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Algorithm of surgical treatment for diaphyseal defects of the forearm bones due to gunshot injuries

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Abstract

Introduction In the current system of providing medical aid to wounded servicemen, along with the conservative primary surgical treatment and minimally invasive extrafocal fixation, high-tech surgical interventions of considerable complexity with the use of additive and tissue-engineering technologies have been coming to the forefront. It is necessary to determine their place in the current algorithm of limb bone defect management, which was the substantiation of our study.

The **purpose** of the study was to improve the algorithm for selecting a treatment method for patients with associated gunshot defects of the forearm based on the literature and clinical observations.

Materials and Methods We analyzed scientific articles in PubMed and Scientific Electronic Library (eLIBRARY.ru) platforms, published from 2004 to 2024, on the basis of which we could refine the algorithm of treatment method selection for patients with associated gunshot defects of the forearm. The developed algorithm was used to treat 178 patients with gunshot fractures of the forearm.

Results The review of the literature established the main provisions and principles that are applied in the reconstruction of the forearm with an associated defect. When choosing the method of bone defect management, a great number of authors tend to build a “reconstructive ladder”, moving from less severe (one bone) and extended defects (small defect up to 2 cm) to more complex (both bones) and massive defect (more than 10 cm). Upon having considered the revealed regularities, we improved the algorithm of surgical treatment of the latter, which is based on two classification principles: defect extention and location. Reconstruction of the forearm as a dynamic system after diaphyseal fractures requires consider the state of the radioulnar joint. The function of the latter depends on the length ratio of the radius and ulna bones. Therefore, we substantiated small (up to 2 cm) forearm bone defects that can be managed by simple surgical methods. Another fundamental addition to the algorithm was the allocation of a patients’ group with a defect of one forearm bone and a fracture of the other bone (defect-fracture); this combination allows avoiding complex surgical methods for reconstruction and use segment shortening.

Discussion The treatment of associated forearm defects is challenging, the choice of reconstruction technique remains uncertain, and the required consensus is lacking. Several forearm reconstruction techniques are available, yet there is no reliable evidence of their effectiveness in terms of treatment time, complications, reoperations, and functional recovery.

Conclusion The algorithm proposed for the treatment of extensive gunshot-associated defects of the forearm allows us to consider the change in the anatomy, make a surgical plan based on the reconstruction vector, and select optimal surgical techniques.

Keywords: gunshot wound, diaphyseal defect, forearm bones, treatment algorithm

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INTRODUCTION

Gunshot injuries to the extremities remain one of the most challenging problems of military medicine. The relevance of this problem is associated with the constant development of firearms and the emergence of new wounding projectiles that cause significant destruction of bone and soft tissue. The problem requires revision of some of the tactical approaches to the treatment of this pathology that have been established over the past decades [1–3].

Diaphyseal fractures of the forearm bones account for 10–15% of all fractures [4]. The average duration of management is 6–8 months [5], and in 6–17% of cases, patients remain disabled [6]. In the treatment of closed fractures, extramedullary and, less commonly, intramedullary osteosynthesis are used, as well as extrafocal fixation [6, 7]. Gunshot injuries of the forearm are characterized by their severity, difficulties in treatment, and a significant rate of complications [8].

Treatment of gunshot-associated forearm defects is a serious reconstructive problem due to high rates of purulent complications, difficulties with soft tissue healing and bone consolidation, and restoration of upper limb function [9]. Particular difficulties arise in defects of one bone that measure more than 5 cm, defects in both bones of the forearm, and bone defects associated with soft tissue deficiencies [10].

In gunshot or blast injuries, primary loss of bone fragments occurs at the moment of impact of the wounding projectile. Modern classifications of open fractures require considering the loss of bone mass. Bone loss is usually described by its anatomical location: diaphyseal, metaphyseal or articular defect. The diaphyseal defect is usually characterized by its length and circumferential loss of the affected bone. From the point of view of reparative bone regeneration, segmental (circular) defects larger than 2 cm are considered not able to be spontaneously restored, even under the condition of stable fixation; partial defects (less than 50% of the circumference) also do not spontaneously restore without additional treatment [11–14]. In recent works, the methodology for determining the size of a bone defect remains the same [15, 16].

Current clinical methods of limb bone defect management include simple (non-vascularized) bone grafting with cancellous or cortical auto- or allografts, membrane-induced osteogenesis (the Masquellet technique), microsurgical vascularized grafting of iliac or fibular bone grafts with blood vessels, and non-free bone grafting under external fixation using the Ilizarov technique [17–19]. Each of these methods has its own advantages and, when used according to appropriate indications, provides good results. In bone defects smaller than 5 cm, non-vascularized auto- or allogenic bone grafting has been usually used. In bone defects larger than 5 cm, microsurgical bone grafts with blood vessels or the Ilizarov technique are used, but the latter is applicable if the soft tissues are in a satisfactory condition [20–22]. Acute segment shortening as a method of bone defect management without subsequent restoration of limb length is possible without functional impairment in the lower limbs with up to 2 cm and in the upper limbs up to 4 cm of discrepancy [23, 24]. One-stage plate fixation and autologous bone grafting can be effective in treating forearm bone defects up to 5 cm [25, 26], however, in defects exceeding 5 cm, the probability of graft resorption is very high [27]. Non-vascularized fibula autograft with plate osteosynthesis was successfully used in 20 patients with medium 2-cm diaphyseal bone defects of the forearm bones [28].

Vascularized fibular autograft or structural allograft with intramedullary fixation, acute limb shortening and Ilizarov bone transport technique is difficult to use in the forearm due to the complexity of the anatomical and functional structure of this segment [29–31]. Free vascularized fibular graft (FVFP) is recommended for extensive defects, although widespread use of this technique is limited by the need for specialized microvascular resources [32, 33]. The use of distraction osteogenesis of bone transport is limited by frequent complications associated with the fixator, impaired bone union at the site of contact of fragments and contractures of the adjacent joints [34, 35]. Additive technologies open new opportunities in the treatment of bone defects, which allow for the maximum implementation of an individual approach in the selection of implants or fixators with the possibility of osseointegration [36–38]. This direction has been considered promising in surgery of injuries of the musculoskeletal system [39].

Due to the significant relevance of the problem of treating bone defects, the variety of causes, severity and high incidence caused by modern weapons, especially for military medical institutions and hospitals located in close proximity to combat zones, the creation of a unified algorithm for providing surgical care is an urgent need. Algorithms for determining the viability of a limb segment and primary surgical treatment have been developed [1–3], but the algorithm for long bone defect management in contemporary conditions requires modification.

In the current system of providing care to wounded military personnel, the following have been established: primary surgical debridement (PSD) of a gunshot wound, minimally invasive extrafocal fixation of a fracture, approaching to the elements of specialized medical care (SMC) or rapid evacuation to the SMC stage. The possibilities of effective active wound treatment are expanding: general (infusion, systemic antibacterial, anti-inflammatory and immunostimulating therapy) and local (plasma, laser, ultraviolet, VAC therapy, local antibacterial and bacteriophage therapy). High-tech surgical interventions using additive and tissue engineering technologies are coming to the forefront, which place must be determined in the current algorithm for treating limb bone defects based on the principle of anatomical location, which was the rationale for our study.

Purpose To improve the algorithm for choosing a treatment method for patients with associated gunshot defects of the forearm based on literature data and clinical observations

MATERIAL AND METHODS

To analyze the current state of specialized surgical care for patients with associated gunshot defects of the forearm and to subsequently form an algorithm for reconstructive treatment, a search was conducted for scientific articles in the PubMed abstract and bibliographic database and the eLIBRARY.ru Scientific Electronic Library, published from 2004 to 2024. The analysis also includes articles by the most prominent scientists published earlier. The results of studies of the mechanism and structure of combat injuries to the extremities, the effectiveness of the methods used to manage bone defects and soft tissues of the forearm were summarized.

The developed algorithm was used to treat 178 patients with gunshot fractures of the forearm. All injuries were defined as associated, since in all cases the presence of bone and soft tissue destruction (muscles, tendons, vessels and nerves) was diagnosed. Isolated fractures of one bone with the other intact one were less common, they accounted for about 32.6 % (58 cases). Most gunshot wounds of the forearm (mainly shrapnel, which account for about 90 %) are characterized by significant destruction of one of the bones with a "relatively simple" fracture of the other bone (53.9 %, 96 cases); significant destruction of both forearm bones was observed in 24 patients (13.5 %). The true size of the bone defect increases since non-viable bone fragments are removed during staged surgical treatments. The assessment of the defects at the stage of reconstruction/osteosynthesis found that the largest number of patients had a defect in one of the forearm bones ranging from 0 to 2 cm (73 patients, 41.0 %) and from 2.1 to 5 cm (48 patients, 27.0%), 42 (23.6 %) patients had a defect from 5.1 to 10 cm; a defect of more than 10 cm was observed in 15 (8.4 %) patients.

Forearm bone grafting using a free fibular flap was performed in 18 (10.1%) cases, while an individual 3D design was required in 2/3 of observations (12 patients). In the remaining cases, non-vascularized bone auto- and allografts were used in combination with various osteosynthesis options.

RESULTS

The available literature contains a large number of methods for treating mechanical injuries of the musculoskeletal system, and in particular the forearm, as well as their complications. One of the earliest relevant algorithms for treating bone defects of the extremities was presented by Keating et al. [40] (Fig. 1).

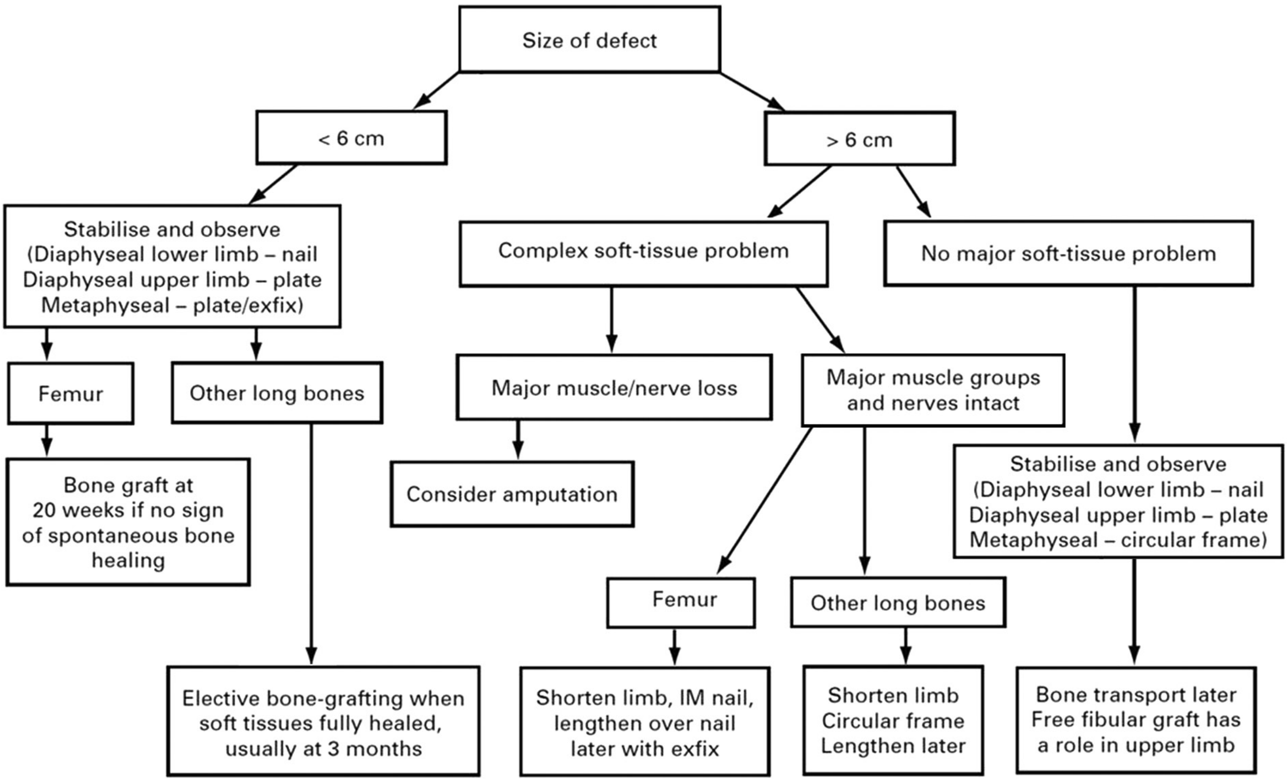


Fig. 1 Algorithm of limb defect management according to Keating et al. (2005) [40]

In this algorithm, defects are divided by length (up to 6 cm and more than 6 cm) and soft tissue problems. In the case of small and extensive (without soft tissue problems) defects, it is proposed to stabilize, observe and then, once the wound heals, use plates in the upper limbs, nails in the lower limbs in the diaphysis, and plates in the metaepiphyseal bone. Ten-year results of using this strategy confirmed the severity and diversity of injuries, on the basis of which Molina et al. [41] proposed to form narrower groups for comparison. Mauffrey et al. [21] proposed changing the algorithm with division into defects up to 1–3 cm (acute shortening is possible), 3–5 cm (non-vascularized bone grafting and internal osteosynthesis), 5–10 cm (shortening in combination with vascularized and non-vascularized grafting), and more than 10 cm (Ilizarov bone transport or vascularized bone autografts).

Unfortunately, there are very few scientific papers in the literature on the treatment of gunshot defects of the forearm bones that would discuss methodological approaches to choosing the optimal reconstruction method and timing of the operation. They mainly consider various issues of the compartment syndrome, antibacterial therapy, the need to remove wounding projectiles, and treatment tactics for individuals with bone defects of gunshot etiology [42, 43].

A comprehensive review of the literature on the treatment strategy for extensive bone defects in the extremities after trauma, infection, or tumor excision is provided by Migliorini et al., who emphasize that the problem remains complex and unresolved, the choice of method is still being discussed, and there is no consensus. Several equivalent methods of bone defect management are used. However, the number of cases, which is insufficient for reliable statistics, does not allow obtaining convincing evidence of their effectiveness. Therefore, the issues of treatment duration, number and severity of complications, frequency and complexity of repeated surgeries remain open and require further study [44].

The algorithm we propose for treating patients with forearm defects is based on two principles of their classification: location and extent. According to the provisions of the Osteosynthesis Association (AO), the treatment of diaphyseal fractures of the forearm bones requires complete elimination of all types of displacement and provision of conditions for the restoration of the function of the radioulnar joints. Therefore, in the event of defects in the forearm bones, it is necessary to ensure their reconstruction in a way that would eliminate the disruption of the anatomical and physiological relationships in the radioulnar joints, which is the basis for subsequent rehabilitation [45].

Defects of one or both bones of the forearm are identified. We consider it necessary to supplement the existing classification by identifying small (up to 2 cm) defects of the bones of the forearm, which can be reconstructed with the simplest methods. Special surgical tactics are required for patients with a defect of one bone and a fracture of the other bone of the forearm (defect-fracture). This type of damage, despite its severity, in some sense makes the surgeon's task easier: to shorten the bone with a simple fracture and avoid bone plasty in the defect zone of the other bone (Fig. 2).

For choosing methods for bone defect reconstruction, most surgeons use the "reconstructive ladder" rule, using simple methods for less severe (one bone) and less extended defects (small defect up to 2 cm) and complex ones for more severe (both bones) and massive (more than 10 cm) defects. In our opinion, modern ideas about ranking methods are becoming broader, from osteosynthesis, possibly with acceptable shortening or non-vascularized bone grafting, through a combination of partial shortening with non-vascularized bone grafting to microsurgical free vascularized bone autoplasty and tissue-engineered complex grafts. The osteosynthesis system has evolved from traditional plates through plates with limited contact and angular stability of screws to custom-made 3D structures. The latter can only perform osteosynthesis of fragments or additionally fix various grafts. 3D bioengineered structures such as a biologically active bone prosthesis that unites with the fragments have been used.

We propose to optimize the choice of the method for forearm bone defect management by using the reconstruction vector rule, which consists in the need to use more complex methods if the size of the defect and the complexity of its structure increases. Thus, the surgeon's efforts are directed from simple to complex, and the possibility of combining various surgical methods in one operation is ensured. This approach allows, by combining the effectiveness of individual methods, to obtain the maximum effect in terms of anatomical and subsequent functional restoration.

Currently, the general trend in reconstructive surgery is the use of a one-stage and comprehensive method. This allows the maximum effect with minimal costs for a more complete recovery with reduced hospitalization and rehabilitation periods. The Ilizarov methods, which have been used in our country for many years, fully comply with the above requirements and allow us to solve almost all issues of treating such patients. However, for the forearm, the Ilizarov apparatus assemblies are quite complex and cumbersome and require constant medical supervision throughout the entire recovery period.

Many of the current one-stage comprehensive surgical treatment methods, in addition to technical complexity, require the use of complex and expensive technological solutions. However, reducing the duration of inpatient treatment and the number of staged hospitalizations and operations, the use of such methods will allow the medical service to compensate for costs and obtain the most complete anatomical and functional restoration in the wounded and injured persons.

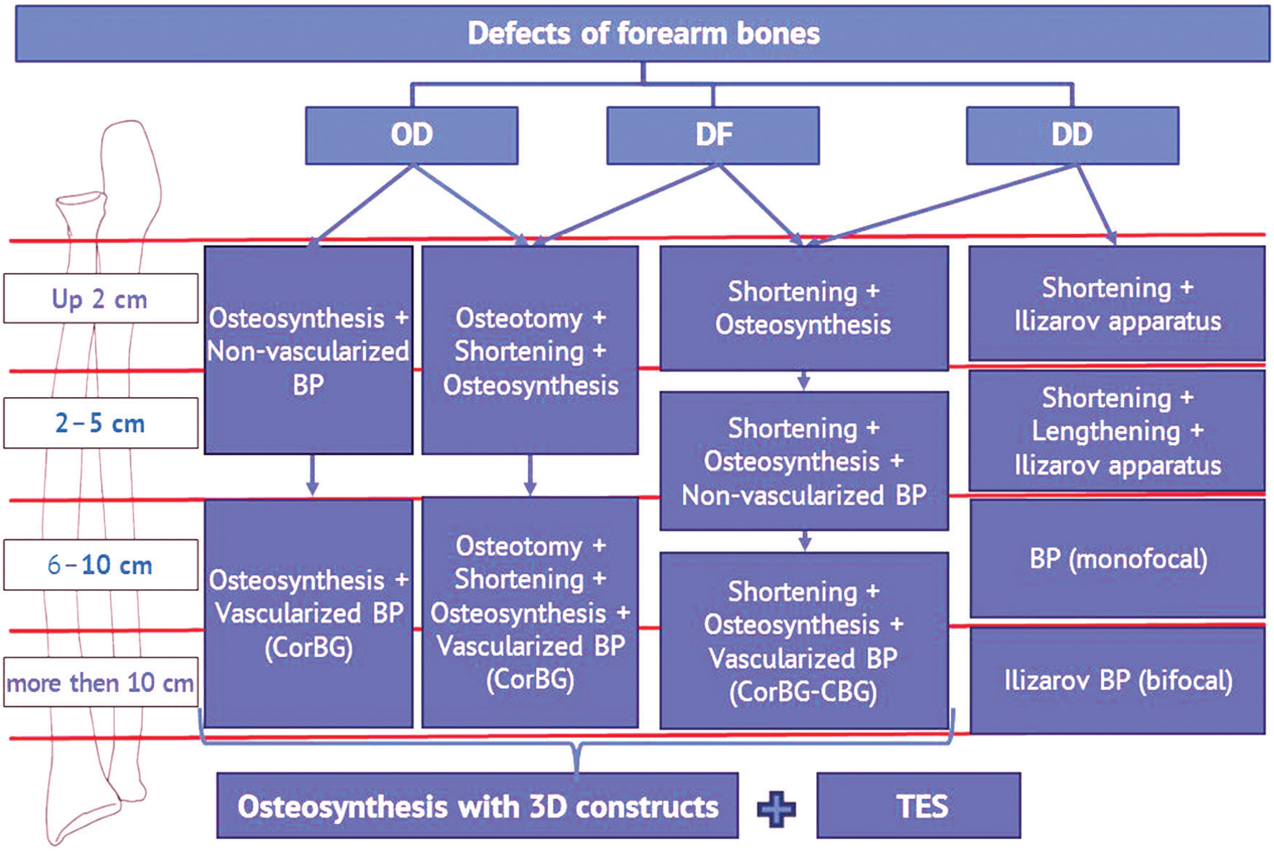


Fig. 2 Algorithm for treating forearm bone defects. OD — one-bone defect of the forearm bones; DD — double-bone defect of the forearm bones; DF — defect of one bone and fracture of the other (defect-fracture); CBG— cancellous bone graft; CorBG — cortical bone graft; TES — tissue-engineered structure

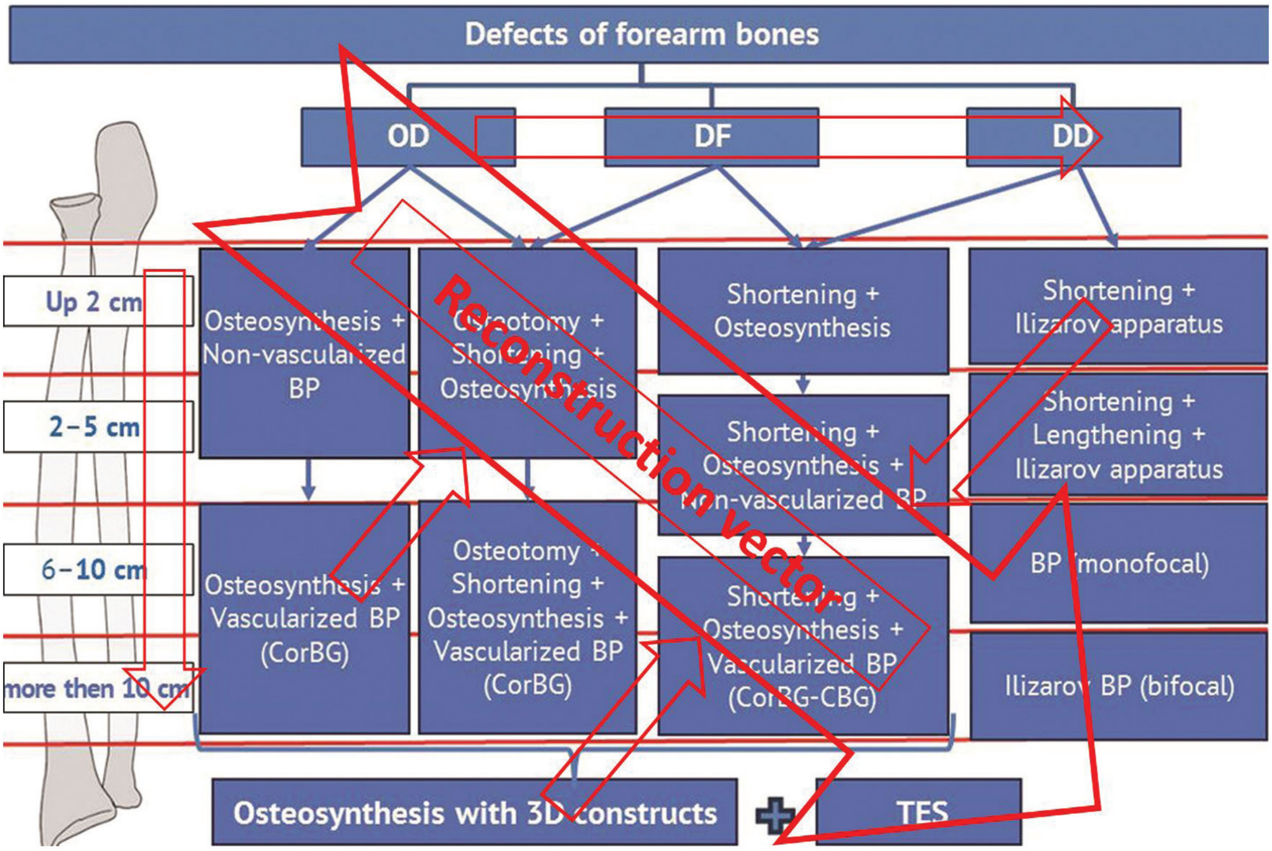
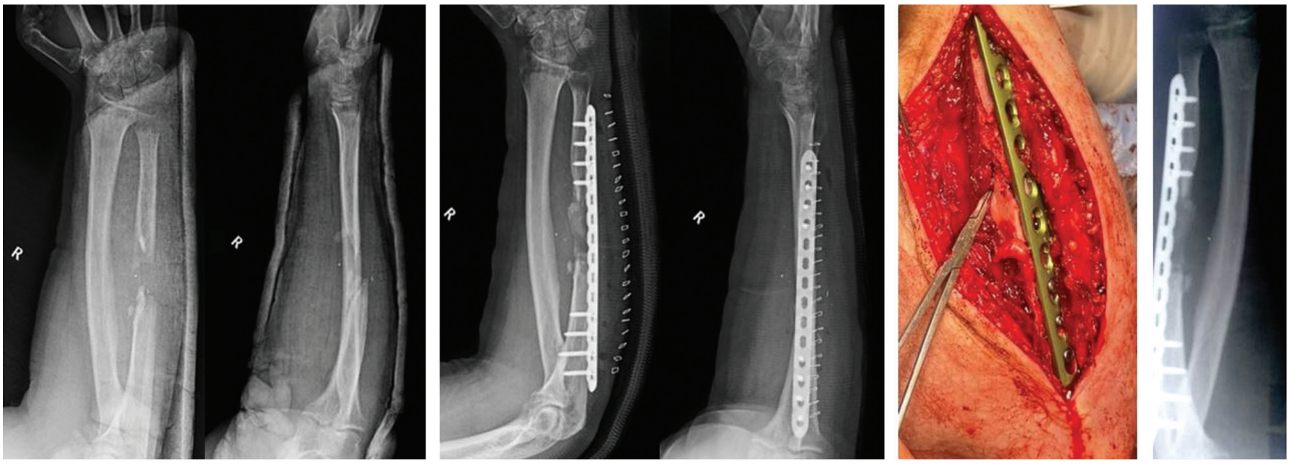


Fig. 3 Diagram of reconstruction vector

Case reports

The simplest method of treatment (osteosynthesis and bone plasty with a non-vascularized cancellous graft) is illustrated by a case of a wounded male G., 36 years old, who received a gunshot wound resulting in a 3.5 cm defect of the ulna in the middle third (Fig. 4 a). After the wound healed, osteosynthesis was performed with a plate with angular stability of screws in a bridge version and the ulna defect was bridged with a cancellous graft from the iliac crest (Fig. 4 b, c). Six months after the operation, signs of graft remodeling are visualized on the radiograph (Fig. 4 d).



a b c d

Fig. 4 Injured male G., radiographs of forearm bones: *a* before surgery; *b* after the surgery; *c* an intra-operative view of the wound, osteosynthesis and cancellous graft from the iliac crest; *d* at 6 months after the surgery

The combination of acute shortening of the forearm due to osteotomy of the intact radius, which allowed reduction of the ulnar defect and perform non-vascularized bone grafting with a cortical bone graft, is illustrated by the case of patient K., 23 years old, who sustained a gunshot wound to the left forearm from a smoothbore gun (shots) on 02.03.2023. The X-ray of the left forearm showed the following: a gunshot wound to the middle third of the left forearm, a gunshot comminuted fracture of the middle third of the ulna with a 6 cm bone tissue defect, multiple foreign bodies in the soft tissues of the left forearm (Fig. 5 a).

The wounded man was taken to a military hospital, where primary surgical treatment and drainage of the left forearm wound were performed, followed by local wound treatment and healing by secondary intention.

On April 26, 2023, at the Burdenko Main Military Clinical Hospital, acute shortening osteotomy of the intact radius (2 cm) was performed, the ulna defect (3 cm) was replaced with a non-vascularized cortical bone autograft and osteosynthesis of both forearm bones was performed (Fig. 5 b).

The postoperative period was uneventful, the wounds healed by primary intention, the radius fracture consolidated (osteotomy site) 4 months after the operation (Fig. 5 c), signs of cortical fibular bone graft fusion were noted 6 months after the operation (Fig. 5 d).

After rehabilitation treatment, the patient was declared fit for service and continued military service (Fig. 5 d).

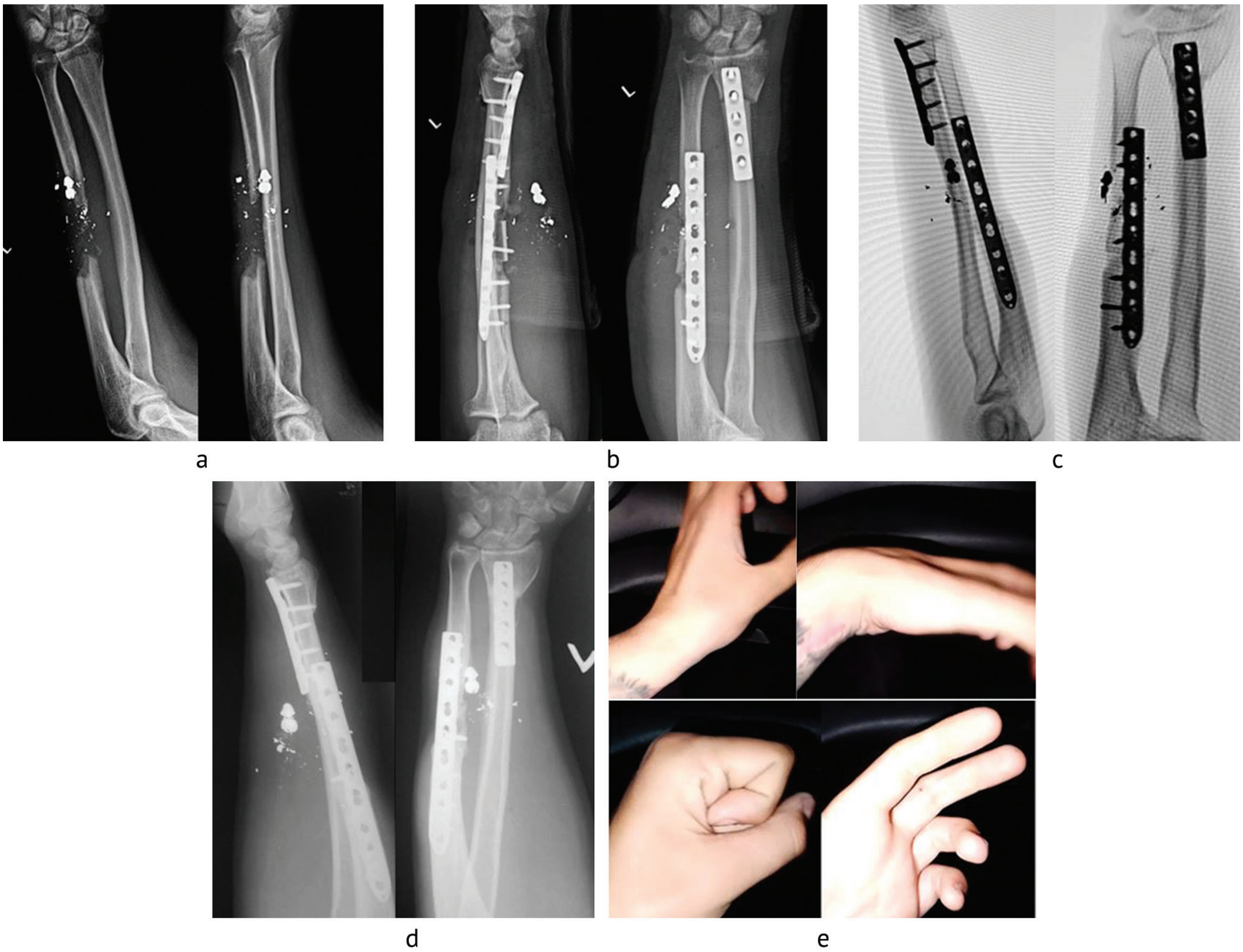


Fig. 5 Patient K.: *a* radiographs of the forearm bones before surgery; *b* radiographs of the forearm bones after surgery; *c* digital radiographs of the forearm bones 4 months after surgery; *d* radiographs of the forearm bones 6 months after surgery; *e* hand function 8 months after surgery (photo taken with a mobile phone camera by the patient himself in the area of a special military operation)

Patient A., 27 years old, sustained a gunshot wound to the right upper limb during combat operations on 20.03.2022. First aid was provided on the site. Then he was evacuated to the N.N. Burdenko Main Military Clinical Hospital, where on 24.03.2022, primary surgical treatment of the wounds of the right forearm, fixation of the right ulna with an external fixation device (EFD) of the military field rod kit (MFRC) and VAC therapy of wounds were performed (Fig. 6 a-d).

On 28.03.2022, repeated surgical treatment of the wounds of the right forearm, skin grafting of the wound defect with local tissues were performed. The wounds healed (Fig. 6 e).

On 27.05.2022, the external fixation device was removed and free vascularized plastic surgery of the ulnar bone defect of the right forearm with fibular graft (8 cm long) was performed and fixed with a 3D construct (Fig. 7 a).

The postoperative period was uneventful; the graft healed after 6 months, the metal implant was removed 12 months after surgery (Fig. 7 b, c). The functional result after rehabilitation treatment is shown in Figure 7 d.

Fig. 6 Patient A.: *a* appearance of soft tissue wound; *b* radiographs of the forearm; *c* view of soft tissue wound during VAC therapy; *d* radiographs of the forearm after fixation of the EFD MFRK; *e* soft tissue wounds after plastic surgery with local tissues

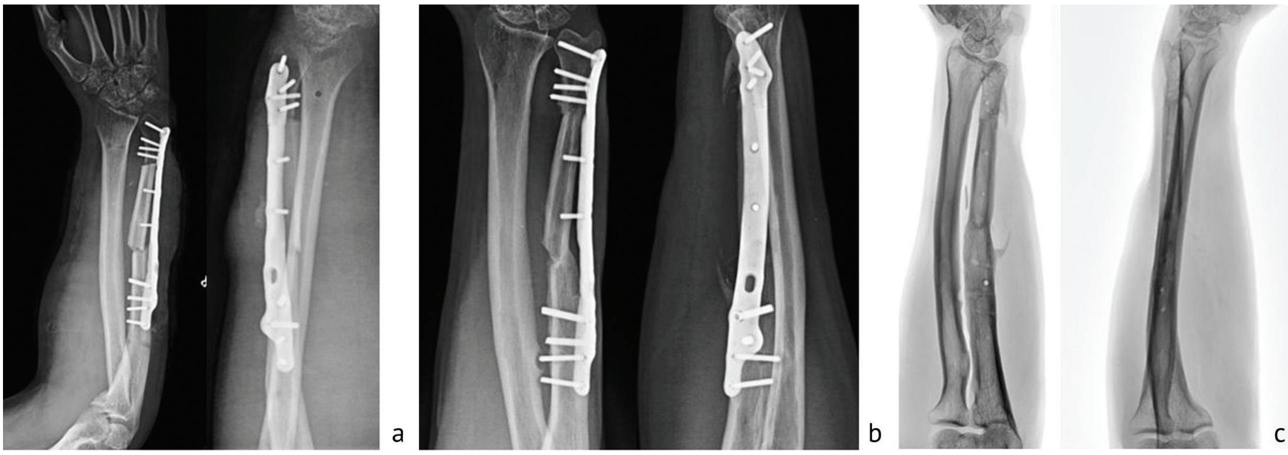


Fig. 7 Injured patient A.: *a* radiographs of the forearm after plastic surgery and fixation with a 3D-implant; *b* radiographs of the forearm 6 months after surgery; *c* digital radiographs of the forearm after removal of the metal implant (12 months after reconstructive surgery); *d* function of the upper limbs after rehabilitation

Fig. 7 (continued) Injured patient A.: *d* function of the upper limbs after rehabilitation

Male patient M., 35 years old, sustained a shrapnel penetrating wound of the left forearm and an open multi-fragmentary fracture in the middle and upper thirds of both bones of the left forearm, with displacement of bone fragments, defect of bones and soft tissues. Primary surgical treatment and immobilization with EFD were performed at the stage of qualified surgical care, after which he was referred to the N.N. Burdenko Main Military Clinical Hospital (Fig. 8 a, b). The wounds healed partially by secondary intention using local tissue grafting. After wound healing and CT scanning of the limb, 3D planning was performed, a resection template and a metal implant were designed (Fig. 8 c–e).

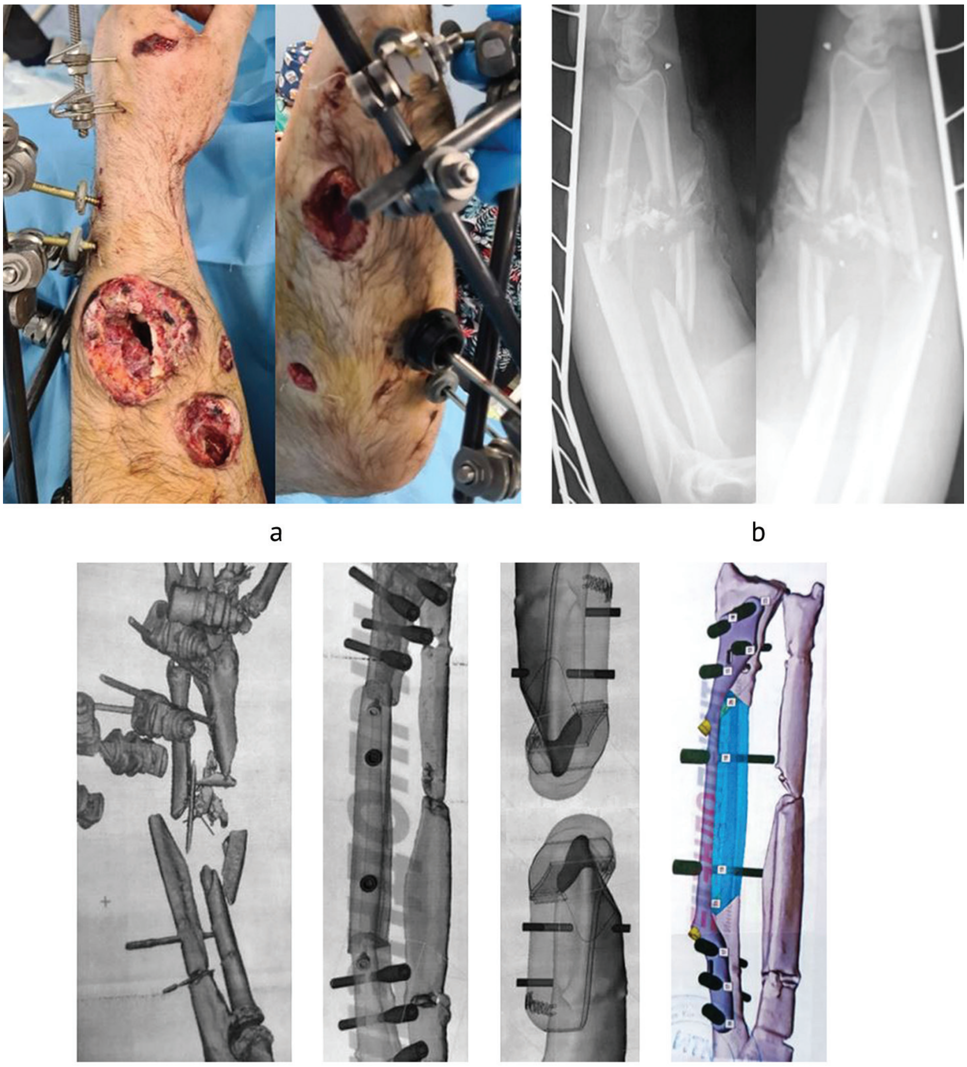


Fig. 8 Patient M.: *a* soft tissue wounds; *b* radiographs of the forearm. Planning the operation: c CT of the forearm bones; *d* planning grafting; *e* resection templates; *f* 3D reconstruction plan

The radial bone defect was repaired using a free vascularized fibular bone graft with a fasciocutaneous flap and 3D metal implant fixation (Fig. 9). The use of a customized implant in this case was determined by the size of the defect and the need to bypass the vascular "pedicle" of the fibular graft. Osteosynthesis of the ulna was performed using a standard plate with angular stability of screws (Fig. 10 a). The wounds healed; the fractures united 6 months after the operation (Fig. 10 b, c).

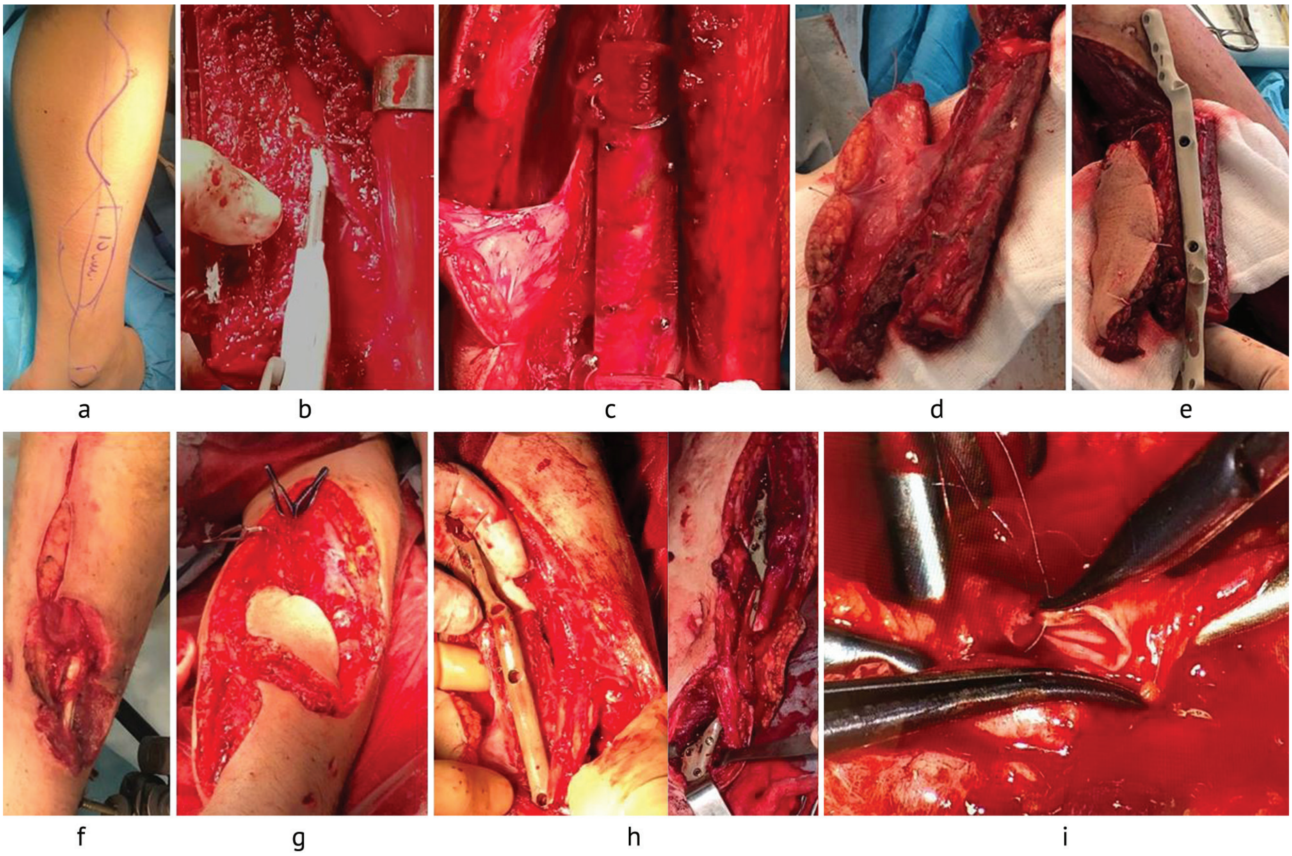


Fig. 9 Patient M.; stages of the operation: *a* graft planning; *b* isolating the fibular graft; *c* use of resection template; *d* appearance of the fibular graft; *e* view of the 3D-construction; *f* excision of the wound edges and mobilization of the vascular bundle; *g* view of the fibular graft; *h* fixation with a 3D-construct; *i* microvascular stage of the operation (suture of the artery of the fibular graft)

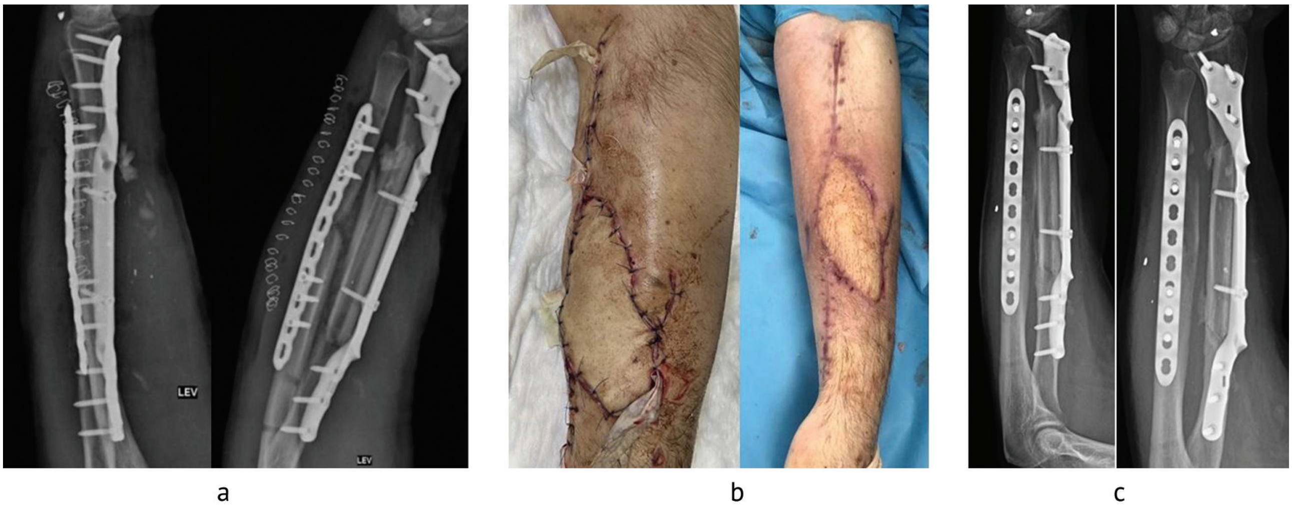


Fig. 10 Patient M.: *a* radiographs after the intervention; *b* views after the operation and after suture removal; *c* radiographs 6 months after the operation

DISCUSSION

The study of specialized literature and the analysis of the hospital's experience in treating wounded patients with severe gunshot injuries to the forearm have shown the difficulties of choosing the optimal surgical tactics. Gunshot wounds differ from other injuries by a primary defect. The size and structure of the latter depend on the magnitude of the energy of the wounding projectile. The characteristics of the secondary defect are largely determined by subsequent treatment. The use of time-tested treatment methods does not always allow for an optimal result in a short time. The experience of treating peacetime trauma to solving the problem of combat trauma requires verification and comprehension in order to be utilized. Nevertheless, the principle of the "reconstruction vector" we propose provides the surgeon with a methodological tool based on the logic and experience of many generations of surgeons.

The algorithm proposed by us is based on the principle of dividing bone defects by their anatomical features (single-, double-bone and fracture defects) and size (these indicators serve as a kind of coordinate axes, based on which the direction of the reconstruction vector should be determined). The end point of the algorithm is a point on the coordinate plane located opposite the corresponding points on the anatomy and size axes. Studying previous experience allowed us to arrange the known proven and proposed new treatment methods from simple to complex on the plane of choosing treatment tactics. Thus, optimal treatment methods are located in the direction of the reconstruction vector, which can be used with a combination of the corresponding structure and size of the defect.

The treatment of bone integrity disorders is based on bone reduction and osteosynthesis. Stable fixation is required after correcting the length, rotational and angular displacements, and can be provided in mild severity cases with standard metal fixators, and in severe cases requires the use of customized 3D constructs. All methods must meet the principle of minimal invasiveness, maintaining and restoring blood supply. Compliance with these principles ensures the possibility of early rehabilitation and working ability, which can serve as confirmation of the correctness of the chosen concept.

The shift of the reconstruction vector to one of the coordinate axes or its reduction indicates a simplification of the surgical task. Thus, in the case of a fracture defect, a relatively simple technique of acute shortening helps to solve the problem of a large defect by reducing the latter, which allows the use of less traumatic non-vascularized bone grafting instead of a complex multi-hour microsurgical intervention.

Bone grafting with iliac crest fragment is one of the frequently used and simple solutions for bone defect reconstruction [46, 47]. Iliac crest graft has all the advantages of autografts: osteogenesis, osteoinduction, osteoconduction and histocompatibility [48, 49]. Bone graft can be obtained from the anterior or posterior part of the iliac crest, vascularized or not, and cortical, cancellous or combined. However, its size and especially mechanical strength are limited [50, 51].

Vascularized fibula grafts are commonly used to reconstruct bone defects larger than 6 cm [52], often associated with soft tissue defects [53]. Three different options of vascularized fibular grafting have been developed: a single vascularized fibula (up to 25 cm in an adult patient), a double technique, and a combined reconstruction with vascularized fibula and allograft [54–56]. However, the bone defect for which this method can be used should not exceed 13 cm in length [57].

Fibular graft healed without further surgical interventions in 70% of patients after an average of 10 months. There were serious complications, such as deep soft tissue infection, pedicle thrombosis, stress fracture not associated with fixation failure, compartment syndrome, but the union rate was 82 % within 2 years of follow-up and 97% after 5 years [58–61]. Our results on the rates and duration of healing are consistent with the work of Liu et al. (2018) [62], who reported on long-term follow-ups of FG: the healing rate was 100% and the average time was 21.3 weeks. The combined reconstruction with vascularized fibula and allograft has the advantages of both previously described techniques [63].

For reconstruction of segmental defects, metal prostheses are an alternative to massive bone grafts; they provide immediate stability, rapid rehabilitation and early weight bearing [64]. However, frequent infectious complications, mechanical loosening and mechanical wear, high risk of prosthetic and periprosthetic fractures have made this technique applicable only to cancer patients with limited life expectancy [65–67]. However, the proposed tissue-engineered structures based on metal scaffolds with a set of biological components are capable of being integrated into living tissues and may soon replace auto- and allografting in separate cases.

The Ilizarov method has long served as a reliable and effective means of solving many problems associated with injuries to the musculoskeletal system. It can be used for any type of defect, which does not contradict the rule of the reconstruction vector. However, its place in the treatment system for associated gunshot defects of the forearm requires clarification.

CONCLUSION

Management of large bone defects is a complex task, the choice of reconstruction method remains labor-intensive and uncertain; the necessary consensus is lacking. Several methods of treating bone defects are available, but there is insufficient quantitative and qualitative evidence to draw convincing conclusions, especially about the timing of treatment, complications and reoperations.

The algorithm proposed for surgical treatment of wounded persons with gunshot defects of the forearm bones allows for a detailed consideration of the anatomical features of pathological changes, drawing the reconstruction vector in specific cases and assists in the optimal choice of surgical treatment method.

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