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Comparations of the 3D Printing Methods for the Production of the Reporting Medical Models

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Abstract: The paper is focused on the area of manufacturing reporting medical models for verifications of custom made implants before the implantation. The CAD/CAM (computer-assisted design/computer-assisted manufacturing) trend of production of personalized implants supports the use of additive and subtractive production technologies with the creation of reporting medical models. The paper describes a geometrical comparison of four same patterns of the skull manufactured by different 3D printing technologies. It was realized actual-nominal comparison of CT scans of the medical models with CAD design of the skull as a reference. Deviations from the shape identified in our experiment, show the range from 1,89 mm to -0,91 mm.

Keywords: Medical model; 3D printing; additive manufacturing; metrotomography

1. Introduction

A worldwide trend in craniofacial surgery and implantology is the use of computer support and 3D technologies for the design and production of made-to-measure implant devices for completely closing cranial defects [11]. The linking of CAD/CAM and additive technologies eliminates in the design phase shape limitations, the size and internal structure, and in the course of the implantation reduces the time of the intervention (on the order of by 1 hour) [11]. The disadvantages and post-implantation complications with the use of autologous tissues are the reason for the trend of searching for a suitable alloplastic biocompatible material without inherent problems [5] [10].

Custom made implants appear to be an advantageous alternative if it is not possible to use autologous bone grafts. It enables easy insertion, anatomical precision, aesthetic simplification of processes with more various complicated defects and a saving of time for the surgical intervention during implantation [1] [2] [9].

The using of the medical reference models for preoperative planning of the implant surgery is an innovative solution for the treatment of the traumatic defects. In using of modern imaging technologies such as CT, MRI and ultrasound are created normative data sets in DICOM format [6] [7] [8]. In using of 3D medical modeling program is created a virtual 3D model of the substantial anatomical segment. This model meets the structural parameters and serves as a model for implantation production equipment [3] [4].

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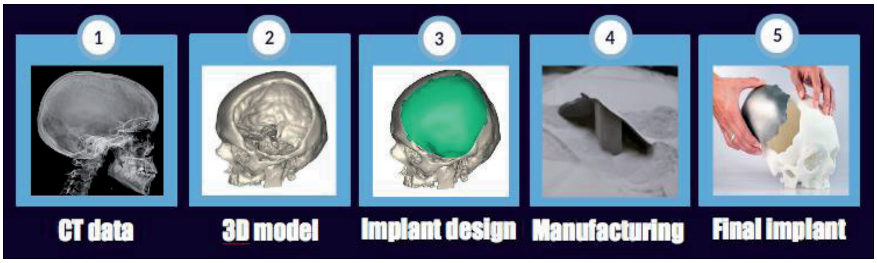

Fig. 1: *Process flow for design and manufacture of computer assisted design/computer assisted manufacturing generated implants [12].*

2. Experimental Section

The medical model is so-called a free form. It means that define it in specific geometric shapes is tough, if is not impossible. Our medical CAD model used in the manufacture of the implant. Now, it is used to test the accuracy of the 3D printer. The model which we chose because of its shape and size suit all printers, because it was limited to the space dimensions of 120 mm x 120 mm x 160 mm.

Fig. 2: *Cranial segment – 3D model.*

As it can be seen in the figure 2, there was cut cranial skull defect beginning in maxillofacial part of the skull, the curvature of the eye, and extends into the frontal part of the skull. The defect was compared to a triangular shape.

Table 1: *Parameters of the model.*

X	Y	Z
83,637 mm	101,676 mm	151,988 mm

2.1 3D printing technologies

Currently there are a variety of the manufacturing technologies of the 3D printing differing from each other by using material, accurate, layer thickness, print speed, getting cost and price of the material.

Our aim was to compare four basic production technologies, which are used in 3D printing prototypes and reference medical models. Three of the four comparison technologies are from the laboratories of the Department of Biomedical Engineering and Measurement, Technical University of Kosice.

Table 2: *3D printing machines.*

3D printing technology			
FFF	SLA	PolyJet	SLS
bq Witbox	Formlabs Form1+	Objet Eden PolyJet 250	EOS Formiga P100

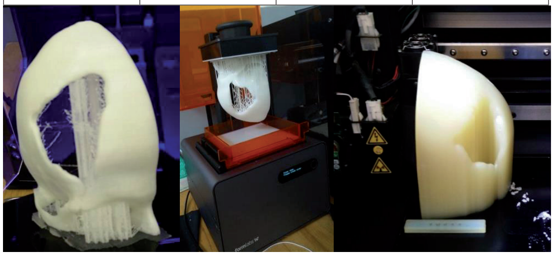

Fig. 3: *Medical models manufactured by available 3D printing technologies.*

FFF (Fused Filament Fabrications) technology is a production technology established on the melting of the material filaments and subsequent laying of the materials in the series of layers according to the defined CAD model. This production technique is characterized by lower initial costs and the reduction of the waste materials during the production, which can have an influence on the overall price of the product and this increase the accessibility of the personalized medical models.

Our goal was to compare FFF technology with other 3D printing technologies, and determine the appropriateness of its use in the production of the reference models. Productions parameters use in other 3D printing technologies were the same.

SLA (Stereolithography) technology. It uses the photopolymer, what is photosensitive plastic, which after the most common irradiation with UV light, polymerizes, solidifies. First, the print

Table 3: *FFF production parameters.*

Layer thickness	0,05 mm
Wall thickness	1,2 mm
The thickness of the top and bottom layer	0,6 mm
Material filler	20%
Printing speed (x, y - displacement of the nozzle)	40 mm/s
Type of Support	Everywhere
Adhesion to the platform	Around the edges

platform immerse in resin. Irradiated with only the points where the material to solidify and makes the desired product.

PolyJet technology is similar to the technology which was used in inkjet printers. It means that the platform was applied to ultra-thin film over the ten nozzles, which were cured immediately after application of UV light. For one moving of the printing head was suddenly applied printing material and support material.

SLS (Selective Laser Sintering) technology is similar to the Stereolithography, but the powdered media is strengthened. First, the platform was headed for the top position. Dispensing was applied to the first layer, followed by laser sintered. The platform was moved to the process step below. Dispensing applied another layer, and excess material was pushed into the material chamber.

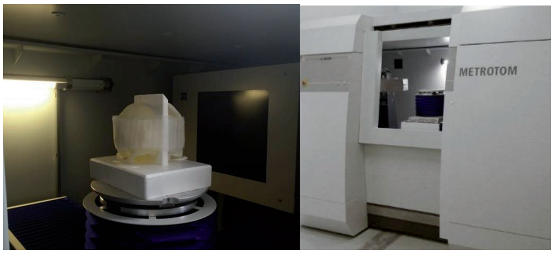

Fig. 4: *Metrotomography of the medical modedels.*

2.2 Scanning

Printed medical reference models we subjected to measurement of the METROTOM 1500.

2.3 Export of data

It is possible to export raw data into several types of files,most often into *.STL due to the universality of its using. This involves a surface triangle mesh.

2.4 Evaluation of obtained data

For the evaluation we used the program GOM Inspect, which is suitable for comparison of actual and nominal dimensions. Gom Inspect V8 program for 3D inspection of cloud points for dimensional analysis obtained either with optical or laser cameras or CT machines and other sources.

Table 4: *Parameters of the METROTOM 1500.*

XYZ measuring range [mm]		350 x 350 x 350
X-ray lamp	voltage [kV]	30- 225
	current [μA]	10 - 1000
	target power [W]	max. 225
X-ray detector	max resolution	1024x1024
	pixel size [μm]	max. 400x400

3. Results and Discussion

The method for evaluating the accuracy of the selected 3D printing technology is compared to the CAD model obtained from medical DICOM data that served as the base model with a CAD model obtained by the metrotomography of the made reference model.

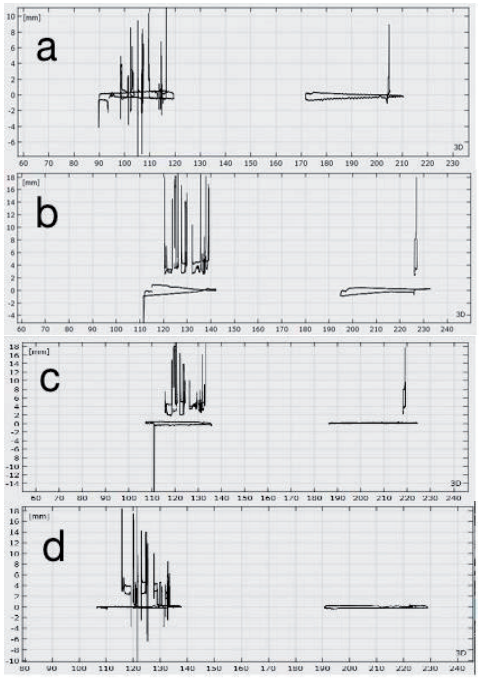

Fig. 5: *Profile characterization FFF(a), SLA(b), PolyJet(c), SLS(d).*

Table 5: *The average deviation from the CAD model in implantable area.*

FFF	**SLA**	**PolyJet**	**SLS**
0,208 mm	0,144	0,093	-0,02

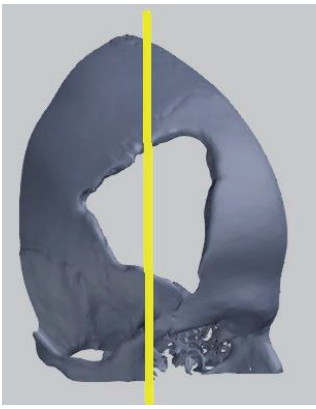

Fig. 6: *Virtual medical model with corresponding profile.*

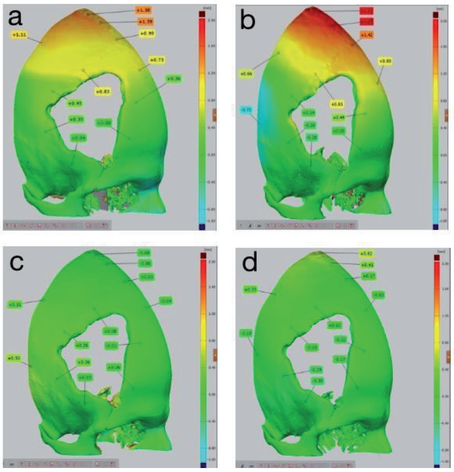

Fig. 7: *Deviations from the CAD model FFF(a), SLA(b), PolyJet(c), SLS(d).*

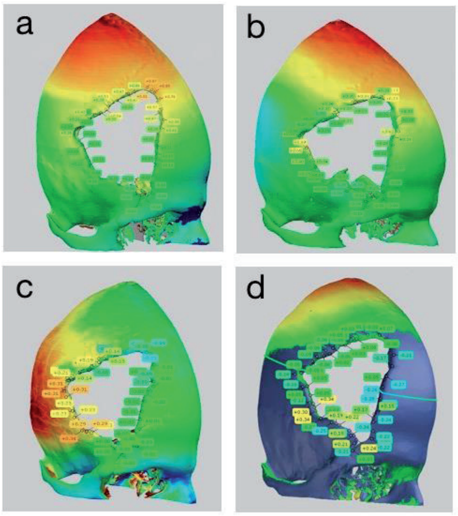

Fig. 8: *Deviations of implantable area from the CAD model FFF(a), SLA(b), PolyJet(c), SLS(d).*

4. Conclusions

Good results with respect the price of the 3D model were recorded at FFF technology. Printing problems in curved part can be caused by a constant speed of printing, which does not work slower at printing smaller parts and shakes the model. Deviations from the measured values ranged up to +1.50 mm - 0.61 mm. SLA technology identified the most deviations, the result was confirmed by least squares method. Deviations of the shape were ranged up to 1.89 mm to -0.91 mm. The values around the defect are not critical, the standard deviation is 0.144 mm. This result attaches to the fact that the model was forced out of the resin, and it can cause the rise of inaccuracies, especially for larger models. The result in PolyJet technology was that the shape deviations ranged from +0.52 mm to -0.45 mm. Inaccurate around the defect is slight. The value of the average deviation around the defect was 0.093 mm. The largest plus deviation appeared on the left side of the model; the greatest minus deviations appeared to the right of the model at the junction of the eye with nasal bone. SLS technology confirms the high quality of the printing. The shape deviations are in the range from +0.75 mm to -0.34 mm. The biggest inaccuracies were created at the top of the model. The value of the average deviation around the defect was -0.02 mm in comparison the CAD reference model. The low-cost technology was above our expectations of inexpensive price, the reduced value of materials at the highest possible accuracy. Getting better results of the precision can be achieved by the another design of driving mechanisms which will be aimed at the further research. This technology can be recommended as the most suitable for printing medical reference models.

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6. References and Notes

[1] Schlickewei W, Schlickewei C. The use of bone substitutes in the treatment of bone defects-The clinical view and history. Macromol Symp 2007;253:10-23.

[2] Parthasarathy J, Parthiban JK. Rapid Prototyping in Custom Fabrication of Titanium Mesh Implants for Large Cranial Defects. RAPID, May 20-22. TP08PUB117 Lake Buena Vista, FL, USA: Society of Manufacturing Engineers; 2008.

[3] Connell H, Statham P, Collie D, Walker F, Moos K. Use of a template for custom cranioplasty. Phidias – EC Funded Network Project on Rapid Prototyping in Medicine 1999;2:7-8.

[4] Scholz M, Wehmöller M, Lehmbrock J, Schmieder K, Engelhardt M, Harders A, et al. Reconstruction of the temporal contour for traumatic tissue loss using a CAD/CAM prefabricated titanium implant-case report. J Craniomaxillofac Surg 2007;35:388-92.

[5] Parthasarathy J, Starly B, Raman S. Patient specific craniofacial implants. In: Medical Manufacturing Year Book. 1 SME Drive Dearborn, MI: Society of Manufacturing Engineers; 2009. p. 39-43.

[6] Abdelaal OA, Darwish SM. Review of rapid prototyping techniques for tissue engineering scaffolds fabrication. Adv Structured Mater 2013;29:33-54.

[7] Camarini ET, Tomeh JK, Dias RR, da Silva EJ. Reconstruction of frontal bone using specific implant polyether-ether-ketone. J Craniofac Surg 2011;22:22057.

[8] Ciocca L, De Crescenzio F, Fantini M, Scotti R. CAD/CAM and rapid prototyped scaffold construction for bone regenerative medicine and surgical transfer of virtual planning: A pilot study. Comput Med Imaging Graph 2009;33:5862.

[9] Hou JS, Chen M, Pan CB, Wang M, Wang JG, Zhang B, et al. Application of CAD/CAM-assisted technique with surgical treatment in reconstruction of the mandible. J Craniomaxillofac Surg 2012;40:e432 7.

[10] Rohner D, Guijarro-Martínez R, Bucher P, Hammer B. Importance of patient-specific intraoperative guides in complex maxillofacial reconstruction. J Craniomaxillofac Surg 2013;41:382 90.

[11] Parthasarathy J. 3D modeling, custom implants and its future perspectives in craniofacial surgery. Ann Maxillofac Surg 2014;4:9-18.

[12] CEIT-BI. from: http://www.ceit-ke.sk

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