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3D-print in the planning of surgical treatment in the case of extraarticular deformity of lower limbs

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An adequate planning of the curative measures is an important factor providing good functional results in the treatment of consequences of long bones injuries, in particular, malunions (post traumatic deformities). 3D-modeling in the preoperative planing gives an opportunity to assess both deformity itself and joint status. Visualization of injured segment with three-dimensional model manufactured using 3D-print in actual size (1:1 scale) provides additional capacities. Objective. To analyze the capacity provided by the usage of three-dimensional models of damaged segments in scale 1:1 while the planning of corrective surgery. Methods. Practicability of the usage of 3D-models, that was worked out on the base of CT-scanning, was studied in the treatment of 52 patients with different post traumatic extraarticular deformities of femur and tibia, after the fractures with intraarticular extension. Clinical results were evaluated using SF-36 and AOFAS scales. Results. Calculation for 3D-modeling was performed mostly virtually using standard computer programs with 3D-reconstruction, but 3D-print technology was used for 5 patients with the most severe and sophisticated deformities of the lower extremities. Changes in functional outcomes, according to SF-36 and AOFAS, for the patients undergone opera- tive treatment, were positive at 12 month of follow-up. Foreign colleagues expose analogous results of the investigations and suggest that the modeling with 3D-print provides mostly more safe, reliable and standardized clinical decisions for every particular patient. Conclusions. Preoperative usage of 3D-print on the stage of preoperative planing allows the surgeons to simulate different stages of operative intervention on the physical model, thus, help him to realize possible technical problems, choose adequate fixation device and proper instrumentation. It facilitates the shortening of surgery time, elimination of possible complications rate and achievement, in sum, good functional results in the treatment of this kind of patients. Key words. Extraarticular deformity, malunion, lower extremity, 3D-print.

Під час лікування наслідків ушкоджень довгих кісток, зокрема, деформації, украй важливою запорукою отримання хороших функціональних результатів є адекватне планування лікувальних заходів. Використання 3D-моделювання в процесі передопераційного планування дає змогу повніше оцінити як деформацію, так і стан суглобів. Додаткові можливості для планування надає візуалізація ушкодженого сегмента за допомогою об'ємної моделі в реальному розмірі, виготовленої методом 3D-друку в масштабі 1:1. Мета. Проаналізувати можливості використання об'ємних моделей деформованого сегмента в масштабі 1:1 під час планування коригувальних операцій. Методи. Вивчено доцільність використання 3D-моделей, розроблених за результатами КТ-обстеження, у лікуванні 52 хворих із різними післятравматичними позасуглобовими деформаціями стегна і гомілки, де під час первинної травми лінія перелому була поширена на ділянку суглоба. Клінічні результати оцінювали за класифікаціями SF-36 і AOFAS. Результати. Розрахунок 3D-моделей проводили переважно віртуально за допомогою стандартних комп'ютерних програм із 3D-реконструкцією, а технологію 3D-друку використано для 5 пацієнтів із найскладнішими випадками післятравматичних деформацій нижніх кінцівок. Динаміка функціональних результатів прооперованих хворих за SF-36 і AOFAS за 12 міс. була позитивною. Аналогічні результати досліджень демонструють зарубіжні колеги та вважають, що моделювання за допомогою 3D-друку здебільшого може сприяти розробленню безпечних, надійних і стандартизованих клінічних рішень для конкретного пацієнта. Висновки. Передопераційне використання 3D-друку на етапах планування хірургічного втручання дозволяє хірургу моделювати його етапи на фізичній моделі, усвідомити можливі технічні проблеми, адекватно вибрати конструкцію та інструментарій для її встановлення. Це сприяє скороченню часу операції, уникненню потенційних ускладнень і досягненню позитивних результатів функціонального лікування таких пацієнтів.

Key words. Extraarticular deformity, malunion, lower extremity, 3D-print

Introduction

Development of extra-articular deformities of the lower extremities is due not only to the severity of the injury and the condition of the musculoskeletal system, but also inadequate orthopedic and trauma care for patients, untimely treatment and rehabilitation measures, and insufficient assessment of complications. A systematic approach has recently been used to assess changes in the injured segment during the treatment of extra-articular deformities. Adequate preoperative planning is an important guarantee of obtaining good functional results [1, 2]. For many years, the approach to deformation correction planning was based on the assessment of standard radiographic images of the damaged segment, performed in a horizontal position in two classical projections. The next step was the assessment of radiographic images of the injured lower limb in a standing position «with a slope». At present, radiography of both lower extremities in the standard position according to D. Paley should be considered adequate [3]. The most modern and consistent with the level of development of visual research methods is the use of 3D-models, which provides more comprehensive evaluation of the deformation and condition of the joints and, accordingly, adequate planning [4]. Visualization of the damaged segment with the help of a three-dimensional model of real size made by the method of 3D printing provides additional opportunities when planning the operation.

As shown in the study of P. Yang et al. [5], 3D imaging technology helps to make corrective osteotomy more accurately, reduce the risk of postoperative deformity and intraoperative blood loss, reduce intervention time and improve treatment outcomes.

Assessing the appropriateness of the use of 3D printing in the case of correction of tibial deformity by an external fixation device, M. Michielsen et al. [6] noted the advantage of the method when planning the intervention. Thanks to the use of this approach, it was possible to reduce the time of additional correction of the external support in the operating room and to facilitate the planning of the actual type of this support. It is especially expedient to use the method in the case of treatment of complex multiplanar deformations.

This opinion was supported by researchers from Barcelona [7]. The use of 3D printing in the planning of surgery for fractures of the proximal tibia helped to reduce the time of the operation and reduce intraoperative blood loss. Therefore, the authors consider that surgical treatment (ORIF) with pre-reproduction of printed 3D models is much better compared to standard ORIF [8].

N. Bruns and S. Krettek [9] draw attention to the use of 3D printing for the manufacture of individual tools for intervention on the correction of deformation.

Evidence of the increasing attention to 3D printing is the increase in the number of publications on this topic, demonstrated by research conducted in China, USA, UK, and their citation in various databases (Pubmed, Cochrane, SCOPUS, Web of Science). The authors of the published analysis came to an optimistic conclusion about the prospects of using this method in orthopedics and traumatology [10]. Therefore, we considered it appropriate to analyze the possibilities of using 3D-visualization, in particular 3D-printing, in the treatment of patients with the consequences of limb injuries.

The aim of the study: to analyze the feasibility of using three-dimensional models of the deformed segment at a scale of 1:1 when planning corrective surgery in patients with post-traumatic deformities of the lower extremities.

Material and methods

The research materials were considered and approved by the local Committee on Bioethics at the Sytenko Institute of Spine and Joint Pathology National Academy of Medical Sciences of Ukraine (Minutes No. 179 of 14 May 2018) in accordance with current regulations.

The study involved 52 patients with various post-traumatic extra-articular deformities of the thigh and lower leg, in whom during the primary injury the fracture line was extended to the joint area. All of them received medical care in the department of traumatology of the musculoskeletal system of the Sytenko Institute of Spine and Joint Pathology National Academy of Medical Sciences of Ukraine. All patients underwent computed tomography (CT) to plan for deformity correction, and examinations according to the methods developed by us [11]. 3D-printing technology was used for 5 patients with the most difficult cases of obsolete post-traumatic extra-articular deformities of the lower extremities. Models of the damaged and contralateral segment in the scale of 1:1 were made.

The calculation of 3D models was performed mainly virtually using standard computer programs with 3D reconstruction. There are four main types of software used in the 3D printing workflow to embed a digital 3D model into a physical 3D object. Editing, viewing and reproducing models for printing were performed in STL format. This software provides a possibility to visualize, modify and correct STL files for printing. Cutting the model into layers was performed using a slicer that converts the STL file into G-code for the printer. Then the model parameters were calibrated for optimal printing.

Assessment of the dynamics of clinical results was performed by SF-36 and AOFAS [12–14]. The type of primary injury was evaluated according to the classification of AO/OTA [15].

Results and their discussion

The process of preoperative planning began with a CT scan of the damaged and contralateral segments with the involvement of adjacent joints. CT results were used for 3D-reconstruction of images, while the contralateral segment after the creation of its mirror image played the role of a pattern to reproduce the normal length and shape of the damaged one. The data was then output to a 3D printing device and three-dimensional models were produced. The next step was to calculate the correction of deformity (in particular, the location and type of osteotomy) and choose the method of fixation. The final stage of planning surgery was simulated osteotomy, restoration of the axis and length of the limb, choosing a fixation device and options for its location, which would reduce the duration of the operation.

All patients whose treatment at the stage of preoperative planning involved CT examination with the proposed method of 3D modeling, were then operated on, taking into account the individual characteristics of the deformity. The time course of functional results of operated patients for SF-36 and AOFAS for 12 months was positive.

An example of the clinical use of models made by 3D printing on the basis of CT scans of the injured and contralateral limb is the treatment of patient M., born in 1965, who was hospitalized with a diagnosis of fracture of the distal tibia fused with residual varus deformity (21°) and recurvatio (32°) in the presence of a fragment of a metal fixator in the distal epiphysis of the tibia (screw fragment) (Fig. 1, a), widespread scarring of soft tissues of the distal right tibia, mixed contracture of the right tibia joint, reduced leaning ability of the left lower extremity (Fig. 1, b).

After the primary injury, the patient was diagnosed with damage to the pilon of the right leg (43C3.1 according to the AO / OTA classification).

In this regard, several surgeries were performed at another hospital using the fixation of the fragments with an external fixation device, a bone plate and a plaster bandage. Preoperative examination, including ultrasonography of the damaged segment, was performed in the conditions of the institute, during which the localization of *a. tibialis anterior / a. dorsalis*

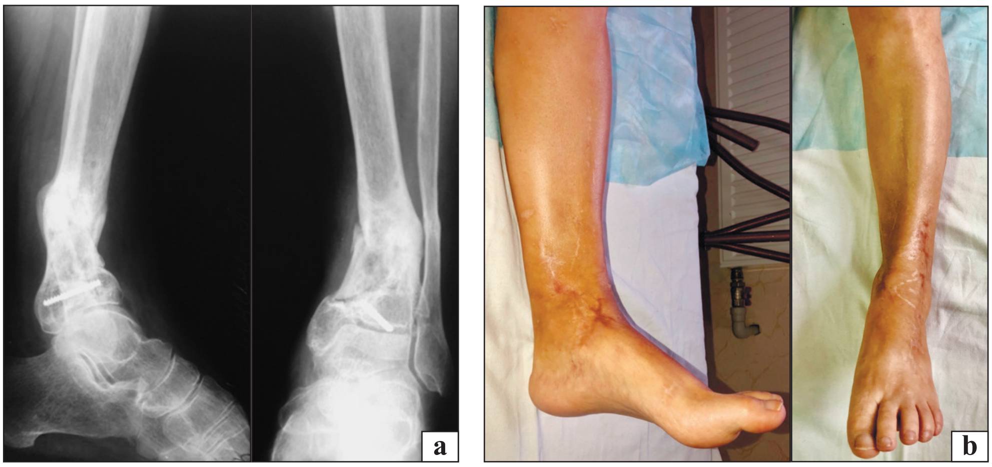

Fig. 1. Radiological images (a) and appearance of the damaged segment (b) of a patient M. on admission

Fig. 2. Marking of the main arteries on skin of a patient's M. according to ultrasonography

Fig. 3. Appearance of a plastic model of the damaged part of the bones of the lower leg and foot, made by 3D-printing at a scale of 1:1 based on the results of CT examination

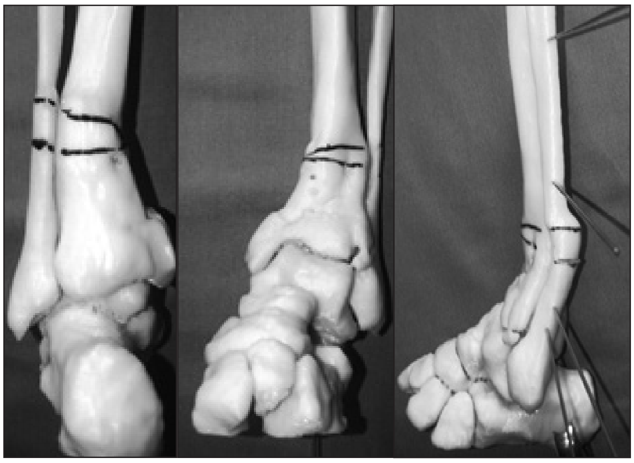

Fig. 4. Marking of corrective osteotomy and partial resection of the bones of the lower left leg on a plastic model of damaged bones of the lower leg and foot of a patient M.

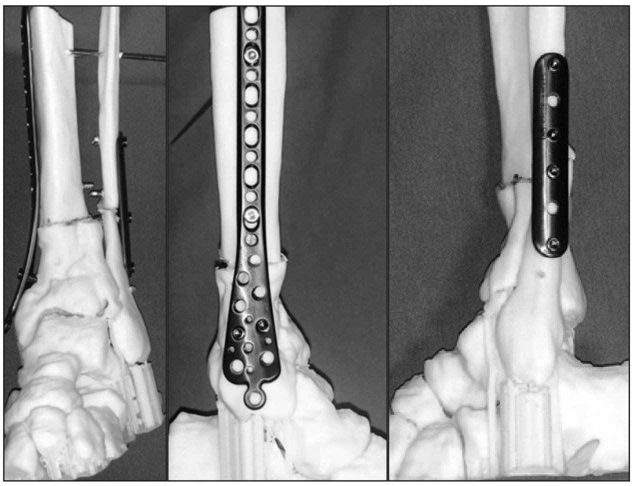

Fig. 5. Modeling on a plastic model of bone fixation of tibial fragments on the inner side and tibial — on the outside after the reproduction of corrective osteotomy and partial resection of the tibia

pedis, a. tibialis posterior та *a. peronea* was established and marked on the skin (Fig. 2).

In addition, cicatricial changes of the skin in the distal part of the tibia were studied and it was decided to perform corrective intervention using two approaches: anterior and posterolateral.

One of the parts of preoperative preparation and planning was the performance of CT examination and production of plastic models of parts of segments (damaged and contralateral) on a scale of 1:1 (Fig. 3). At the same time, the computer 3D image of the contralateral segment was mirrored and became a template for planning a corrective intervention.

After that, the levels and type of osteotomy (by the type of closed wedge) of the tibia and resection of the tibia were noted (Fig. 4).

After establishing the level of osteotomy, a simulation of corrective intervention was performed with resection of the tibia, corrective osteotomy of the tibia and two options for fixing fragments: 1) bone fixation of tibial fragments on the inner surface and tibia — on the outer; 2) fixation of fragments of the tibia with a plate and screws on the outer surface in the case of intraoperative establishment of a high risk of damage to the scarred soft tissues of the distal tibia (Fig. 6).

During the operation performed from the planned accesses, the second fixation option was selected (Fig. 7).

In 4.5 months there was fusion of fragments of the tibia (Fig. 8, a) and a significant improvement in the functionality of the damaged limb (Fig. 8, b).

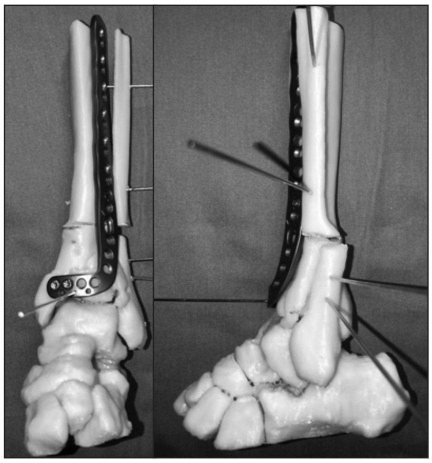

Fig. 6. Modeling on a plastic model of bone fixation of tibial fragments (on the outside) after reproduction of corrective osteotomy and partial resection of the bones of the left tibia. The two lateral holes in the horizontal part of the plate were not used, because the implant left over from previous interventions and the bone defect that will occur after its removal make the use of these holes inappropriate

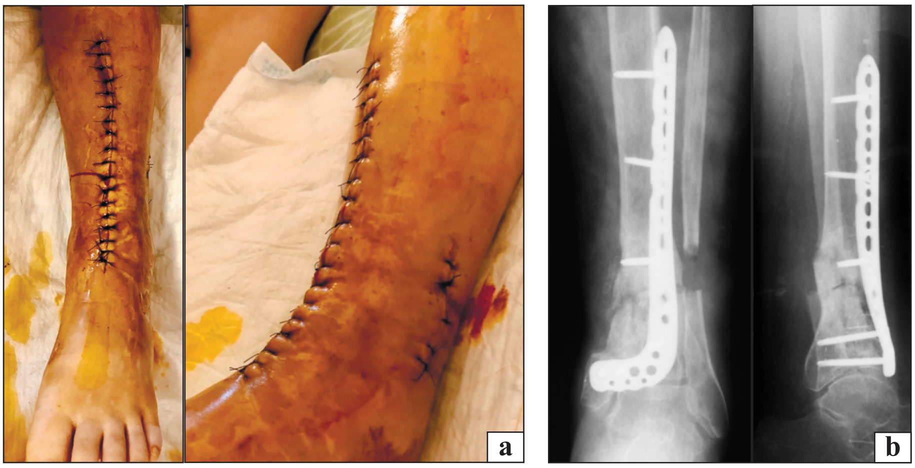

Fig. 7. Appearance of the lower left leg and foot (a) and radiological image (b) of a patient M. after corrective surgeries

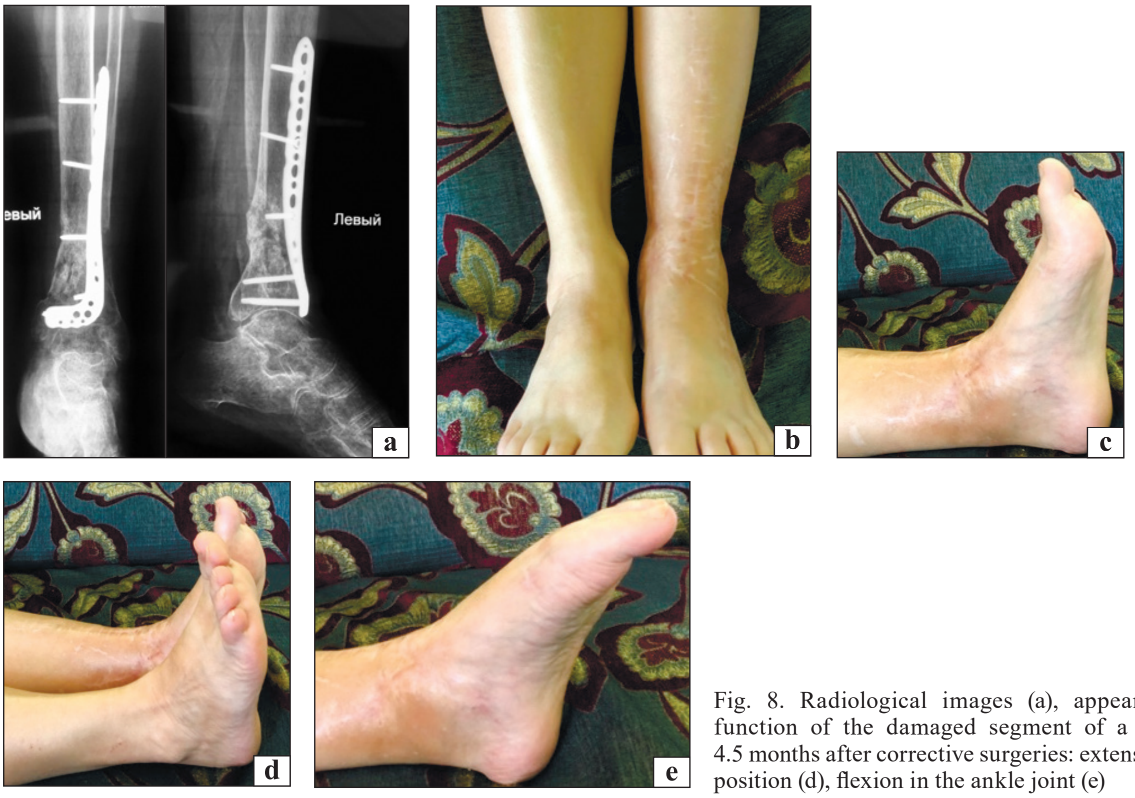

Fig. 8. Radiological images (a), appearance (b) and function of the damaged segment of a patient M. in 4.5 months after corrective surgeries: extension (c), neutral position (d), flexion in the ankle joint (e)

Time course of AOFAS ranged from 37 points before surgery to 78 points in 6 months after the intervention.

The results obtained by us are consistent with the experience of foreign colleagues on the feasibility and possibility of using three-dimensional printing in orthopedic surgery. This technology provides flexibility in the design of skeletal surgery and allows the effective implementation of both ready-made and personalized therapeutic agents that better meet the needs of patients than traditional manufacturing processes [10]. 3D-printing is used not only for anatomical models, but also for non-standard individual implants, instruments and prostheses [9]. Today it is a very promising branch of surgical orthopedic science that requires careful attention and study.

Modeling using 3D printing, according to the experience of foreign colleagues, should contribute to the development of safe, reliable and standardized clinical solutions for a particular patient [16].

Conclusions

The use of three-dimensional computer models when planning corrective surgery allows the surgeon to increase the accuracy of the correction and significantly reduce the time of the operation. Additional reproduction of plastic models of parts of segments (damaged and contralateral), made by 3D-printing at a scale of 1: 1, allows the surgeon to model the stages of intervention on a physical model, understand possible technical problems, adequately select the design and tools for its installation. This helps to reduce the time of surgery, avoid potential complications and achieve positive results of functional treatment of such patients. In addition, 3D modeling with 3D printing can be an effective tool for the learning process.

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

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3D-PRINT IN THE PLANNING OF SURGICAL TREATMENT IN THE CASE OF EXTRAARTICULAR DEFORMITY OF LOWER LIMBS

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