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Experience of using vascularized bone grafts to treat nonunion fractures and limb bone defects

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Background. *Vascular bone graft transposition is the one of most effective method of nonunion fracture and bone defect treatment. However, the use of this technique is associated with some difficulties. One is the adjustment of recipient bed size and the graft. The other is the difficulty to reconstruct the alignment and length of bone. A promising method of preparing for the vascular bone graft transposition is virtual three-dimensional planning based on computed tomography data and three-dimensional printing templates.*

The aim *was to summarize our experience in the treatment of bone nonunion and defects with vascular bone autografts using tree-dimensional virtual planning and printing.*

Material and methods. *We analyzed the treatment process and outcomes of 4 patients with limb bone nonunion and 6 patients with bone defects. In all cases, we used vascular bone grafts. Internal fixation of grafts was used in 7 cases; external fixation was used in 3 cases. At preparation stage in 4 cases, we used tree-dimensional virtual surgery planning and printing templates.*

Results*. One case was diagnosed with bone graft necrosis caused by venous thrombosis. Consolidation was achieved in all patients; a late consolidation was observed in 2 cases. Hematoma in donor area was seen in 2 patients. When using three-dimensional virtual planning and tree-dimensional printing templates, the operation time was decreased by 1 hour 5 minutes. We identified two cases of poor reposition in the group without virtual planning. No poor reposition was observed in the cases where tree-dimensional planning was used.*

Conclusion. *Vascularized bone grafts provide an effective method to treat bone defects and nonunion. But the planning of graft and recipient site sizes is associated with certain difficulties. Our preliminary results have shown that virtual three-dimensional planning and printing allow improving the precision of the surgical procedure and decreasing operative time.*

Keywords: nonunions and bone defects of limbs, vascularized bone grafts, virtual surgical planning, tree-dimensional printing of surgical templates

Introduction

The problem of treating nonunion fractures and bone defects of the limbs is relevant, since the consequences of severe limb injuries are one of the most common causes of disability [1]. The treatment of this pathology is characterized by a long duration and a high rate of unsatisfactory outcomes [2, 3]. It is important to note that there are no clear treatment algorithms for these conditions. Various authors have proposed re-osteosynthesis, bone grafting by non-vascular autograft, Ilizarov non-free bone grafting, and other techniques [4].

One of the most reliable methods of treating limb bone defects and nonunions is the vascularized bone autografting. The use of the following donor sites has been noted in the literature: a fibula bone flap, bone grafts formed of the distal femoral metaepiphysis, of the distal radius bone metaepiphysis. When applying this technique of bone grafting, the achievement of consolidation is approaching 100%. [5, 6].

However, the use of this promising technology is associated with the need for using microsurgical techniques, instruments, and an operating microscope [7]. Another factor hindering the widespread use of these techniques is the long duration and traumatic nature of the surgical interventions. The surgery duration might be reduced when working with two teams of surgeons, as well as with detailed planning of surgical interventions. One of the important achievements in this field has been the use of three-dimensional technologies for planning surgical interventions based on computed tomography data [8]. These methods allow modeling the surgical intervention in computer-assisted three-dimensional mode, calculating the required size of the bone graft and its configuration. Three-dimensional printing allows creating templates for cutting out a vascularized bone graft of the desired size and a template for the donor bed [9, 10]. There are many published reports on the use of this technique for maxillofacial reconstructions, but there have been very few papers on the use of these techniques in limb surgery [11].

The purpose of this work is to summarize the experience of the N.V.Sklifosovsky Research Institute for Emergency Medicine and the Central Clinical Hospital of the Russian Academy of Sciences in the treatment of limb nonunion fractures and bone defects with vascularized bone autografts using preoperative three-dimensional modeling and printing.

Material and methods

We studied the treatment course and the outcomes of 10 patients with limb fracture nonunions and bone defects. Vascularized bone grafts were used for all patients. Meantime, we used free vascularized bone grafts that required making microanastomoses in 5 patients, and non-free ones on local vessels in other 5 patients; preoperative 3D modeling was used in 4 cases. There were 2 patients with tibial defects, 2 patients with the scaphoid bone nonunion, 1 patient with a scaphoid bone defect, 2 patients with the radius bone nonunion, 2 patients with ulna defect, and 1 patient with humerus nonunion. The patients were 7 men and 3 women the mean age was 43.5 years. The mean time interval from the moment of injury to reconstructive surgery was 4.86 months.

Surgical interventions for limb bone nonunions and defects were performed according to the following procedure. The access to the nonunion or defect area was obtained. The bed for a vascularized bone graft was formed using a saw and a gouge. Then, a free or non-free bone graft was cut out that was moved to the defect area. If a free vascularized bone graft was used, the vessels were microanastomosed using an operating microscope. The stable fixation was performed before or after moving the vascularized bone graft. Fracture fixation was performed using an internal fixator device in 7 cases, and external fixation in 3 cases.

When performing surgical interventions for limb bone nonunions and defects with using vascularized bone grafts, some difficulties occurred with restoring the anatomical shape of the bone, and the problems also arose during the work of two surgical teams, namely, the final preparation of the donor bed was impossible until the bone autograft had been cut out.

For solving those problems, a preoperative three-dimensional modeling of surgical intervention was used in 4 patients. The source for constructing the models included the computed tomography data of the recipient area, or the donor area in 2 cases. The software used for preoperative 3D planning was obtained free of charge. The STL model of the recipient and donor areas was constructed on the basis of the DICOM data. The models were refined and simplified using the MeshLab software. The three-dimensional Blender Editor was used to model the surgical procedure and to calculate the required dimensions of the vascularized bone graft. The same program was used to work out the templates necessary for the surgery, such as the template for preparing the donor bed and the template for cutting out the bone graft. The templates worked out at preoperative planning stage were printed out using polylactate plastic on a three-dimensional printer. After plasma sterilization, the templates were used at surgery to cut out the graft of a desired size and to prepare the recipient bed.

The short-term postoperative results were assessed based on computed tomography data and radiographs. Long-term results were evaluated in the period from 6 to 12 months. Due to a small sample size, namely, the number of clinical cases where the vascularized bone grafts were used, the statistical data processing was not performed.

Results

In 1 case, the vascularized bone graft necrosis caused by venous thrombosis was noted (a patient from the group where the preoperative computer-assisted planning was not performed). In 2 cases, hematoma was formed in the donor area (1 patient from the group where the preoperative computer-assisted planning was performed and 1 patient from the group where it was not performed). In 1 patient from the group where the preoperative computer-assisted planning was performed, a long-term pain syndrome was revealed after surgery. Bone union was achieved in 8 patients at common timing; and in 2 cases where no preoperative computer-assisted planning was used, a delayed consolidation was noted. The average period of consolidation when using vascularized bone grafts was 4.37 (from 2.5 to 12) months.

We also assessed the surgery duration for the cases of using three-dimensional planning and printing-out of templates and the cases without them. Thus, in 6 patients in whom the technique was not used, the average surgery duration was 5 hours and 30 minutes. In 4 patients in whom the preoperative three-dimensional surgery planning was used, the average surgery duration was 4 hours and 25 minutes.

The assessment of surgery anatomical results in patients for whom the three-dimensional planning of intervention was not used showed 2 cases where reposition was found to be unsatisfactory, according to X-ray results. In 4 cases where 3D planning of surgical intervention was performed, there were no cases of unsatisfactory reposition.

We present the clinical case where the vascularized graft was applied without using preoperative three-dimensional planning, and the case where three-dimensional planning was used.

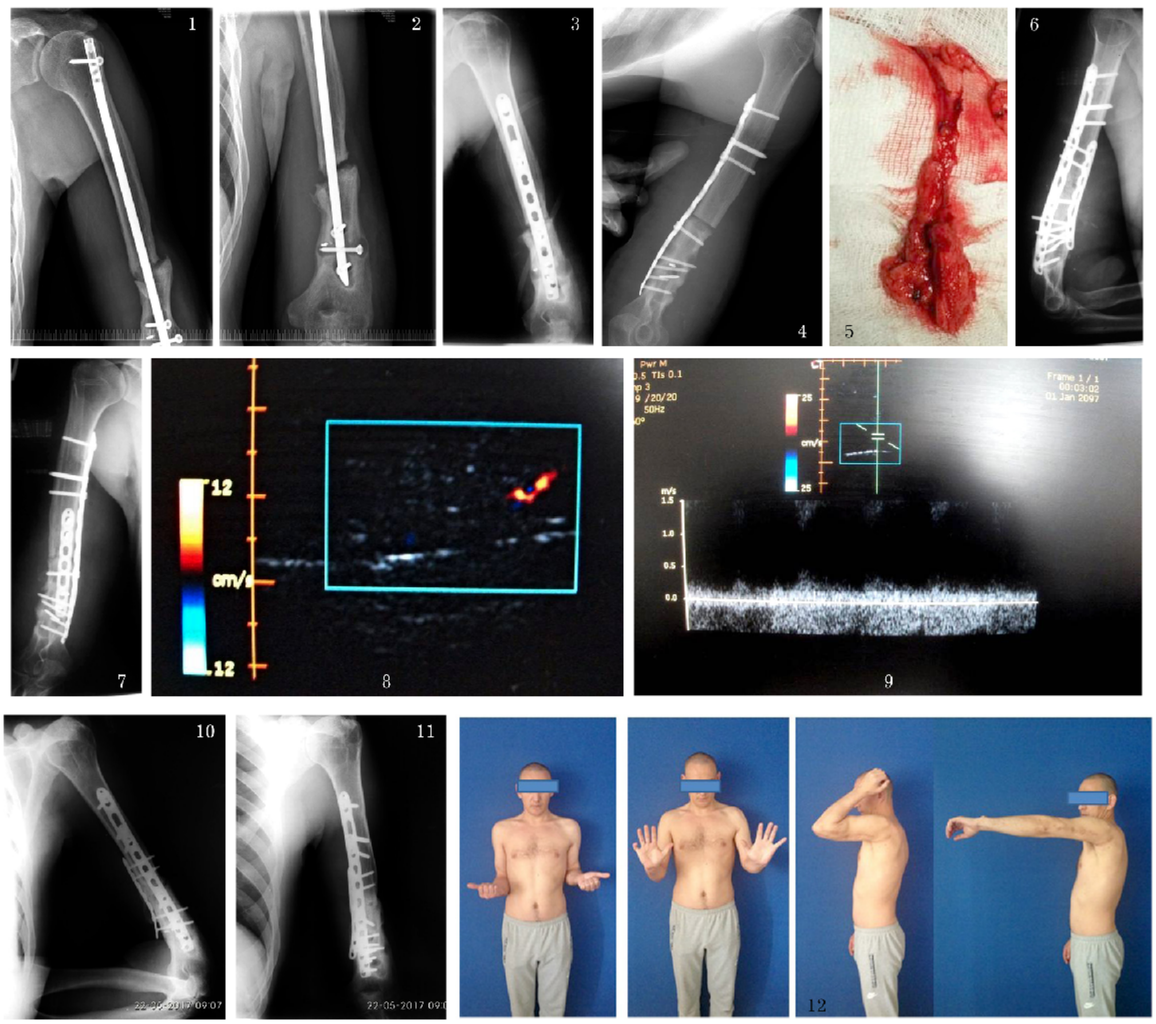

Fig. 1. Patient E., 26 years old. Diagnosis: nonunion fracture, the left humerus defect at the border between the middle and lower third:

1, 2: X-ray images before starting the treatment. 3, 4. X-ray images on completing the 1st stage of surgical treatment: the bone nonunion area was resected, plate osteosynthesis was performed. 5: The view of the bone graft on the vascular pedicle isolated from the medial condyle of the femur. 6, 7: X-ray images on completing the 2nd stage of surgical treatment, grafting the nonunion area with vascularized bone graft, fixation with a plate. 8, 9: Ultrasound Doppler sonography at 7 days after surgery, blood flow through the graft pedicle is visualized, doppleroscopy shows a distinct pulsation. 10, 11: X-ray images at 5 months after surgical treatment, there are signs of consolidation in the nonunion area. 12: A functional result at 7 months after the surgical treatment.

Patient E., 26 years old, sustained an injury at work a year and a half before before being seen at our clinic. He had a history of an open fracture of the right shoulder, and the humerus fracture ostheosyntesis performed with a nail. At referral, he complained of pain, the instability in the area of the right shoulder. The clinical and radiological data suggested a fracture nonunion, a right humerus defect, the condition after nail osteosynthesis. At the first stage of surgical treatment the nail was removed, the nonunion area was resected, and a plate osteosynthesis was performed. In order to improve blood circulation in the nonunion area and to fill bone defects, the second stage of surgical treatment was performed 2 weeks later, namely, the reconstruction of the bone nonunion with a vascularized bone graft obtained from the femoral medial condyle. The surgery duration was 6.5 hours. At surgery, there were technical difficulties associated with adjusting the sizes of the donor bed and the graft. Postoperative wounds healed without complications. The Doppler ultrasound study on day 7 after surgery showed blood flow in the vessels of the graft. Control radiographs at 5 months after surgery showed the signs of humerus consolidation. At 7 months after surgery, the upper limb function restored, and the patient returned to work.

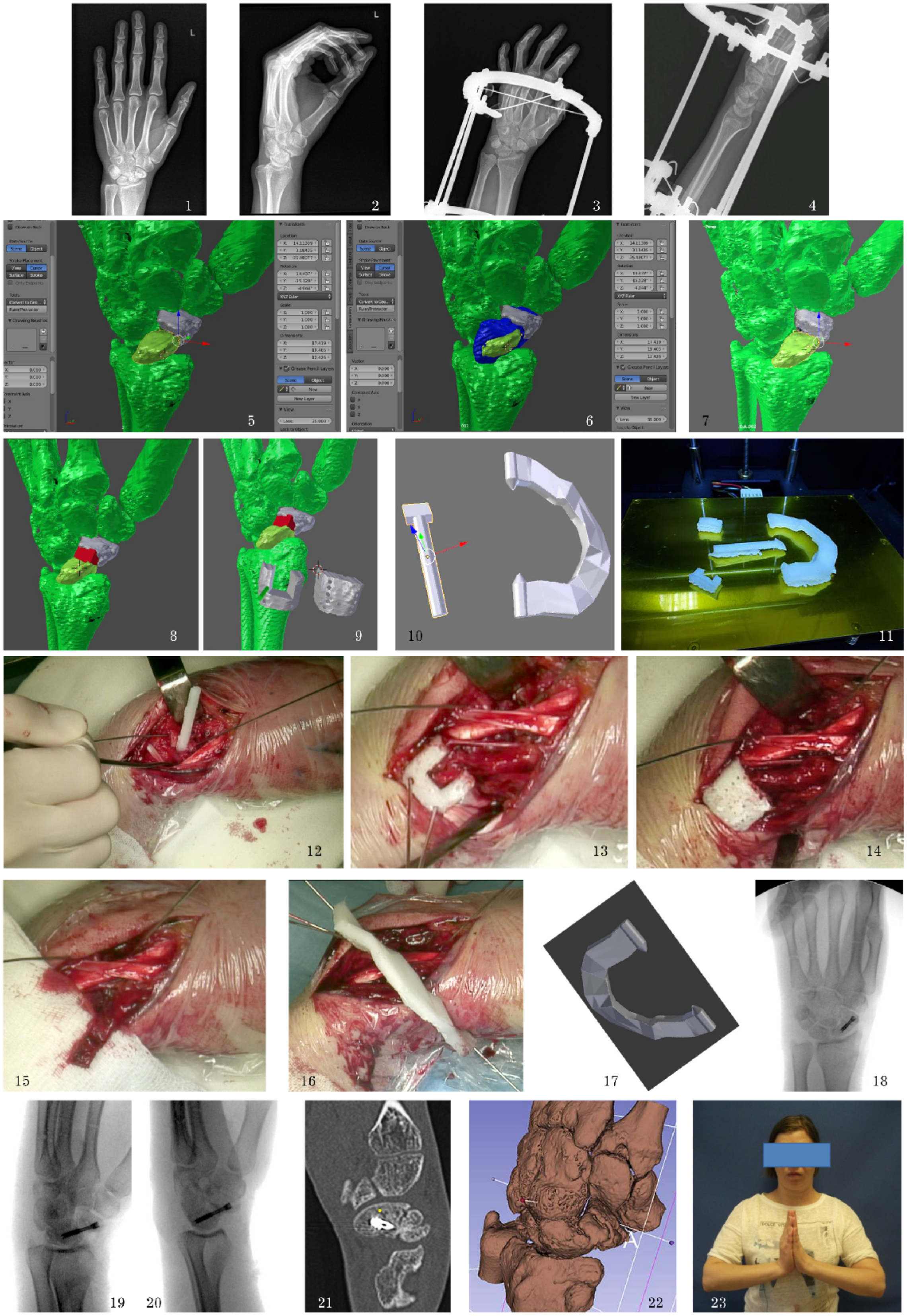
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Fig. 2. Patient K., 28 years old. Diagnosis: nonunion fracture of the right scaphoid bone: 1, 2: X-ray before starting the treatment. 3, 4: X-ray after the first stage of the surgical treatment, namely, the external fixation devise placement. 5: Three-dimensional model of the patient's wrist as created basing on the computed tomography data. 6: The superimposition of the damaged bone model and the mirrored intact scaphoid bone. 7: The scaphoid deformity corrected. 8: Choosing the bone graft dimensions. 9, 10: Modeling the templates for the surgical intervention. 11: Printing out the templates on a desktop three-dimensional printer. 12: Using the template for preparing the recipient bed in the scaphoid bone. 13, 14: Using the templates to customize a vascularized graft made of the radius bone distal metaepiphysis. 15: The view of the bone graft isolated on a vascular pedicle. 16, 17: Using the guide to pass the cannulated screw into the scaphoid bone; 18, 19, 20: X-ray images obtained after surgery. 21, 22: Computed tomography images at 4 months after surgery, there are signs of consolidation of the scaphoid bone. 23: Patient's hand function at 6 months after surgery.

Patient K., 28 years old, fell onto her arm and sustained a fracture of the right scaphoid bone, received conservative treatment 4 years before being seen at our clinic. At referral, she complained of the pain in her right wrist. Based on clinical and radiological data, she was diagnosed with the nonunion of the right scaphoid fracture. At the first stage, the distraction device was applied. Before surgery, a computed tomography of the damaged hand and the non-affected one had been performed. On the basis of computed tomography data, the preoperative planning of surgery was performed, and the templates for cutting out the bone graft and passing the screw were printed on a three-dimensional printer. One week after the first stage of surgery, osteosynthesis of the right scaphoid bone with a plastic screw was performed using a vascularized graft obtained from a distal radius bone metaepiphysis. With using the templates and guides, the surgery duration was 2 hours; no technical difficulties occurred at surgery. Postoperative wounds healed without complications. The computed tomography at 6 months after surgery showed the signs of the scaphoid bone consolidation. Pain in the wrist area regressed.

Discussion of results

The treatment of limb bone nonunions and defects has been one of the most difficult and largely unsolved problems of trauma and orthopedic surgery [2]. There is currently no ideal treatment for this pathology. Various techniques have been used, one of which is the treatment by applying the Ilizarov apparatus [12]. This method allows creating compression in the area of nonunion, stimulating this area, and providing conditions for the bone defect replacement using the non-free bone grafting according to Ilizarov. However, the Ilizarov technique application has significant drawbacks, such as the need to wear the external fixation device, a high incidence of inflammation in the area of the apparatus percutaneous elements, and a high rates of nonunion relapse [13].

The treatment of limb bone defects and nonunions using non-vascular bone autografts in combination with internal osteosynthesis is the most traditional technique [14]. However, many authors have noted a high incidence of a recurrent nonunion, unfeasibility of using non-vascular grafts in cases of infection, and the outcome dependence on the vascularization of surrounding tissues [15, 16].

The vascularized bone grafting is one of the most reliable ways to treat various limb bone nonunions and defects. The advantages of this technique include keeping the cells in the graft viable, the possible revascularization of the non-union area through the graft vessels, the resistance of the graft to infection, and a rapid union of the fracture [17].

Surgery to reconstruct bone defects, in contrast to soft-tissue surgery, requires precision techniques, an accurate selection of the bone graft size, the restoration of the length and axis of the limb. Traditionally, such surgery planning has been based on radiographs. However, the development of computed tomography and the use of three-dimensional technologies for planning surgical interventions have reduced the surgery duration and improved the anatomic results of surgery. These advantages have been reported in many papers, especially in the field of maxillofacial surgery. Our preliminary results indicate the efficacy of this approach in limb reconstruction surgery. Many authors have noted the need to use a specially-developed software and industrially manufactured three-dimensional printers to implement the technology of surgery planning [18]. Meantime, there are few reports describing the use of free software and desktop three-dimensional printers; yet, this leads to a significant reduction in the costs of applying this technology [19].

Conclusions

1. Our experience of using vascularized bone grafts for the treatment of limb bone defects and nonunions has demonstrated that this is an effective method to achieve the bone consolidation, which allows success in almost 100% of cases.

2. The application of vascularized bone grafts requires using microsurgical techniques, thorough selecting the sizes of the donor bed and the graft, which make the surgery average duration as long as about 5 hours and 30 minutes.

3. Preliminary assessments of clinical outcomes have shown that the detailed preoperative planning of surgery using the models created on the basis of computed tomography data, and the three-dimensional printing of the guides and templates for surgery reduce the duration of interventions by 1 hour 5 minutes and decrease the cases of unsatisfactory reposition.

Conflict of interests. Authors declare no conflict of interests.
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