Journal for Technology of Plasticity, Vol. 39 (2014), Number 2

INFLUENCE OF SECONDARY RECONSTRUCTION ON RAPID PROTOTYPING TOOTH MODEL ACCURACY

Dejan Movrin[1*], Aljoša Ivanišević[1], Igor Kačmarčik[1], Tijana. Lainović[2], Aleksandar Spasić[3], Larisa Blažić[4]

[1]Faculty of Technical Science, University of Novi Sad, Serbia

[2]Faculty of Medicine, School of Dentistry, University of Novi Sad, Serbia

[3] Clinical Center of Vojvodina, Center for Radiology, Novi Sad, Serbia

[4]Faculty of Medicine, School of Dentistry, Clinic of Dentistry of Vojvodina, University of Novi Sad, Serbia

ABSTRACT

Medical tools and accessories often have a complex geometry, and therefore, rapid prototyping technologies are in advantage compared to conventional machining and forming technologies in medical object producing. Accuracy of the produced medical tools and accessories is very important. Input file (3D model), which is often obtained from a computed tomography scan, has a direct repercussion on their accuracy. For exporting scanned (DICOM) file in file readable to rapid prototyping systems (for example STL), specialized software based on secondary reconstruction can be used. In this paper, influence of software 3D Doctor and CT scanner parameters on accuracy of the fabricated model (human tooth) was investigated. Models were fabricated using two rapid prototyping technologies: Fused deposition modeling, and 3D inkjet printing. Diameters of the conical root canal in the master, and produced models, were measured and compared. For precise measuring, the coordinate measuring machine Carl Zeiss CONTURA G2 RDS was used.

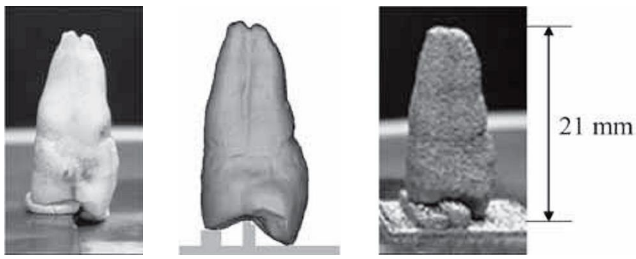
Key words: *Computer tomography, secondary reconstruction, dentistry, rapid prototyping*

1. INTRODUCTION

Rapid prototyping (RP) technologies enable very simple and fast production of physical objects from 3D CAD model files. These technologies are especially suitable for a small scale production and have a wide application in dentistry, as dental implants and prosthetics products are very individualized components with high production prices. 3D CAD models are usually generated by input data obtained by CT or MRI scanning. The main advantages of RP technologies are short production times and a possibility of making simple and fast adjustments of gathered 3D models.

*Corresponding author's email: movrin@uns.ac.rs

In paper [1] several fields of application of RP technologies in dentistry are given, such as manufacturing of dental devices and tools, surgical planning, customized implant designing, visualization, diagnostics, education, forensics, production of biologically active implants, etc. An example of tooth manufacturing by RP is presented in paper [2]. In Fig.1a, a real tooth (upper first premolar) is given and in 1b and 1c, 3D CAD and RP produced physical model are presented respectively. Physical model was produced by selective laser sintering from titanium.



a) b) c)

Fig. 1 *- Example of tooth produced by RP: a) Tooth, b) 3D model and c) RP model [2]*

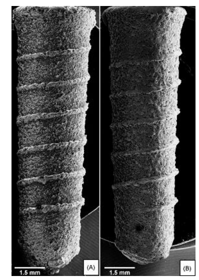


Fig. 2 *- Titanium dental implant obtained by DMLS [3]*

Paper [3] elaborates production of a titanium alloy implant (Fig.2) by DMLS rapid prototyping technology. Considering the fact that the dental implant is embedded in the jaw, it is essential for it to possess appropriate mechanical and biochemical characteristics, as well as excellent biocompatible features. Therefore in this study, RP produced model was treated with appropriate acids, in order to achieve lower roughness and higher biocompatibility. Titanium alloy Ti-6Al-4V with 1-10 µm particle size was used.

Another application of RP in dentistry is given in paper [1]. In this paper a design and manufacturing of a drill guide is presented. Drill guide has a function to assist a surgeon in drilling a location for implant (Fig.3). Initially, a CT scan was used to obtain a 3D model of the jaw. This model enables dentists to virtually search the best location for the implant in the jaw. Based upon the 3D model of the jaw, a virtual model of the guider system was designed and fabricated by SLS. The accuracy of produced model is very important for using RP technique in dentistry. Preparation of a STL file from CT or MRI has direct repercussion on the final RP model accuracy. There are several steps for generating STL file from radiological devices which are explained in the following sections of the manuscript.

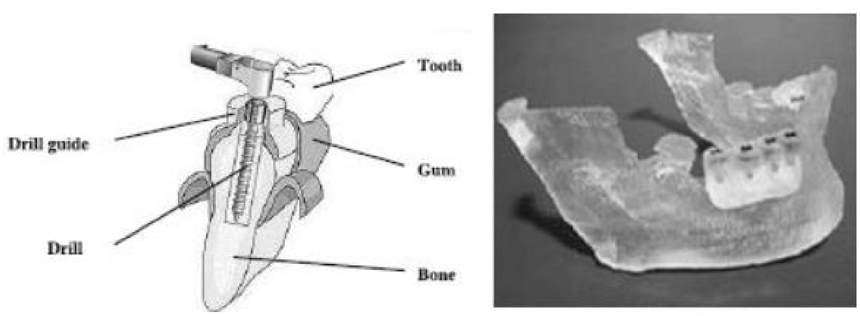


Fig. 3 *- Schematics of drill guide and model of a jawbone manufactured by stereolithography [1]*

2. EXPERIMENTAL RESEARCH

2.1 Human maxillary central incisor (master model) preparation

In order to determine the accuracy of RP model, a human maxillary central incisor, extracted as a consequence of a periodontal disease, was used in the current study. This tooth has been chosen as an optimal tooth for this examination, due to its favourable anatomic characteristics, as it is a single root-single-canal tooth, with a relatively wide and straight pulp chamber and canal, which could be relatively easily prepared in a proper form. The extracted tooth was cleaned and disinfected, and then processed simulating the standard clinical procedure. The dental operator conducted the endodontic treatment and the filling procedure of the root canal, followed by the canal preparation for the fabricated dental reconstructive post, made of a fiber-reinforced composite (so called ñFRCò post). After the access cavity preparation, the root canal was shaped by the Protaper shaping instruments for the canal preparation (final dimension ï F3, Protaper, Dentsply). The canal was irrigated, cleaned and dried, and filled with the root canal sealer (AH plus, Dentsply), and an optimally-sized gutta-percha (F3 size). Afterwards, the root canal was prepared for the dental reconstructive post by using the adequate instrument for the post preparation (blue instrument for the post preparation from the Core & Post System, Dentsply). Final design of the prepared tooth is shown in Fig.4.

Fig. 4 *– Endodontically treated maxillary central incisor prepared for the "FRC" tooth-reconstructive post*

2.2 CT scanning

After preparation, tooth was scanned using CT (Computed Tomography) technology. CT medical imaging is a powerful tool for viewing the internal structure of the human body. Tomography is a technique in which images of cuts or sections of an object are obtained. The operating principle of medical CT is shown in Fig.5. An ionizing radiation beam from X-ray tube passes through an object which is positioned at the patient table, while a set of detectors picks up the radiation that is passed through, and the computer converts it into a digital image [5].

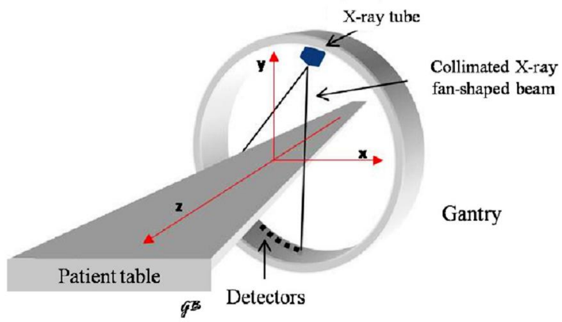


Fig. 5 *- Schematic representation of a computed tomography (CT) system [4]*

CT imaging is limited by its 2D image presentation which does not allow doctors to quickly diagnose 3D tissue changes caused by a disease and explain symptoms, diagnosis and recommended therapy to patients [6]. Medical images in 3D solid models are therefore very important in the diagnosis and treatment process. All reconstructed 3D solid models can be converted to RP physical models and Virtual Reality Modelling Language (VRML) format for visualization.
Prepared tooth was immersed in radiological gel in order to be easy positioned (Fig.6a) and scanned (Fig.6b). Two different irradiating setups (protocols) were performed, for both adult and child. Parameters for both protocol and type of devices are given in table 1.

a) *b)*

Fig. 6 *– CT scanning a) master model placed on CT device, b) one tomogram of scanned tooth*

Table 1 *– CT irradiating setups*

Type of CT device	**Pixel size (mm)**		**Tube voltage (kV)**		**CTDIvol**		**Dose length product**	
	Child	**Adult**	**Child**	**Adult**	**Child**	**Adult**	**Child**	**Adult**
SIEMENS Sensation Cardiac 64	0.326	0.297	120		9.97	59.43	168	957

2.3 3D model preparation based on second reconstruction

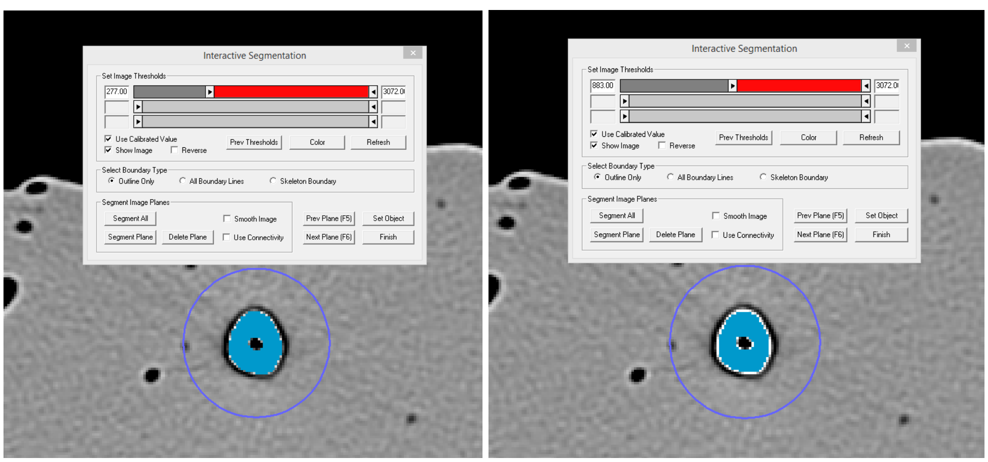
Standard files that are used as input for 3D printing are STL or VRML files. There are numerous special commercial and free software for conversion of CT data to these files. Considering the presence of numerous different CT systems, DICOM (Digital Imaging and Communications in Medicine) standard, readable for all users was developed. The DICOM-format data were processed by using the 3D-Doctor software in order to obtain 3D model.

There are three steps needed to obtain 3D model from DICOM files: image acquisition, primary reconstruction and secondary reconstruction.

Data acquisition is the first step in 3D model reconstruction and it is mostly dependent from type and setup of CT device. The primary reconstruction is based on Fourier transformation and as a result, a set of images as slices in Z direction are obtained. The secondary reconstruction is last phase in 3D model generation. In this phase the human factor has significant influence. Also, noise and other artefacts can be reduced or completely removed in the secondary reconstruction which enables high accuracy of the final model.

For segmentation of all tomograms, thresholding setup was varied in two ways. Thresholding was used to create a first definition of the segmentation object. The object can be defined based on one lower threshold, or based on both lower and higher threshold. The threshold value can be changed by moving the sliders in the thresholding toolbar with real time visual feedback. The threshold value will be displayed in the threshold toolbar and the segmentation area is changed accordingly. With the two sliders, both minimal and maximal thresholds can be set. In most cases, only the minimal value needs to be set [8].

For both protocols (CT device setups) same values of maximal thresholding were used. The maximal thresholding was set at 3072 which is the maximal allowed value in 3D Doctor and the minimal values were set in two different values. In the case 1, it was set at 277 (Fig.7a) and in the case 2, at 883 (Fig.7b).



a) b)

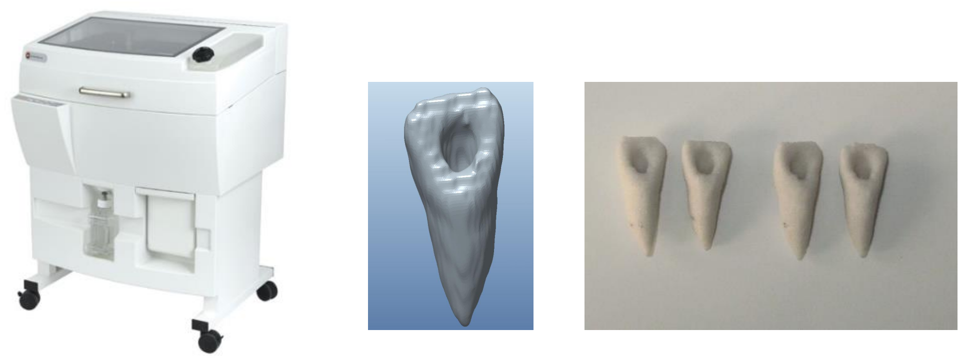
***Fig.** 7 – Thresholding setups a) case 1, b) case 2*

3D printing

Two different rapid prototyping systems were applied for models fabrication and both use STL files as input.

2.4.1. Inkjet 3D printing

Inkjet 3D printing is a technology based on a joining of the powder particles together, using a liquid binder at selected regions of the spread powder (layer). In this way the one layer (cross-section) is created. When the layer is completed, the build piston is lowered, a new layer of powder is spread over its surface by a metal roller, and the process is repeated. The part grows layer by layer in the build piston until the part is completed, completely surrounded and covered by loose powder. The shape of all layers in X-Y plane (the shape of the regions which are glued together) corresponds to the virtual cross section of the CAD model.
In this experimental research, monochromatic 3D printer Z310 plus (Z Corporation ï 3D Systems) was used (Fig. 8a). Powder used in the experiment was ZP 131, binder zb90 and layer thickness was 0.1 mm. After printing, the parts with low mechanical properties, called green parts, were produced. For obtaining final mechanical properties, infiltration with epoxy resin or cyanoacrylate was needed. Loctite cyanoacrylate was used as an infiltrant in the experimental research. According to STL model (Fig. 8b), four models (teeth) with two different CT device setups, two variation of thresholding, and the same process parameters of 3D printing were produced (Fig. 8c).

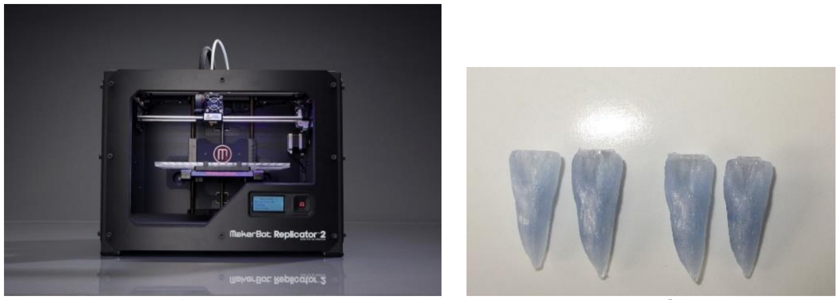


a) b) c)

***Fig. 8** – Ink jet 3D printing a) 3D printer Z310 plus, b) STL file, c) teeth models*

2.4.2 Fused deposition modelling

The material in filament (spool) form was melted in a specially designed head, which extruded on the model. As it was extruded, it was cooled and thus solidified to form the model. The model was built layer by layer, like in the other RP systems [9]. In this experimental research, Makerbot Replicator 2 device was used (Fig.9a), with main characteristics: type of filament PLA thermoplastic, filament diameter 1.75 mm, nozzle diameter 0.4 mm, build volume 28.5x15.3x15.5 cm , x-y precision 11 microns, z-precision 2.5 microns.
As in Ink jet 3D printing technologies, four models of human teeth were printed using neon blue PLA thermoplastic and the same devices setup, for each model (Fig. 9b).



a) b)

Fig. 9 *– Fused deposition modelling a) device b) teeth models*

2.4 Measuring

Because of the complexity of the outer surface of the tooth model, only the prepared root canal geometry was measured and compared with the master model, and with the object dimensions from the computed tomograms. Dimensions and approximation of the prepared root canal shape were derived on the coordinate measuring machine Carl Zeiss CONTURA G2 RDS (Fig.10).
For comparison of the master and the printed models, diameters of the root canal were measured at two different depths, and their values were compared.

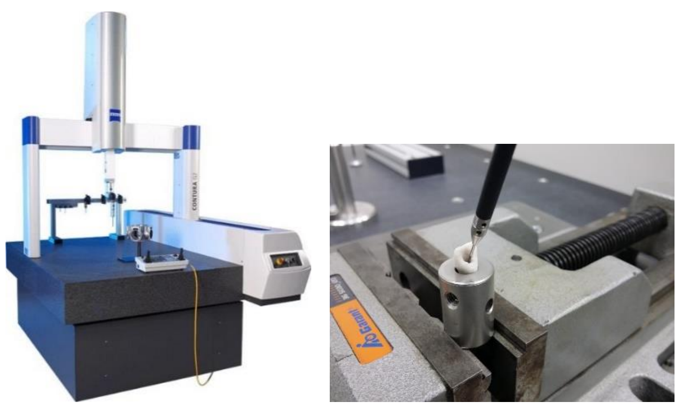


Fig. 10 *– Coordinate measuring machine Carl Zeiss CONTURA G2 RDS*

3. RESULTS AND DISSCUSION

As previously noted, diameters of the master model were measured at two cross-sections (two different root canal depths). Also, diameters of the master model based on the CT scan were measured in the same way using Syngo fastView software for DICOM files viewing. Because prepared root canal does not have an accurate circle shape at the corresponding cross-section, in one tomogram three dimensions were measured, and average value was set as diameter (Fig.11).

According to the two measured diameters in the two cross-sections, the cone angle was calculated and compared with the master model. Diameters and the angle of the master model, measured by the coordinate measuring machine, and obtained by a cross section measuring in Syngo fastView software, are shown in table 2, while measured diameters of RP models are given in table 3.

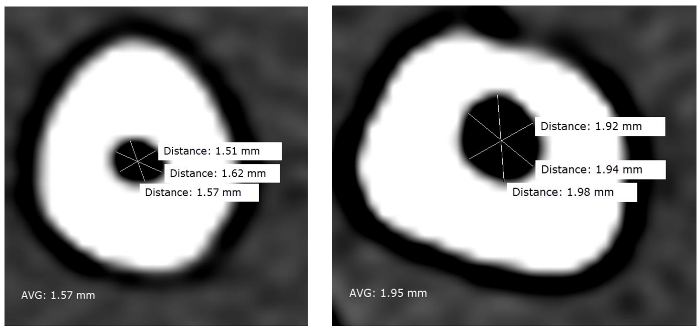


Fig. 9 *– Diameters in the two different cross-sections*

Table 2 *- Results of master model measuring*

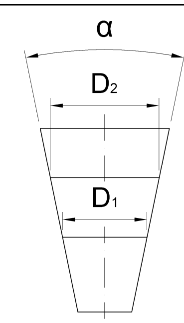
No	Measuring method	CT Protocol	D_1 [mm]	D_2 [mm]	α [^{0}]	
1	Coordinate measuring machine	/	1.50	1.90	21.80	
2	Syngo fastView	Adult	1.57	2.10	20.81	
3	Syngo fastView	Child	1.60	2.01	22.29	

Table 3 *– Results of RP models measuring*

No	RP system	CT Protocol	Thresholding [min-max]	D_1 [mm]	D_2 [mm]	α [^{0}]
4	FDM	Adult	277 ï 3072	1.18	1.58	21.80
5			883 - 3072	1.62	2.00	20.81
6		Child	277 ï 3072	1.46	1.86	21.80
7			883 - 3072	1.86	2.22	19.80
8	3D printing	Adult	277 ï 3072	1.74	2.16	22.78
9			883 - 3072	1.76	2.18	22.78
10		Child	277 ï 3072	1.96	2.34	20.81
11			883 - 3072	1.98	2.38	21.80

In regards to the master model, the measures of CT (DICOM) files and RP models had a dimensional deviation in the range of plus 0.32 mm, and minus 0.48 mm, which can be seen from tables 2 and 3. The protocol of CT device also had a large influence on both virtual and RP model. The variation of the thresholding had a greater impact in the case of FDM, then in the case of 3D Inkjet printing technology. Models produced by 3D inkjet printer had deviation in the range of ±0.01 mm compared with each other, while FDM models had deviation ± 0.2 mm.

4. CONCLUSION

In this paper, the influence of the secondary reconstruction on a dimensional accuracy of STL and physical model was investigated. Diameters of prepared root canal in master, RP and CT model were measured and compared.

Three different parameters were varied: setup (protocol) of CT device, value of the thresholding, and rapid prototyping device. All the three parameters had the influence on the accuracy of rapid prototyping model. The secondary reconstruction had a more significant influence on the model produced by FDM device, than on the model produced by 3D inkjet printing device. The influence of the two other parameters was not negligible. The dimensional accuracy was checked using simple conical hole (prepared root canal) in the model. In further investigation, complex surface should also be verified. Likewise, more different rapid prototyping techniques should be tested based on the same model, CT and thresholding parameters.

Acknowledgement:

Results of investigation presented in this paper are part of the research realized in the framework of the project ñResearch and development of modeling methods and approaches in manufacturing of dental recoveries with the application of modern technologies and computer aided systemsñï TR 035020, financed by the Ministry of Education, Science and Technological Development of the Republic of Serbia.

3 LITERATURE

[1] Liu Q., Leu M.C., Schmitt S.M.: Rapid prototyping in dentistry: technology and application, Int J Adv Manuf Technology, Vol 29, 2006, pp 317-335.

[2] Gibson I., Rosen D. W., Stucker B.: Additive Manufacturing Technologies ï Rapid Prototyping to Direct Digital Manufacturing, Springer, ISBN: 978-1-4419-11 19-3.

[3] Kruth, J. P., Vanderbroucke, B., Van Vaerenbergh, J., Naert, I.: Manufacturing of dental prostheses by means of Selective Laser Sintering/Melting, 2nd International Conference on Advanced Researc in Virtual and Rapid Prototyping, Leirias, portugal, 2005.

[4] Giovanna Bertolini, Mathias Prokop: Multidetector-row computed tomography: Technical basics and preliminary clinical applications in small animals, The Veterinary Journal 189, 2011., pp.15ï 26.

[5] Basilio Ramos Barbero, Elena Santos Ureta: Comparative study of different digitization techniques and their accuracy, Computer-Aided Design 43 (2011) 188ï 206.

[6] Bradley C, Currie B. Advances in the field of reverse engineering. Computer-Aided Design and Applications 2005;2(5):697ï 706.

[7] Stanojevic M., Sljivic M., Plancak M., Djurdjevic D.: advanced investigation on rapid prototyping techniques in maxillofacial surgery and implanting preparation, Journal for technology of plasticity, Vol.31, No.1, 2014., pp.11-20.

[8] Zhang J., Yan CH., Chui CK., Ong SH.,: Fast segmentation of bone in CT images using 3D adaptive thresholding, Comput Biol Med., Vol.40, No.2, 2010., pp.231-236.

[9] Chua C.K., Leong K.F., Lim C.S.: Rapid prototyping, principles and application, World Scientific Publishing Co. Pte. Ltd., 2003

UTICAJ SEKUNDARNE REKONSTRUKCIJE NA TAČNOST MODELA ZUBA IZRAĐENOG RAPID PROTOTYPING TEHNOLOGIJAMA

Dejan Movrin[1*], Aljoša Ivanišević[1], Igor Kačmarčik[1], Tijana. Lainović[2], Aleksandar Spasić[3], Larisa Blažić[4]

[1]Fakultet tehničkih nauka, Univerzitet u Novom Sadu, Srbija
[2]Medicinski fakultet, Katedra za stomatologiju, Univerzitet u Novom Sadu, Srbija
[3] Klinički centar vVojvodine, Centar za radiologiju, Novi Sad, Srbija
[4]Medicinski fakultet, Katedra za stomatologiju, Klinika za stomatologiju Vojvodine, Univerzitet u Novom Sadu, Srbija

REZIME

Medicinski instrumenti, implantati i pribori su vrlo često složenih oblika i geometrije. Zbog toga su tehnologije brze izrade prototipova u velikoj prednosti u odnosu na konvencionalne proizvodne tehnologije u proizvodnji medicinskih objekata. S obzirom na polje primene, potrebno je obezbediti visoku tačnost medicinskih uređaja i pribora. Direktan uticaj na tačnost izrađenog modela ima ulazni fajl, koji se često dobija na osnovu CT snimka. Za eksportovanje skeniranih (DICOM) fajlova u fajl čitljiv sistemu za brzu izradu prototipova (npr. STL), koriste se specijalizovana programska rešenja. U radu je ispitivan uticaj podešavanja parametara programa 3D Doctor i CT uređaja, na tačnost izrađenih modela tehnologijom brze izrade prototipova. Modeli su izrađeni korišćenjem dve tehnologije: deponovanjem istopljenog filamenta i 3D štampanjem. Na osnovnom modelu (humanom zubu), i odštampanim modelima, mereni su prečnici endodontski obrađenog kanala korena zuba, i upoređene su njihove vrednosti. Za precizno merenje prečnika korišćena je koordinatna merna mašina Carl Zeiss CONTURA G2 RDS.

Key words: *Kompjuterizovana tomografija, sekundarna rekonstrukcija, stomatologija, brza izrada prototipova*