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Evaluation of Polyjet and SLA 3D printers

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Purpose: To present and compare models created by two different rapid prototyping (RP) methods.
Materials and methods: Using a three-dimensional graphic program (Blender, Blender Foundation) a 10 × 10 × 2 mm test specimen was created and printed with a Formlabs Form 2 (Formlabs Inc.) SLA printer of photopolymerization resin and with a Stratasys Objet 30 Orthodesk (Stratasys GmbH) Polyjet printer of acrylate. After printing, the post-processing was performed according to the manufacturer's instructions, and then the specimens were examined by various physical, optical and imaging diagnostic methods.

Results: Our results showed that the two different technologies result in different morphological images and parameters. Between the digital reference specimen and the x and y value of the VeroGlaze MED 620 and Dental SG materials, there was a significant difference ($P < 0,001$).

Conclusions: The currently available rapid prototyping methods with limitations are suitable for dental use with the measured parameters.

Keywords: 3D printing, SLA, Polyjet, rapid prototyping

Introduction

The three-phase process of the CAD/CAM (Computer-Aided Design/Computer-Aided Manufacturing) has remained essentially unchanged since its introduction in dentistry in the mid of '80s [6, 11]. A scanner is used to create three-dimensional digital information; following a software design phase, and the desired object is created using various manufacturing technologies [6, 13].

There are three basic ways for creating a physical model: formative, subtractive, and additive [6, 8, 13]. The formative technique is used in mass production, the best-known representative of it is injection moulding [8]. In the subtractive process, the material is removed from the workpiece – which can be up to 90% for an average denture – using a tool along a precisely designed path until the final product is formed, typically with a layer thickness of 15–500 μm [6, 8, 13]. 3D printing – a term used more commonly in the media – or additive manufacturing technology, which is more commonly used by professionals, and rapid prototyping (RP) are more or less synonymous in the literature [3, 8]. Rapid prototyping can nowadays be used to create not only prototypes but also final products such as surgical guides [9, 13].

Additive technologies were categorized by manufacturing technology (ASTM Active Standard F2792) in 2012 by the International Committee of the American Society for Testing and Materials (ASTM) as follows: binder jetting, direct energy deposition, material extrusion, material jetting, powder bed fusion, sheet lamination, vat photopolymerization. The range of materials that can be used is very wide, such as thermoplastic materials, composites, polymers, ceramics and metals [5, 7, 8, 13]. The products of additive technologies are most commonly used for surgical planning, as a material for training, diagnostic tool, final prosthetic specimens, and in the form of maxillofacial surgical laser sinter implants [2, 7].

In our research, 3D printers were examined, that can be classified into the vat photopolymerization and material jetting categories according to the above-mentioned ASTM classification. In the former technology, a liquid photopolymer in a vat is selectively polymerized using laser light, while in the latter, the material to be printed is delivered to specific locations on the work surface utilizing nozzles and then polymerized with UV light [3, 12]. Other subcategories of vat photopolymerization are known, such as Digital Light Processing (DLP) and Stereolithography (SLA) [8].

This work aims to present and compare the accuracy of 3D printers using SLA and a Polyjet (material jetting) technology.

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Materials and methods

Designing the test specimen

Using a three-dimensional graphic program (Blender, Blender Foundation, Amsterdam, Netherlands) we created a 10 × 10 × 2 mm test specimen *(Figure 1)*, with 5 equally spaced, 400 µm wide and deep grooves and generated a standard tessellation language (STL) file. For the printing procedure, the same file was used for both 3D printers.

Printig process

Five specimens were printed on a Formlabs Form 2 (Formlabs Inc., Sommerville, USA) SLA printer of photopolymerization resin (Dental SG, Formlabs Inc., Sommerville, USA) with a resolution of 50 µm. Five specimens were also printed with a Stratasys Objet 30 Orthodesk (Stratasys Ltd., Rehovot, Israel) Polyjet printer of acrylate (VeroGlaze Med620, Support SUP705, Stratasys Ltd., Rehovot, Israel) on X- and Y-axes with a resolution of 42 µm and on Z-axis of 28 µm. For both printers, the specimens were placed in the same spatial position; the height value of 2 mm was read along the Z-axis, and the groove running along the X-axis. After printing, the post-processing was performed according to the manufacturer's instructions, and then the specimens were examined by various physical, optical and imaging diagnostic methods.

Stereomicroscopic evaluation

For the stereomicroscopic examination, an Olympus SZ61 (Olympus Corp., Tokyo, Japan) device was used under 40× magnification. *Figure 1* shows a typical image of the two above mentioned printed materials.

Micrometre measurement

Five specimens were measured 10 times per side on the X and Y axes with an Absolute Digimatic (Mitutoyo Corp., Kawasaki, Japan) disc micrometre with a resolution of 1 µm by one calibrated researcher, on the same day, one after another. Detailed measurement results are shown in Table 1 and *Figure 2*. Statistical analysis was performed using Student's T-test.

Table 1

Disc micrometre measurements

	n = 5	mean (mm)	SD (mm)	min. (mm)	max. (mm)
VeroGlaze Med620	x	10,213	0,031	10,156	10,259
	y	10,217	0,040	10,141	10,217
Dental SG	x	9,915	0,014	9,890	9,942
	y	9,946	0,026	9,903	9,985

Scanning electron microscopy examination

The specimens were examined by a Hitachi S4300-CFE scanning electron microscope (Hitachi Ltd., Tokyo, Japan). Typical scanning electron microscopy images are shown in *Figures 3* and *4* of the printed test specimens.

MicroCT examination

The specimens were examined by microCT (Skyscan 1272, Bruker Corp., Billerica, Massachusetts, US). Scanning parameters were following: image pixel size: 5 microns, matrix size: 2688 × 4032 (rows × columns), source voltage = 50 kV; source current = 200 µA. Flat-field correction and geometrical correction were used. After scanning, the SkyScan NRecon package (version 2.0.4.2) was used to reconstruct the cross-sectional images from the tomography projection images. *Figures 5* and *6* depict an arbitrarily selected slice and 3D image of the printed specimens.

Discussion

The present study investigates the trueness and precision values of specimens made by two different rapid prototyping methods. These two parameters describe the accuracy of a measurement method stated in ISO 5725-1:1994. Trueness refers to the closeness of agreement between the arithmetic mean of a large number of test results and the true or accepted reference value. Precision refers to the closeness of agreement between test results.

In the case of the Formlabs Form 2 3D printer, our measurements showed that trueness values were high-

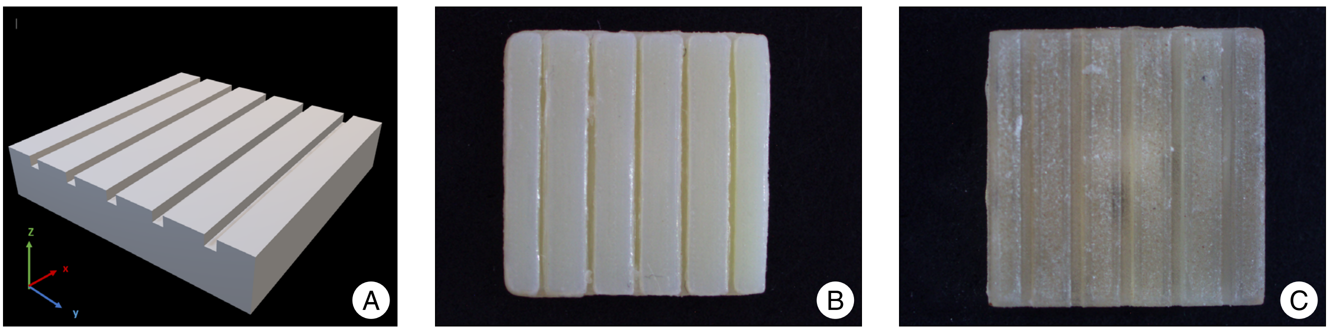

Figure 1: Three-dimensional test specimen (A), VeroGlaze Med620 stereomicroscopic image (B), Dental SG stereomicroscopic image (C)

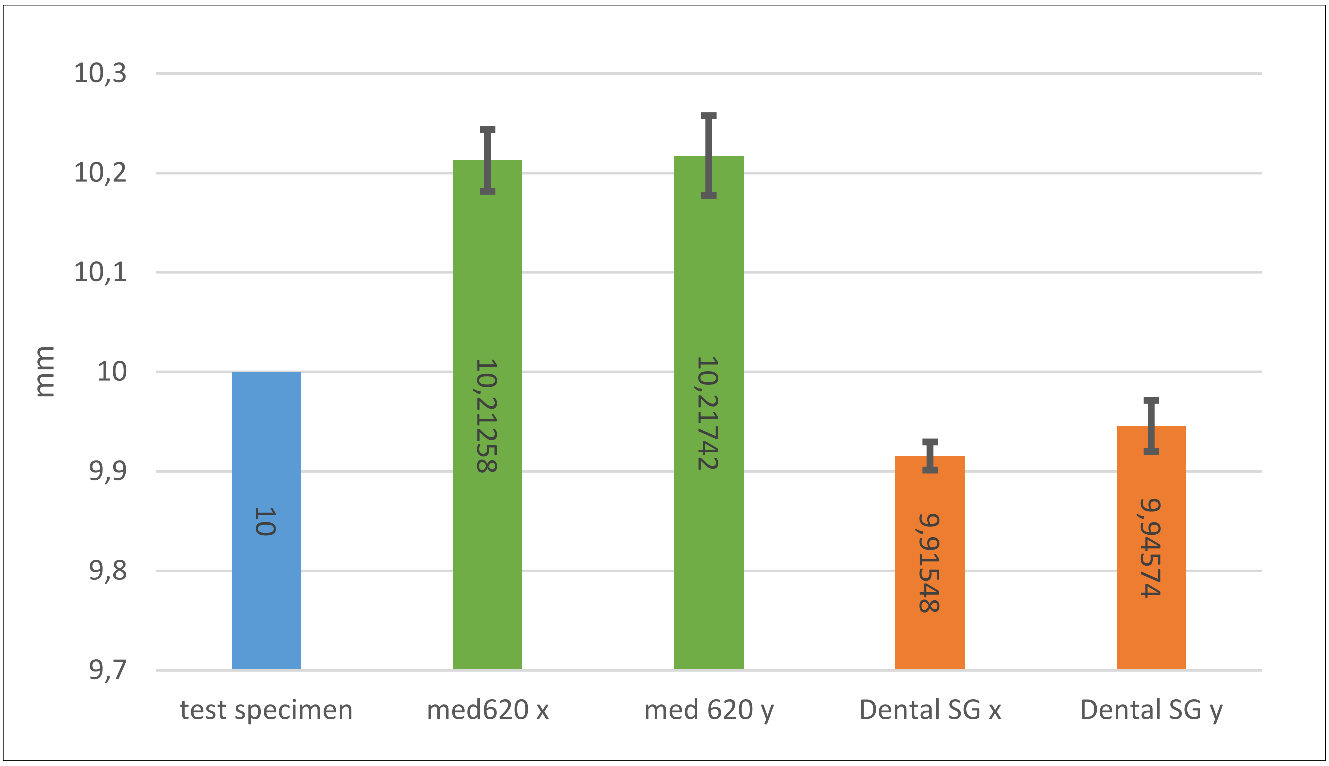

Figure 2: The results of the disc micrometre measurement.
Between the x and y values for the VeroGlaze MED 620 and Dental SG materials, there was no significant difference.
Between the digital reference specimen and the x and y value of the VeroGlaze MED 620 and Dental SG materials, there was a significant difference (P < 0,001).

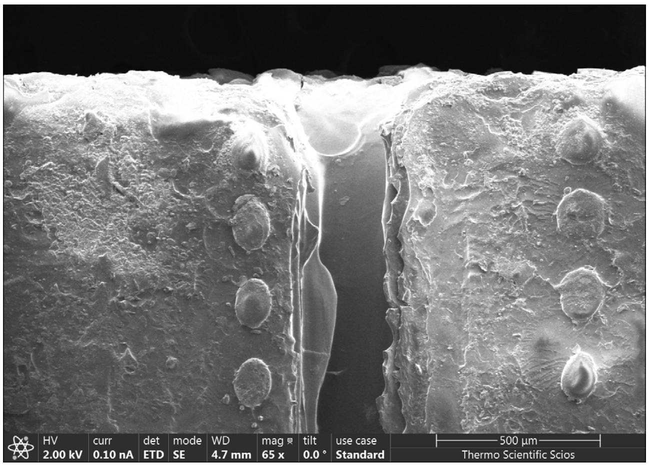

Figure 3: A representative scanning electron microscopy image of a VeroGlaze Med 620 test specimen

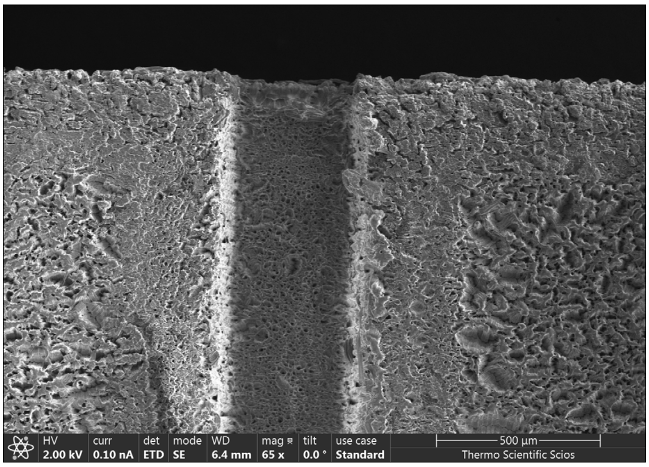

Figure 4: A representative scanning electron microscopy image of a Dental SG test specimen

er. The test specimens were printed with supports, and the layer thickness was set to the smallest value. For Form 2 3D printer the resolution value was 50 µm; for Stratasys Objet 30 Orthodesk Polyjet printer on X- and Y-axes 42 µm and on Z-axis with 28 µm.

Emir et al [3] found that the Polyjet technology was more precise than the SLA. However, in terms of accuracy, the latter technology was superior in Z- direction. The study showed that the printed 3D models could be used to produce fixed restorations, as the accuracy was found to be within the clinical tolerance. Yoo et al [14] reported that there were no significant differences in the precision of MJP (Multi-Jet printing), DLP and SLA casts, and the MJP casts showed the highest accuracy. The accuracy of the models was in the clinically acceptable range to use as a working model for manufacturing dental prostheses. Another study stated, that a measurement difference is clinically acceptable if it is less

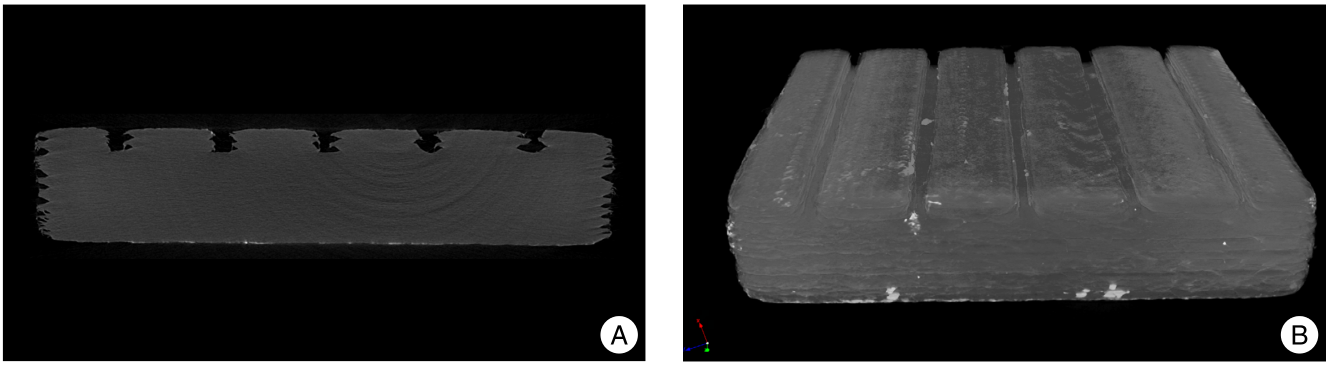

Figure 5: A typical MicroCT section (A) and 3D image (B) of the VeroGlaze Med 620 specimen

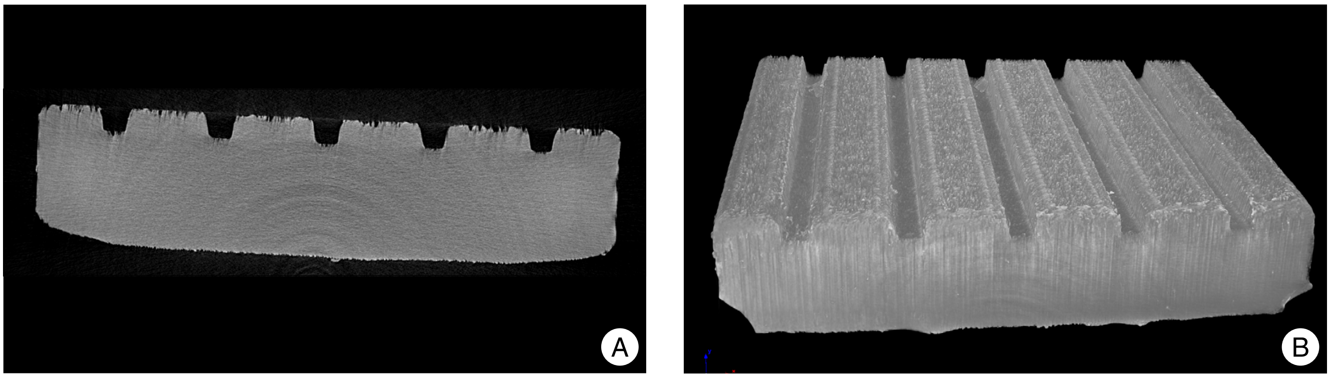

Figure 6: A typical MicroCT section (A) and 3D image (B) of the Dental SG specimen

than 200 μm because the reliability for manual measurements is nearly equal to this value [4]. Banjar et al reported that the clinically acceptable misfit is between 150 and 200 μm [1].

Compared to the literature data, we can state that our results are similar to those measured by others, although it is practically impossible to standardize the comparison. The differences may be attributed to various factors that can affect the trueness and precision of the printed models, such as building direction, layer number, thickness and postprocessing [3, 10].

Our study has limitations, e.g. the layer thickness was set according to the manufacturer's recommendations for both materials, and measurements were only made on the x and y axes with a disc micrometre. Further studies are needed to investigate the accuracy of rapid prototyping methods used in dentistry.

Conclusion

Our results showed that the two different technologies result in different morphological images and parameters; and suggest that the specimens have special surface character and special cross-sectional surfaces examined under scanning electron microscope and microCT. There was no significant statistical difference between the x and y values for the VeroGlaze MED 620 and Dental SG materials, whereas between the digital reference specimen and the x and y value for the tested materials the difference was significant. The currently available rapid prototyping methods with limitations are suitable for dental use with the measured parameters.

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Conflict of interest

The authors deny any conflicts of interest related to this study.

Author contribution

SMJ contributed to data conception design, data acquisition, analysis, interpretation and drafted the manuscript. BM contributed to data acquisition, analysis, and reviewed the manuscript. CSA contributed to data acquisition and drafted the manuscript. CSL contributed to data acquisition and revised the manuscript. HCS contributed to conception design, interpretation and critically revised the manuscript.

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Eredeti cikk

Polyjet és SLA 3D nyomtatók összehasonlító vizsgálata

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Célkitűzés: Két különböző rapid prototyping (gyors prototípusgyártás) módszerrel készített modellek bemutatása és összehasonlítása.

Anyag és módszer: Háromdimenziós grafikai programmal (Blender, Blender Foundation) létrehoztunk egy 10 × 10 × 2 mm-es próbatestet, majd kinyomtattuk Formlabs Form 2 (Formlabs Inc.) SLA nyomtatóval fotopolimerizációs műgyantából és Stratasys Objet 30 Orthodesk (Stratasys GmbH) Polyjet nyomtatóval akrilátból. A nyomtatást követően az utókezelést a gyártó utasításai szerint végeztük el, majd a mintákat különböző fizikai, optikai és képalkotó diagnosztikai módszerekkel vizsgáltuk.

Eredmények: Eredményeink azt mutatták, hogy a két különböző technológia eltérő morfológiai képet és paramétereket eredményez. A digitális referenciamodell és a VeroGlaze MED 620 és a Dental SG anyagok x és y értéke között szignifikáns különbség volt ($P < 0{,}001$).

Következtetések: A jelenleg rendelkezésre álló rapid prototyping módszerek a mért paraméterek mellett korlátozásokkal alkalmasak fogászati felhasználásra.

Kulcsszavak: 3D nyomtatás, SLA, Polyjet, rapid prototyping