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Presurgical practice of supracondylar domosteotomie of cubitus varus deformity on 3D printed humerus

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Abstract: Complicated fractures of bones can be difficult to treat, and there is a high probability that further operative corrections need to be carried out. In the present work, we present a case study, where a model of the humerus of a six-year-old male patient was 3D-printed from a segmented CT-dataset for a preoperative optimization of the geometric parameters of a supracondylar domosteotomy. The experimental simulation of the treatment has proven very useful to the physician, and the patient has been treated successfully.

I. Introduction

Among the most common bone fractures in clinical practice, the upper arm, and the forearm, as well as the femur and the tibia in the lower extremity are common subjects to posttraumatic treatment. In case of complicated fractures close to joints or with joint involvement, the treatment can be challenging and sometimes requires multiple interventions to restore the patient's full mobility. We evaluate the experimental simulation of an osteotomy by using 3D-printing technology to produce models of the bone from radiologic datasets.

In the present case a left supracondylar humerus fractur of a pediatric patient (Type IV according to v. Laer) healed in misalignement after the initial operative treatment and lead to a cubitus varus deformity[1,2], which is denoted by a towards the body angled joint axis. Clinically, there was limited mobility, chronic pain and a cosmetic deformity ("gunstock deformity") present. A supracondylar domosteotomy, in which a triangular bone structure is removed in order to reconstruct a physiological joint axis angle was planned and carried out. The cutting planes for the osteotomy were calculated based on radiographic projection images. During this study, 3D-printed models of the patient's humerus were used to test different approaches to precisely transfer the cutting planes onto the humerus.

II. Material and methods

A computed tomography (CT) dataset of the humerus of a six-year-old male patient was semi-automatically segmented by a threshold and some manual correction. The segmented structure was converted into a printable polygon-surface mesh. In order to reduce the roughness of the surface, most likely caused by local segmentation uncertainties and the discretization into volumetric pixels, the mesh was smoothed using a Laplacian smoothing filter. The segmented structure was printed with a common 3D-printer (Ultimaker 3, Ultimaker B.V., Geldermalsen, Netherlands) in the fused deposition modelling method (FDM). The segmentation as well as the printed bone model were inspected to comply with the CT data of the anatomical structure by an experienced radiologist specialized in pediatrics. Four models were printed from polylactic acid (PLA) and could be used for practicing the surgery by positioning Kirschner wires to mark the cutting planes. The angles between these were measured and adjusted until they matched the previously calculated angles. The models were then sawed along the cutting planes defined by the wires. The procedure of the training surgery was slightly altered for each model to find the best case-matching approach.

The outcomes of the procedures were discussed by the surgeons and the best was chosen to be applied onto the cubitus varus deformity. The operation was performed as in the chosen training setting, except for the measurement of the angles: During training the angles between the cutting planes could be measured directly at the Kirschner wires, whereas the angles on the patients arm were determined on radiographic projection images from an X-ray C-arm to sustain sterility. In order to benchmark the intervention, the mobility of the patient's arm was recorded, and the deformity angles were determined on X-ray projections before surgery and after the healing process was completed.

III. Results and discussion

The surgery could significantly decrease the displacement angle, which lead to a significant increase in the mobility of the patient's arm. During the practice of the surgery, the Kirschner wires were easy to place in the printed part, while sawing the material used for the production of the models turned out to be difficult, due to the low melting temperature of the thermoplastic PLA. As it has been expected, the 3D-printing material behaves differently than real bone when it comes to sawing and drilling.

Figure 1:X-ray of posttraumatic cubitus varus deformity on six-year-old male patient.

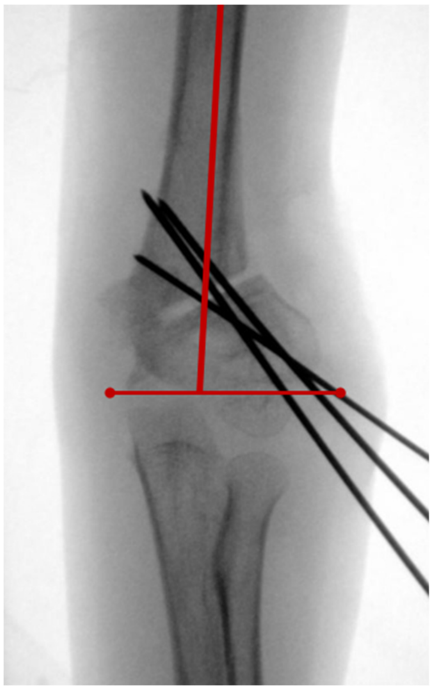

Figure 3: Postoperative X-ray.

However, practicing different variants of the supracondylar domosteotomy be means of 3D-printed bone models has turned out very helpful for the planning of the surgery. The clinical course was uneventful. The postoperative radiographs showed a good bony healing. The percutaneous K-wires could be removed after 4 weeks in the outpatient clinic.

Clinically, the varus angle was 20° preoperatively and 0° postoperatively. The elbow showed a good joint function and better cosmetic appearance. The lateral condyle was slightly prominent.

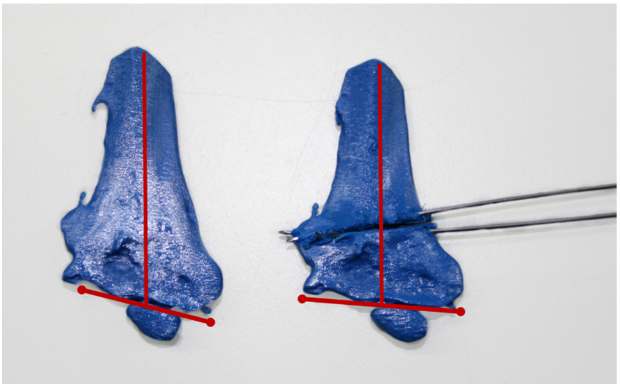

Figure 2: Simulated supracondylar domosteotomy on 3D-printed bone model, with varus angle (red line).

IV. Conclusions

Even though experienced physicians are familiar to work with X-ray projection images and datasets from CT, the possibility to plan a surgery with a real physical model of the defect can increases the insight into the geometric intricacies of the affected bone. The proposed method shows, that 3D-printing enables to train a complex surgery on anatomical models, which precisely resemble the patient's anatomy. Therefore, the surgery can be performed after testing different approaches. However, the choice of the material which is used to produce the models can be improved in order to allow for a more precise simulation of the treatment with standard surgical instruments and to get closer to the physiological properties of bones. Other helpful items for the described surgery are drilling- and cutting guides, as these are medical devices, there are a number of regulatory implications. Furthermore, the sterilization of 3D-printed objects to clinical standards needs further attention.

Acknowledgments

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Author's statement

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