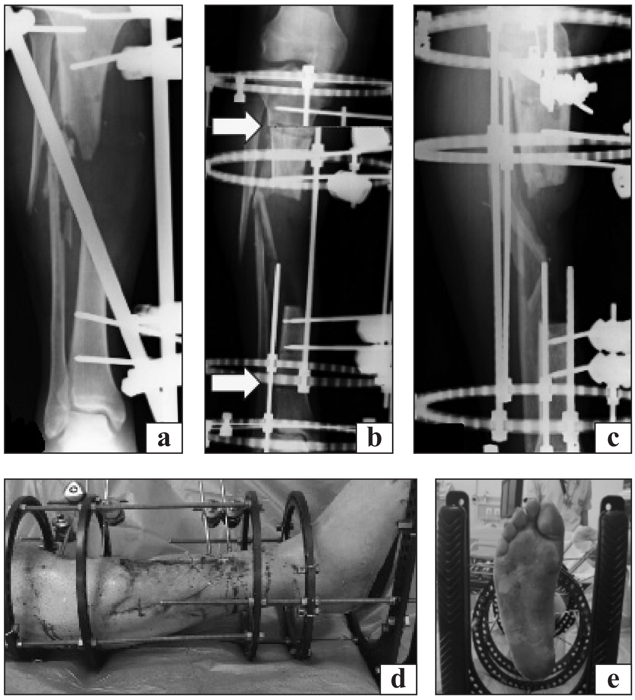

Fig. 7. Treatment of a segmental defect of the lower leg with a length of 160 mm by trifocal (antegrade and retrograde) bone transport and ring EFD (radiographs: a) during hospitalization; b) after fixation with a ring EFD and performing osteotomies — direct projection; c) side projection); d, e) clinical photos of the lower extremity in the ring EFD

rection of distraction and is divided into three parts: two of greater density, which are adjacent to the remaining bone segments, and a central radiolucent area.

The duration of the period of active distraction depends on the distance to which the segment is transported and the type of bone movement, which can be uni-, bi- and trifocal. The period of consolidation (holding phase), during which active mineralization of the distraction regenerate takes place, lasts from the end of traction to the moment of removal of this device. For the most part, its duration should exceed three times the duration of the distraction period and varies depending on the patient's age. Bone maturation with the final formation of a normal structure lasts about a year or more [31].

Today, the possibilities of distraction osteogenesis in the treatment of combat trauma of the limbs include transport: EFD (monolateral, bilateral, circular); EFD along the intramedullary rod; EFD along the plate; self-growing intramedullary rods.

We analyzed our own clinical cases with segmental bone defects and limb shortening for the period 2019–2023. 39 patients (37 (94.87 %) men and 2 (5.13 %) women). Average age (37.36 ± 2.11) years (the oldest patient — 68 years, the youngest — 19 years). The average size of the defect is (115.28 ± 6.78) mm (the largest is 195 mm, the smallest is 50 mm). Abnormality of the lower limb was diagnosed in 38 cases (segmental defects of the hip — 9, lower legs — 29), of the upper limb — 1 person (segmental defect of the ulna). According to the execution technique, mono- and bilateral distraction osteogenesis was performed in 13 (33.34 %) patients, annular — 11 (28.20 %), EFD along the rod — 10 (25.64 %), EFD along the plate — 4 (10.26 %), EFD along the TEN — 1 (2.56 %).

According to the type of bone transport, the patients were divided as follows: retrograde — 14, antegrade — 18, their combination — 3, distraction — 2, antegrade trifocal — 1 case.

Soft tissue plastic surgery was performed on 25 (64.1 %) atients, 14 (35.9 %) did not require it. We are currently analyzing treatment outcomes in patients, which we are going to publish later.

Below are the clinical cases that illustrate the given method of treatment.

Clinical case No. 1

Treatment of a gunshot injury of the lower leg with a bone defect by the method of distraction osteogenesis along the rod

A 31-year-old patient, diagnosis: gunshot wound through the lower leg with a multifragmentary fracture of the tibia with a defect, a fracture in the subcapital part of the fibula. Primary surgical treatment of the wound and external stabilization of the fracture were performed in the hospital at the patient's place of residence (Fig. 2). On the 7th day, the patient was transferred to Ternopil Regional Hospital. On the 8th day, a secondary surgical treatment of the leg wound was performed, the EFD was removed, the tibia was fixed with an intramedullary rod, and the soft tissue defect was filled with cement "beads" with gentamicin (Fig. 3).

After 5 days, the cement "beads" were removed and sewn up. The wounds healed, there was no discharge from them. After 3 weeks, an osteotomy of the upper 1/3 of the tibia was performed and a distraction EFD was installed on the anterior-medial surface. The latent period was 10 days. On the 11th day, distraction was started at a speed (0.25 mm × 4 times a day).

Fig. 8. X-ray in 2 projections after the end of bone transport and plastic repair of the joint area with bone autograft + bioglass (BoneAlive)

It was carried out for 65 days before reaching the junction of the main fragments (Fig. 4). After that, plastic "joint area" was performed with cancellous bone autograft from the back of the pelvis, separated by an acetabular rimer. After 2 months, due to progressive signs of fracture union and reconstruction of the regenerate, the EFD was removed.

The patient started to undergo complex rehabilitation treatment. After 8 months progressive ossification of the bone regenerate and consolidation in the "site of the junction of fragments" were noted. The intramedullary rod was left in place (Fig. 5).

Clinical case No. 2

Treatment of a segmental defect of the upper 1/3 of the thigh with distraction EFD along the PFNA rod

A 20-year-old patient, diagnosis: segmental defect of the upper 1/3 of the femur about 145 mm. He visited our institution 9 months after the injury. Internal fixation of the femur with a PFNA rod (Synthes), osteotomy of the lower 1/3 of the femur was performed, EFD was installed on the lateral surface of the thigh with a distraction device (Fig. 6, a). The latent period was 10 days, the distraction rate was 0.25 mm × 4 times a day. After completion, the EFD was removed, decortication and bone plasty of the "joint area" with a bone autograft, and augmentation with an LCP plate on the lateral surface were performed (Fig. 6, b, c). After 6 months computer tomography (Fig. 6, d, e) showed ossification of the bone regenerate and consolidation in the "joint area".

Clinical case No. 3

Treatment of a 160 mm long segmental defect of the tibia by trifocal (antegrade and retrograde) bone transport with ring EFD

A 54-year-old patient, mine-explosive injury of the lower limb. He was hospitalized 6 weeks after the injury, with a diagnosis of a segmental tibial defect of 120 mm, a shortening of the lower limb of 40 mm, and a soft tissue defect of the anterior surface of the tibia in the middle third. The extremity was stabilized by monolateral EFD (Fig. 7, a). After closing the soft tissue defect with a rotational muscle flap and a split skin graft, soft tissue healing was achieved. Fixation of the shin in the ring EFD was carried out, two osteotomies were performed (in the upper 1/3 and in the lower 1/3 of the shin) (Fig. 7, b, c).

First, the length of the limb was corrected by distraction on the lower ring, and then the management of the segmental defect by counter bone transport. Appearance of the limb (Fig. 7, d, e). X-rays (Fig. 8) after the end of bone transport and plastic repair of the joint area with bone autograft + bioglass (BoneAlive).

Conclusions

Distraction osteogenesis is an effective method of treating segmental defects and limb shortening in patients with combat trauma and infectious complications that led to the formation of the defect. The use of an intramedullary rod, along which distraction osteogenesis is carried out, allows better control of the axis of the limb and the transport fragment, reduces the time of EFD administration, and the fixation devices can be of a simpler configuration. Carrying out transport along the plate can be used to maintain the correct axial relationships in the presence of short peri-articular fragments and improve the quality of fixation, but increases the risks of FRI and reoperations.

Conflict of interest. The authors declare no conflict of interest.

References

1. Mathieu, L., Bazile, F., Barthélémy, R., Duhamel, P., & Rigal, S. (2011). Damage control orthopaedics in the context of battlefield injuries: The use of temporary external fixation on combat trauma soldiers. *Orthopaedics & Traumatology: Surgery & Research, 97*(8), 852–859. https://doi.org/10.1016/j.otsr.2011.05.014
2. Baus, A., Bich, C. S., Grosset, A., de Rousiers, A., Duhoux, A., Brachet, M., Duhamel, P., Thomas, M., Rogez, D., Mathieu, L., & Bey, E. (2020). Medical and surgical management of lower extremity war-related injuries. Experience of the French Military Health Service (FMHS). *Annales de Chirurgie Plastique Esthétique, 65*(5-6), 447–478. https://doi.org/10.1016/j.anplas.2020.05.008
3. Guthrie H, Clasper J, Kay A, et al (2011) Initial Extremity War Wound Debridement: A Multidisciplinary Consensus *BMJ Military Health.157*:170-175.
4. Hoyt, B. W., Wade, S. M., Harrington, C. J., Potter, B. K., Tintle, S. M., & Souza, J. M. (2021). Institutional Experience and Orthoplastic Collaboration Associated with Improved Flap-based Limb Salvage Outcomes. *Clinical Orthopaedics & Related Research, 479*(11), 2388–2396. https://doi.org/10.1097/corr.0000000000001925
5. Haines, N. M., Lack, W. D., Seymour, R. B., & Bosse, M. J. (2016). Defining the Lower Limit of a "Critical Bone Defect" in Open Diaphyseal Tibial Fractures. J*ournal of Orthopaedic Trauma, 30*(5), e158-e163. https://doi.org/10.1097/bot.0000000000000531
6. Rigal, S., Mathieu, L., & de l'Escalopier, N. (2018). Temporary fixation of limbs and pelvis. *Orthopaedics & Traumatology: Surgery & Research, 104*(1), S81—S88. https://doi.org/10.1016/j.otsr.2017.03.032
7. https://media.aofoundation.org//media/files/mgmt_limb_inj_ukrainian_by_chapter/mgmt-limb-inj-ukr-ch8.pdf?rev=bba-a4d3e0ef1458d936b53d1bd8a65a5.
8. Strafun, S. S., Shypunov, V. G., Savka, I. S., Tsivina, S. A., Sobkova, J. E., & Borzykh, N. A. (2021). Application of spacers in combination with plastic muscle flaps in treatment of gunshot of the bones of the lower limbs complicated with compartment syndrome development. *Current Aspects of Military Medicine, 28*(1), 164-177. https://doi.org/10.32751/2310-4910-2021-28-1-14
9. Tseluyko, O. B., Tymchuk, O. B., & Aslanyan, S. A. (2020). Negative pressure wound therapy treatment of soft tissue gunshot wounds of the limbs. *Current Aspects of Military Medicine, 27*(2), 201-208. https://doi.org/10.32751/2310-4910-2020-27-43
10. Bich, C. S., Brachet, M., Baus, A., Duhoux, A., Duhamel, P., & Bey, É. (2020). Le lambeau neurofasciocutané sural: fiabilisation par le prélèvement d'un lambeau en raquette. *Annales de Chirurgie Plastique Esthétique, 65*(4), 300–305. https://doi.org/10.1016/j.anplas.2020.02.003
11. Solomin, L., & Slongo, T. (2016). Long Bone Defect Classification: What It Should Be? *Journal of Bone Reports & Recommendations, 02*(01). https://doi.org/10.4172/2469-6684.100016
12. Nauth, A., Schemitsch, E., Norris, B., Nollin, Z., & Watson, J. T. (2018). Critical-Size Bone Defects. *Journal of Orthopaedic Trauma, 32*, S7—S11. https://doi.org/10.1097/bot.0000000000001115
13. Franke, A., Hentsch, S., Bieler, D., Schilling, T., Weber, W., Johann, M., & Kollig, E. (2017). Management of Soft-Tissue and Bone Defects in a Local Population: Plastic and Reconstructive Surgery in a Deployed Military Setting. *Military Medicine, 182*(11), e2010–e2020. https://doi.org/10.7205/MILMED-D-16-00372
14. Younger, E. M., & Chapman, M. W. (1989). Morbidity at Bone Graft Donor Sites. *Journal of Orthopaedic Trauma, 3*(3), 192–195. https://doi.org/10.1097/00005131-198909000-00002
15. Laurencin, C. T., & Nair, L. S. (2015). Regenerative Engineering: Approaches to Limb Regeneration and Other Grand Challenges. *Regenerative Engineering and Translational Medicine, 1*(1–4), 1–3. https://doi.org/10.1007/s40883-015-0006-z
16. Wu, D., Wang, Z., Wang, J., Geng, Y., Zhang, Z., Li, Y., Li, Q., Zheng, Z., Cao, Y., & Zhang, Z.-Y. (2018). Development of a micro-tissue-mediated injectable bone tissue engineering strategy for large segmental bone defect treatment. *Stem Cell Research & Therapy, 9*(1). https://doi.org/10.1186/s13287-018-1064-1
17. Zhi, W., Wang, X., Sun, D., Chen, T., Yuan, B., Li, X., Chen, X., Wang, J., Xie, Z., Zhu, X., Zhang, K., & Zhang, X. (2021). Optimal regenerative repair of large segmental bone defect in a goat model with osteoinductive calcium phosphate bioceramic implants. *Bioactive Materials, 11*, 240–253. https://doi.org/10.1016/j.bioactmat.2021.09.024
18. Alkindi, M., Ramalingam, S., Alghamdi, O., Alomran, O. M., Binsalah, M. A., & Badwelan, M. (2021). Guided bone regeneration with osteoconductive grafts and PDGF: A tissue engineering option for segmental bone defect reconstruction. *Journal of Applied Biomaterials & Functional Materials, 19,* 228080002098740. https://doi.org/10.1177/2280800020987405
19. Yu, Y., Wang, Y., Zhang, W., Wang, H., Li, J., Pan, L., Han, F., & Li, B. (2020). Biomimetic periosteum-bone substitute composed of preosteoblast-derived matrix and hydrogel for large segmental bone defect repair. *Acta Biomaterialia, 113*, 317–327. https://doi.org/10.1016/j.actbio.2020.06.030
20. Shen, Z., Lin, H., Chen, G., Zhang, Y., Li, Z., Li, D., Xie, L.,

Li, Y., Huang, F., & Jiang, Z. (2019). Comparison between the induced membrane technique and distraction osteogenesis in treating segmental bone defects: An experimental study in a rat model. *PLOS ONE, 14*(12), e0226839. https://doi.org/10.1371/journal.pone.0226839
21. Tong, K., Zhong, Z., Peng, Y., Lin, C., Cao, S., Yang, Y., & Wang, G. (2017). Masquelet technique versus Ilizarov bone transport for reconstruction of lower extremity bone defects following posttraumatic osteomyelitis. *Injury, 48*(7), 1616–1622. https://doi.org/10.1016/j.injury.2017.03.042
22. Akgun, U., Canbek, U., & Aydogan, N. H. (2018) Masquelet technique versus Ilizarov bone transport for reconstruction of lower extremity bone defects following posttraumatic osteomyelitis. *Injury, 49*(3), 738. https://doi.org/10.1016/j.injury.2018.01.014
23. Masquelet, A. C., & Begue, T. (2010). The concept of induced membrane for reconstruction of long bone *The Orthopedic clinics of North America, 41*(1). https://doi.org/10.1016/j.ocl.2009.07.011
24. Mauffrey, C., Hake, M. E., Chadayammuri, V., & Masquelet, A. C. (2016). Reconstruction of Long Bone Infections Using the Induced Membrane Technique: Tips and Tricks. *Journal of orthopaedic trauma, 30*(6), e188–e193. https://doi.org/10.1097/BOT.0000000000000500 defects. The Orthopedic clinics of North America, 41(1), . https://doi.org/10.1016/j.ocl.2009.07.011
25. Masquelet A. C. (2017). Induced Membrane Technique: Pearls and Pitfalls. *Journal of orthopaedic trauma, 31* Suppl 5, S36–S38. https://doi.org/10.1097/BOT.0000000000000979
26. Morelli, I., Drago, L., George, D. A., Gallazzi, E., Scarponi, S., & Romanò, C. L. (2016). Masquelet technique: myth or reality? A systematic review and meta-analysis. *Injury, 47*, S68–S76. https://doi.org/10.1016/s0020-1383(16)30842-7
27. Ilizarov G. A. (1990). Clinical application of the tension-stress effect for limb lengthening. *Clinical orthopaedics and related research,* (250), 8–26. https://doi.org/10.1097/00003086-199001000-00003
28. Yin, P., Zhang, L., Li, T., Zhang, L., Wang, G., Li, J., Liu, J., Zhou, J., Zhang, Q., & Tang, P. (2015). Infected nonunion of tibia and femur treated by bone transport. *Journal of orthopaedic surgery and research, 10*, 49. https://doi.org/10.1186/s13018-015-0189-5
29. Hamdy, R. C., Rendon, J. S., Tabrizian, M. (2012) Distraction osteogenesis and its challenges in bone regeneration. In Haim Tal (Ed.), *Bone Regeneration* (pp. 185–212). IntechOpen. https://doi.org/10.5772/32229
30. Rowe, N. M., Mehrara, B. J., Luchs, J. S., Dudziak, M. E., Steinbrech, D. S., Illei, P. B., Fernandez, G. J., Gittes, G. K., & Longaker, M. T. (1999). Angiogenesis during mandibular distraction osteogenesis. *Annals of plastic surgery, 42*(5), 470–475. https://doi.org/10.1097/00000637-199905000-00002
31. Catagni, M. A., Guerreschi, F., & Lovisetti, L. (2011). Distraction osteogenesis for bone repair in the 21st century: lessons learned. *Injury, 42*(6), 580–586. https://doi.org/10.1016/j.injury.2011.04.004

The article has been sent to the editors 27.11.2023

EXPERIENCE OF THE SEGMENTAL BONE DEFECTS' TREATMENT FOR PATIENTS WITH COMBAT TRAUMA USING THE METHOD OF DISTRACTION OSTEOGENESIS

S. V. Hariyan [1], O. S. Tsybulskyi [1], V. P. Makhovskyi [1], Z. V. Salii [2]

[1] Ternopil Regional Hospital. Ukraine
[2] I. Horbachevsky Ternopil National Medical University. Ukraine

✉ Serhiy Hariyan, MD, PhD: drhariyan@gmail.com
✉ Oleksandr Tsybulskyi, MD: tsybulskyj.oleksandr@gmail.com
✉ Vasyl Makhovskyi, MD: makhovskyvasyl@gmail.com
✉ Zoia Salii, MD, PhD, DSc: zoia_salii@ukr.net