Infinite Science | Publishing

Evaluation of 3D-printing materials for the simulation of osteotomies

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Abstract: As 3D printing has tremendously gained momentum in various disciplines for many years, it is also becoming more and more promising for medical engineering. Not only to replace body-parts, but also to build anatomical models which can improve the planning of operations. However, previous studies revealed, that the choice of materials has a high impact on the usability of such anatomical models. Therefore, we compare different common 3D-printing materials with the focus on their suitability to simulate osteotomies.

I. Introduction

The medical treatment of bone fractures is of very high clinical relevance. Fortunately, the treatment of fractures in general has a high success rate and the mobility of the patients can usually be restored. However, there is still a large number of cases, where complicated fractures are more challenging to cure. In these complicated cases it occurs, that fractures do not heal as expected, and deformities occur, which need to be invasively corrected by means of an osteotomy. [1]

An osteotomy is a surgical technique, where the physician has to cut the bone, remove or add material and put the parts back together in order to correct the geometry of the bone. Even though humans in general have the same basic anatomy, the procedure is highly patient specific, because the defects vary significantly. In order to provide the best possible treatment to the patient, it is highly advantageous to cure the defect with a minimal number of operations. [2]

The goal of the following experiments is to help the surgeon to prepare for the operation in the best possible way. By having a 3D-printed model of the individual affected bone, it is possible to haptically analyze the malposition before the operation. Usually, the planning of the surgery is based on computed tomography (CT) data or three-dimensional images on a two-dimensional screen. Having a printed model, makes it easier to detect problematic parts, to identify important landmarks and to plan the approach experimentally. Furthermore, different variants of the osteotomy can be evaluated and the optimal approach can be chosen based on the comparison of the outcome. This way, the duration of the surgery can be reduced, while providing a better treatment to the patient. To optimize the preconditions for the experimental simulation, different materials were tested in experiments.

II. Material and methods

The material properties are investigated by different methods, such as the subjective impressions while sawing and drilling. To provide a realistic basis for the comparison, first of all, a bone was segmented out of a CT dataset and postprocessed to assure printability. To achieve this, the software Amira (Thermo Fisher Scientific, Waltham, Massachusetts, USA) was used for segmentation, and the open source software MeshLab for surface modifications. The chosen bone parts are about 10 cm of a human radius and ulna next to the elbow from the body of a donor. Narrow gaps in the joint were closed through segmentation to preserve the original orientation of the ulna and radius to each other.

For the experiments, three different printing materials were used: PLA (Pro1 from Innofil3D, Emmen, Netherlands), which was printed on an Ultimaker 3 (Ultimaker B.V., Geldermalsen, Netherlands), Clear-resin (FLGPCL04 from Formlabs, Somerville, Massachusetts, USA) printed on a Formlabs Form 2, and VisiJet M3 X (3D Systems, Rock Hill, South Carolina, USA) printed on a Projet 3510 HD Plus. From the latter one, only a 9 cm piece of the human radius has been printed, to reduce printing time and material costs.

Figure 1: Anatomic bone model printed from PLA

DOI: 10.18416/AMMM.2019.1909S03P03

Figure 2: Anatomic bone model printed from Clear Resin

Figure 3: Anatomic bone model 3D-printed from VisiJet M3 X

The behavior of all three materials, when sawed and drilled, was tested. For evaluation the same procedure was made with the femur of a pig to have real organic bone as a reference.

III. Results and discussion

The black PLA-model (*Figure 1*) has a very distinct layer structure, which under load favors breaking along the different layers. Due to its thermoplastic nature, it also melts easily, which can cause fibrous clumping during sawing and may jam the saw. On the last 6 mm of the cut, the material broke off while sawing. Drilling a small hole on the other hand was no problem at all.

The Clear-resin-model (*Figure 2*) easily splintered the first millimeter of sawing, until there was a significant indentation. A well-defined sawdust accrued and the remaining cut was clean and it was easy to saw, however, on the last 3 mm of the cut, it broke off. Boring a small hole was easily done.

The VisiJet M3 X-model (*Figure 3*) has a high tendency for splintering as well, apart from this sawing was easy and it also produced a well-defined sawdust. Only the last 1 mm of the clean cut broke off. During boring, a circular discoloration occurred around the hole and the end of the hole splintered a little. Furthermore, it smelled like the material melted, as the temperature of the material significantly increased during the boring.

Compared to the synthetic materials the bone showed no splintering during sawing. Well-defined sawdust has been created here as well, and the clean cut broke off around 1 mm to the end. The bone marrow is soft, stays at its place and feels like a solid paste. Boring was no problem at all, but bone marrow accumulates at the boring bit.

IV. Conclusions

So far, it can be summarized, that the thermoplastic PLA has a reasonably low melting temperature to make it suitable for the FDM-method, where melted material is extruded from a small nozzle to build up the object from layers. This affects the printed part in a way that it easily softens under the blade of sawing tools even at low speeds, which can make it difficult to apply precise cuts in a simulated osteotomy, whereas, the precise drilling of holes was easily possible. In contrast, the photopolymers (Clear-resin and VisiJet M3 X) behave not that different from real bone, when it comes to sawing. A disadvantage of the photopolymers from this study is, that they are relatively brittle and in general more expensive.

Up to now, we only investigated material properties based on subjective impressions. Further experiments and testing procedures will be necessary to evaluate more materials and their mechanical properties quantitatively, but all materials so far are interesting options for the planning, and the experimental preparation of an osteotomy. Furthermore, it would be interesting to include other 3D-printing technologies in our investigations.

ACKNOWLEDGMENTS

We thank Maik Stille for his helpful advice and for providing the CT dataset.

AUTHOR'S STATEMENT

The authors gratefully acknowledge the Federal Ministry of Education and Research, Germany (BMBF) for funding this project under Grant Nos. 13GW0071D (SKAMPI) and 13GW0230B (FMT). The human cadavers used for the CT data in this study were dissected and used in this examination under permission of the „Gesetz über das Leichen-, Bestattungs- und Friedhofswesen (Bestattungsgesetz) des Landes Schleswig-Holstein vom 04.02.2005, Abschnitt II, 9 (Leichenöffnung, anatomisch)". In this case it is allowed to use the body of a donor for scientific purposes. Authors state no conflict of interest.

REFERENCES

[1] C.A. Ho, *Cubitus Varus—It's More Than Just a Crooked Arm!,* Journal of Pediatric Orthopaedics. 2017, Sep 1, 37(6,2), pp. S37-S41

[2] T. Takagi et al., *Supracondylar osteotomy of the humerus to correct cubitus varus: do both internal rotation and extension deformities need to be corrected?,* The journal of bone and joint surgery, 2010, Jul 7, 92, pp. 1619-26