საქართველოს მეცნიერებათა ეროვნული აკადემიის მოამბე, ტ. 17, №1, 2023
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*Experimental Medicine*

# 3D-Printing in Planning and Carrying out Resectional Femur Osteotomy in Gonarthrosis Patients

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**The research represents stages of the technology to design and manufacture individual navigation systems for operations involving axial femoral deformities corrections in knee gonarthrosis patients. With a clinical example, the authors demonstrate the application of a 3D-printed navigation system in a patient suffering from knee osteoarthritis with valgus deformity of a femur. Thanks to the 3D printing technology, the surgery applied a single-use customized navigator to position surgical instruments accurately on the femoral bone. The technology ensures precise correction of deformities, reduces surgery time and radiation load on both patient and surgeon. The represented stages make the method of designing customized navigation systems available for bioengineers and orthopedic and trauma surgeons at the centers specialized in complex multiplanar osteotomies.** *© 2023 Bull. Georg. Natl. Acad. Sci.*

individual navigation systems, 3D-modeling, gonarthrosis, corrective osteotomies, knee joint

Among the kinds of big joint osteoarthritis (OA), a place of honour is possessed by gonarthrosis – damage to knee joints. It is defined as the most widespread form of OA, typical of patients under 50 years old. According to sources, OA affects knee joints approximately in 75% of cases. In the majority of gonarthrosis cases, diagnosis exposes insulated damage of a single area of a joint. For such a situation, corrective osteotomy of femoral or tibial bone could be a method of choice [1]. However, if a patient has a well-expressed valgus or varus knee deformity, a multipole corrective osteotomy is indicated. Its most important task is to correct deformities of lower limbs.

Nowadays, medicine uses 3D-modelling to plan complex surgical interventions in maxillofacial surgery, neurosurgery, cancer orthopaedics, regular orthopaedics, and traumatology [2]. 3D-printing technology enables us to create a prototype of an anatomical area planned for surgical treatment on the grounds of CT and MR imaging results. With this dummy prototype, a surgeon can test different surgical scenarios, consider difficulties able to arise during the operation, accurately select a serial implant or develop an individual one [3, 4].

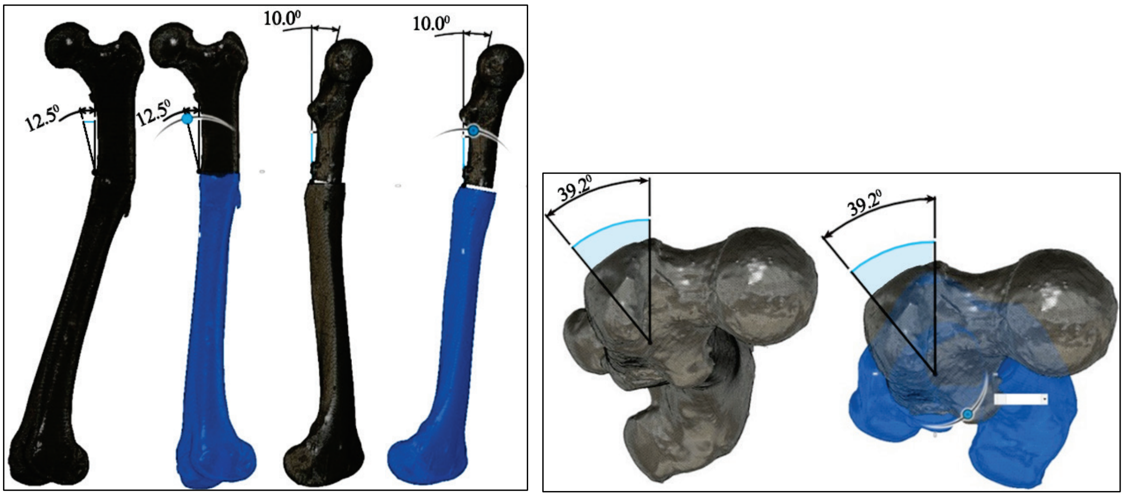



**Fig. 1.** Deformity angles of the femur to be corrected.

Moreover, 3D-printing opens wide opportunities for manufacturing individual navigation systems (INS) [5, 6]. First, INS is valuable for an individual implant or a so-called custom-made implant production. It will ideally fit a specific patient's bone geometry, considering all defects. In other words, INVS opens possibilities for personalized surgery. In our case, it is about a single-use customized guide, produced for the accurate positioning of surgical tools (drills, chisels, saws, etc.) or implants in relation to the target organ (bone).

## Materials and Methods

We share our own experience in 3D-printed INS design, describing them stepwise for your convenience. The INS design is represented stepwise on the example of a left femur fracture malunion with 2nd stage posttraumatic gonarthrosis in a female 32-years-old patient. At the SI "The Institute of Traumatology and Orthopedics, NAMS of Ukraine", the patient underwent corrective multiplane osteotomy with INS, osteosynthesis with a metal plate and screws. Stepwise designing of an INS usually includes 9 stages, from imaging a patient's bone to the final manufacturing and sterilization of the INS.

**Stage 1. Imaging of a bone.** For imaging of the bone, the computed tomography of the anatomical segment is required, with the minimum thickness of layers (≤1 mm).

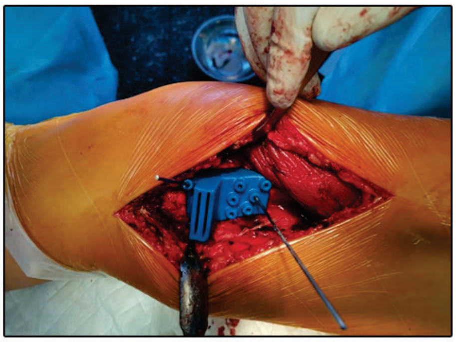
**Stage 2. Segmentation of CT images, creating an STL-model.** Segmentation means extracting special areas of the CT layers to be used for the 3D STL-model formation. The segmentation could be made using computer applications like Osirix MD, 3D Slicer, Mimics, or others. To get a model of high quality, we recommend extending automatic segmentation with a manual one.

**Stage 3. Defining bone deformity angles.** CAD programs are useful to define the angles of the deformity. In our specific case, we have to eliminate: varus deformity of 12.5°, antecurvation of 10.0°, internal rotation of 39.2° (Fig. 1).

**Stage 4. Basing the INS.** To base the INS, one shall determine its location on a bone the surgeon can bare during the operation. As a rule, it corresponds with the tip of the bone's deformity. The surface of the bone's navigation system mimics the contours of the bone, so bone irregularities in this area improve the fixation of the INS during the operation. Dimensions of the navigator must be as small as is it possible preserving the strength of its structure and the reliability of its fixation.

**Stage 5. Slots for oscillatory saw.** Directions of the slots coincide with osteotomy planes to be calculated by a team of a bioengineer and a surgeon

a



b

**Fig 2.** 3D model of the right femur with the INS for supracondylar resectional varus osteotomy (a), the INS in use during the operation (b).

according to the plan of the operation. The slots shall be designed 0.5 mm thicker than the blade of the saw, with their length ensuring free motions of the blade to process the complete diameter of the bone.

**Stage 6. Holes for rotation marks.** To eliminate a rotational deformity, a surgeon may need holes for rotation marks are required if a rotational deformity shall be eliminated. Through these holes in the navigator, the surgeon makes small incisions 1 mm from the osteotomy edges using a thin drill of a wire. To eliminate the rotational displacement, the surgeon matches these marks after the removal of the navigator.

**Stage 7. Holes for fixing wires.** The INS shall be fixed to the bone using wires. We recommend designing not less than three wire holes for distal and proximal parts of the bone.

**Stage 8. Additive production of the bone's prototype and INS.** Simulation of the surgical operation. FDM (Fused Deposition Modeling) serves most frequently to create an individual dummy prototype, scale 1:1. To form the object, a melted thread of work materials is deposited layer by layer. It is expedient to use printers with a work chamber of 300 x 300 x 300 mm.

After printing dummy prototypes of the bone and the INS, the surgeon verifies their accuracy, carrying out a simulated surgery. If everything fits, the INS goes to the "final" production.

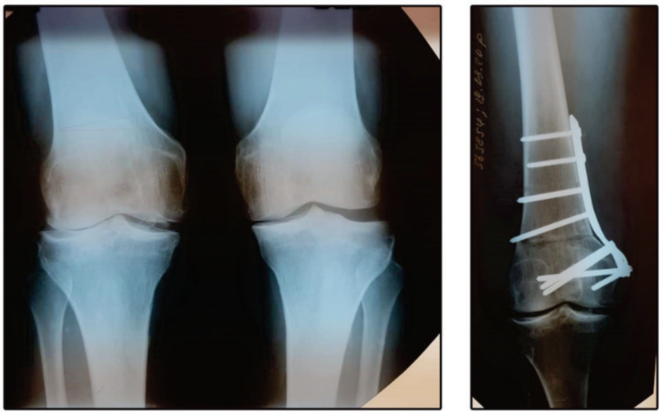
**Stage 9. "Final" production and sterilization of the INS.** Final INS is made by 3D-printing from biocompatible photopolymer resins or plastics. After sterilization, they can serve the intended purpose.

## Results

Here we share our own successful experience of INS application for a supracondylar varus osteotomy to the right femoral bone. A patient T., 48 years old, applied with complaints of pain and deformation of her right knee. After a range of clinical examinations, we diagnosed a bilateral 3rd stage gonarthrosis with a valgus deformity on the right and a varus on the left. The surgical treatment took place at the SI ITO NAMSU. The patient underwent a supracondylar varus osteotomy of her right femoral bone (Fig. 2, 3). The use of the INS enabled us to reduce the time of surgery by about a third, make fewer intraoperational X-ray images and enhance the accuracy of corrections to the angular deformities. The postoperative period passed without complications. On the 3rd day after the surgery, we discharged the patient for rehabilitation at her place of residence.

## Discussion

Today, the most valuable feature of the INS is its accuracy in directing wires, drills, oscillatory saws, chisels [7]. During a surgical operation, a surgeon



a b

**Fig. 3.** X-ray images of the patient's knees before the surgery (a) and after the supracondylar varus osteotomy of her right femur (b).

places the navigation system in the correct position, fixes it on the bone and carries out all necessary manipulations. Radermacher K. and his colleagues did many operations using the INS and reported encouraging accuracy. Positioning measurements showed deviations less than 0.6° for spine surgery and -1° for femoral and tibial osteotomies. Cadaver tests showed clinically acceptable results of INS used for spine surgeries, with slight mistakes < 2 mm, compared to usual methods. Talking about the total surgery time, INS reduces it significantly [8]. The paper by Radermacher K. et al. (1995) has shown that INS is associated with a smaller period required to find entry points for drilling vertebras [9]. A piece of study dedicated to triple pelvic osteotomies covered 24 patients, 13 of whom underwent osteotomies using the INS. In 4 cases, it was impossible to install an INS due to the high density of soft tissues. To solve this problem, INSs were modified and surgical approaches changed. The research lasted 2 years. The analyzed results showed that the surgery time dropped by 23% [10]. It is worth mentioning that the technology described allowed decreasing X-ray irradiation of patients, as considerably fewer intraoperational images are needed.

We got identic results using INS for corrective femur osteotomies due to gonarthrosis.

## Conclusions

1. Relying on the literature sources analysis and our own surgical experience, we recommend INS for complex multiplane femoral osteotomies in patients with knee OA. It improves the accuracy of the surgery, reduces the number of intraoperative X-ray images required, as well as the time of the operation.
2. The stages proposed to design navigation systems make this method available for bioengineers and orthopaedic and trauma surgeons in medical facilities carrying out complex multiplane osteotomies.

*ექსპერიმენტული მედიცინა*

# 3D-(სამგანზომილებიანი) ბეჭდვა გონართროზის მქონე პაციენტების რეზექციული ბარძაყის ოსტეოტომიის დაგეგმვასა და ჩატარებაში

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**უკრაინის მედიცინის მეცნიერებათა ეროვნული აკადემია, ტრავმატოლოგიისა და ორთოპედიის ინსტიტუტი, უკრაინა*

(წარმოდგენილია აკადემიის წევრის რ. ხეცურიანის მიერ)

კვლევაში წარმოდგენილია მუხლის გონართროზის მქონე პაციენტებისთვის ღერძული ბარძაყის დეფორმაციის საკორექციო ოპერაციებისას ინდივიდუალური ნავიგაციური სისტემების შექმნისა და წარმოების ტექნოლოგიის სტადიები. კლინიკური მაგალითით ავტორები გვთავაზობენ 3D- (სამგანზომილებიანი) ბეჭდვითი ნავიგაციის სისტემის გამოყენებას ბარძაყის ძვლის ვალგუსური დეფორმაციით მუხლის ოსტეოართრიტის მქონე პაციენტის შემთხვევაში. 3D-ბეჭდვითი ტექნოლოგიის დამსახურებით ქირურგიული ოპერაციის დროს გამოყენებულ იქნა ერთჯერადი ინდივიდუალური ნავიგატორი ქირურგიული ინსტრუმენტების ბარძაყის ძვალზე ზუსტად მოთავსების მიზნით. ამგვარი ტექნოლოგია უზრუნველყოფს დეფორმაციების კორექციას სრული სიზუსტით, ამცირებს ქირურგიული ოპერაციის დროსა და გამოსხივებას პაციენტსა და ქირურგზე. წარმოდგენილი სტადიები ინდივიდუალური ნავიგაციური სისტემების შექმნის მეთოდს ხელმისაწვდომს ხდის ბიოინჟინრების, ქირურგ-ორთოპედებისა და ტრავმატოლოგებისთვის კომპლექსურ მრავალსიბრტყულ ოსტეომიების შემთხვევაში სპეციალიზებულ კლინიკებში.

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