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ORIGINAL ARTICLE

Comparison of Popular Three-Dimensional Printing Materials for Oral and Maxillofacial Surgical Guidance Model

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ABSTRACT

The application of three-dimensional (3D) models in the medical field has become popular. However, the accuracy of 3D models for surgical guidance varies among different materials and 3D printing technologies, such as printing machine usage. **Objectives:** This study aims to obtain more information about the effect of three different materials printed using a fused deposition material printer from the same digital data source. This study also aims to compare, analyze, and test the materials' ability. **Methods:** Each of the filament materials (acetylbutane stearate [ABS], polylactic acid [PLA], and high-impact polystyrene [HIPS]) are printed at two infill densities, their weight, volume, and dimension are measured, and infill materials are prepared. Printing time is estimated and calculated on the basis of printing properties by using Simplify3D© software. The strength and surface tension of each sample are examined via a drilling test. **Results:** PLA is better than ABS and HIPS for printing our 3D model because of its properties. **Conclusion:** Ideal 3D materials for printing 3D models should fulfill the criteria on accuracy, strength, weight, and durability for usage. However, production time and cost should also be considered.

Key words: 3-dimensional model, polymer filaments, surgical guidance

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INTRODUCTION

Three-dimensional (3D) model printing is the process of joining materials to create objects from digital 3D model data. It is a promising technology in oral and maxillofacial surgery. However, the management of lost craniofacial tissues due to congenital abnormalities, trauma, or cancer treatment poses a challenge to oral and maxillofacial surgeons.[1,2] Combining these two conditions, where 3D models and the need of a better oral surgery management, the use of these 3D models as medical or surgical guidance is expanding rapidly. Polymer filament materials can be used to fabricate these models by using initial data from medical images, such as Digital Imaging Communications in Medicine, and print on 3D printers. These models can then be used for preoperative planning, education, and surgical simulation purposes, such as locating osteotomy lines; therefore, they can significantly reduce operating time.[3,4,5] Standard reconstructive plates and other appliances can be pre-bent using a medical model.[3] Currently, a gold standard for the accuracy measurements of medical models is yet to be developed. Previous study measured a dry skull and a 3D virtual model made with cone beam computed tomography (CBCT) images. The measurement uncertainty of the 3D model is much higher than that of the dry skull.[3,6] The accuracy of 3D models varies among different materials and 3D printing technologies, such as machines. This important aspect has not been investigated sufficiently although medical applications of 3D models have been widely reported in craniomaxillofacial surgery. Furthermore, the requirements for accuracy depend on each application type.[7]

The use of 3D printing models is limited because of the high cost of commercial 3D printers, and it delays time because the manufacturing process can take hours

Figure 1. Patient's 3D model data prepared using the 3D software and printed using the FDM 3D printer with filament materials to produce a 3D model with the same specification as the original data source.

Figure 2. 3D cube mode. Printed using the FDM printer and ABS, PLA, and HIPS filament materials. Each type of the filament material cube is printed in 50% infill and 100% infill settings.

in printing and require more work hours.[6] Low-cost consumer-level fused deposition material (FDM) 3D printers can be used to produce complicated models; with more developing materials, several options of popular 3D materials, such as acrylonitrile butadiene styrene (ABS), polylactic acid (PLA), and newly introduced high-impact polystyrene (HIPS), are used.[8,9]

Acrylonitrile butadiene styrene, which was discovered earlier rather than two other materials, is a common material in 3D printing; as such, it gains popularity because of its strength, but PLA is stronger than ABS.[10] However, the ability of PLA as a biodegradable material affects the durability of models produced using this material, especially if it is heated under certain conditions.[9] HIPS is introduced as a material that is similar to ABS, but it is stronger and more flexible than ABS.[9]

This research proposes the best 3D materials in terms of production time, accuracy, low cost, and appropriate strength for use as a surgical guidance by applying the same production methods and digital data source, comparing, and testing the properties of the three types of 3D materials.

METHODS

The manufacturing process of a 3D model involve preproduction preparation, such as 3D model data analysis with digital software; printing with 3D materials in the form of filaments that are extruded using a FDM printer; and postproduction through which the model and support materials of the 3D model are disassembled using manual tools or monobath liquid for convenience. The whole process is illustrated in Figure 1.

3D Model Data

The Standard Tessellation Language format (.stl data) used in this study is obtained from a cube file object database in 3D Builder© (Microsoft, U.S).[11] A cube model is chosen because it represents a solid, bulk, measurable, and modifiable 3D model. All the samples are printed as cubes, so they can represent linear and uniform objects for comparison (Figure 2). The cube file is originally presented in a 3D manufacturing format (.3 mf) with file data having a size of 20 kb. The data are processed using 3D Builder to obtain data in.stl format and prepared for printing by using Simplify3D© (Simplify3D, U.S). The weight, volume, dimension, and infill materials are prepared, and printing time is estimated and calculated on the basis of printing properties. Each sample is examined in terms of their strength and surface tension via a drilling test.

3D Materials and Printing Process

Three kinds of 3D printing materials, namely, ABS, PLA, and HIPS, are fabricated in this research. The three materials have their unique characteristics, but all of them are popular printing materials for FDM printing. Source data are processed using Simplify3D to prepare the data with the adjusted infill and support density materials. Two types of 3D model sample are used in each sample material: (1) 50% infill material and (2) 100% solid infill material. The dimension, weight, volume, and time processing of each sample are also determined with this software.

Baich and Marie (2015) concluded that 100% infill or solid infill for 3D models is recommended for mechanical applications, and 50% infill or low-density infill is recommended for bending applications; both types affect the production cost.[12]

In terms of the usage of the 3D model in the oral and maxillofacial surgery field, the properties of the 3D model should satisfy the requirements for surgical guidance that simulates the original condition and for prebending reconstruction plates. All the data are printed using the same FDM printer (UP300 3D Printer by Tiertime, China) at the same room temperature and humidity in a 3D laboratory (3DSolutions Lab, Indonesia).

Measurement

Height, length, thickness, volume, weight, and printing time are measured and compared with the results from the digital data on computer software and the results from the printed 3D model samples. The dimension is measured using an electronic digital caliper with an

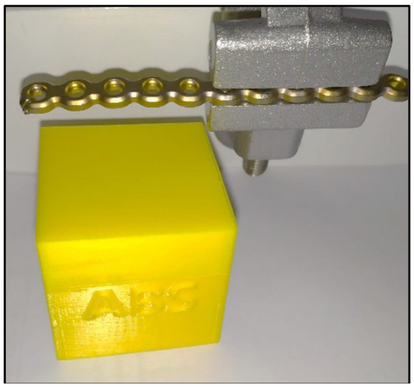

Figure 3. Reconstruction plate previously tested with the same size of the 3D cube surface length (40 mm) to measure the resistance of the minimum weight for bending the plate, which is 20 kg.

Figure 4. A. titanium screw 10 mm-long for reconstruction plate. B. 3D model cube with a screw inserted in the center of the surface for the weight test. Each change that appears during the weight test is analyzed and measured.

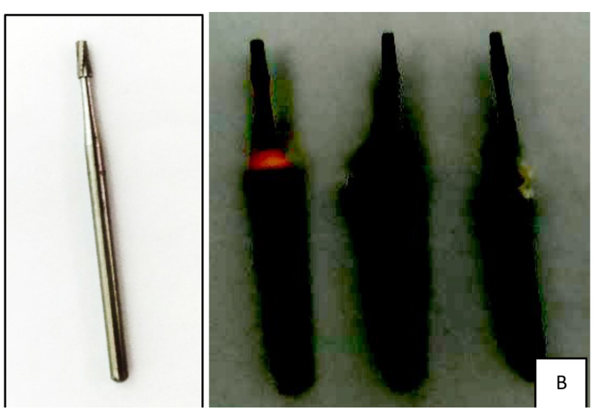

Figure 5. A. Metal fissure bur for the bone drill. B. Fissure bur after the 3D cube model is drilled with a melted residue from the filament materials. Fissure bur after 100% infill cube materials are drilled, and measurement is taken from the drill hole and the distance from the tip of the bur to the top melted residue.

accuracy of 0.01 mm. The weight is determined using an electronic digital scale with an accuracy of 0.01 mg. All the data samples are then examined via weight, drop, and drill tests. The variables are analyzed via impact and compression tests in accordance with the methods described by Sivasankaran et al. (2019), who tested the mechanical stress on a 3D model with PLA materials produced by an FDM printer.[13] Measurement was performed by a single observer (intra-examiner), and each measurement was conducted in duplo.

A weight test is carried out by drilling on the surface of the 3D samples at the center by using a 10 mm 2.4 titanium screw with a depth of 8 mm (Figures A and B). The 3D cube is then hung to a weight of 10, 15, or 20 kg in each test, and the comparison of the dimensions of the 3D cube and the reconstruction plate is shown in Figure 3. A drop test is performed to simulate if a weight is given in 3D models that fall off to the ground with a certain weight. The same test condition is the same as the weight test, but the weight is dropped free from a height of 1 m.

For the drill test, a standard fissure bone drill, which is usually used in oral and maxillofacial surgery, with a length of 25 mm and a diameter of 0.5 mm is utilized. Each 3D model is drilled without any cooling irrigation to examine the ability of the 3D materials to compensate the heat and melt condition because of continuous drilling (Figure 5). For the weight and tension test, a weight tension digital scale with an accuracy of 0.01 kg is used. For the drill test, the drill hole and the fissure bur that go through the 3D model surface is measured with a digital caliper that has an accuracy of 0.01 mm.

RESULTS

The sample test shows that all the samples printed using the FDM machine have a smaller dimension, although the difference is small. Similarly, the weight of the samples printed is lighter than the weight estimated using the software. However, the estimated printing time and the actual printing time to print the 3D cube model are significantly different (Table 1).

The weight test reveals that all the samples with 100% infill are strong enough to hold the weight, but one material in the 50% infill model is stronger than the two other materials in terms of holding all the weight. In the drop test, each sample is attached to the weight and dropped from a height of 1 m. All the 100% infill materials can hold the weight without making any changes or even a crack and a break. A different result is observed in the 50% infill group. In the drilling test, all the 50% infill density samples show that the bur can penetrate (25 mm) through the material in optimal depth without any melting residue. However, in 100% infill materials, a melting residue adheres to the fissure bur (Table 2). Consequently, the fissure bur fails to pass through the material bulk.

Table 1. Comparison of the control group (digital data) and the 3D model sample (printed data) with the three types of 3D printing materials in terms of infill density, dimension (height, length, and thickness), volume, weight, and printing time. Data from the 3D model samples are the mean data collected from two measuring trials.

Control Group (Digital Data)						**Variables**	**3D Model Samples (Printed Data)**					
ABS		**PLA**		**HIPS**		**Material**	**ABS**		**PLA**		**HIPS**	
50%	100%	50%	100%	50%	100%	Infill density	50%	100%	50%	100%	50%	100%
40.00	40.00	40.00	40.00	40.00	40.00	Height (mm)	40.03	40.10	40.16	40.19	40.15	40.05
40.00	40.00	40.00	40.00	40.00	40.00	Length (mm)	39.93	39.88	39.75	39.98	39.74	39.69
40.00	40.00	40.00	40.00	40.00	40.00	Thickness (mm)	39.78	39.75	39.86	39.76	39.72	39.65
64.072	64.000	64.000	64.000	64.000	64.000	Volume (mm^3)	63.587	63.567	63.630	63.886	63.375	63.027
38.03	71.02	41.14	80.33	36.31	67.40	Weight (g)	25.60	64.85	28.67	74.11	23.88	61.25
2.35	6.39	2.35	6.39	2.35	6.39	Printing Time (Hour·Min)	2.43	6.19	2.43	6.19	2.43	6.19

Table 2. 3D model samples with the treatment of the weight, drop, and drill tests.

Weight Test (with weight)							
Score: + = normal/no changes - = crack surface - - = break surface	10 kg	+	+	+	+	+	+
	15 kg	+	+	+	+	-	+
	20 kg	-	+	+	+	- -	+
Drop Test (with weight and released from a height of 1 m)							
Score: + = normal/no changes - = crack surface - - = break surface	10 kg	-	+	+	+	-	+
	15 kg	- -	+	-	+	- -	+
	20 kg	- -	+	- -	+	- -	+
Drill Test (using a 25 mm fissure bur)							
Score: + = normal/no changes - = crack surface - - = break surface	Melting bulk	-	+	-	+	-	+
	Depth gauge (mm)	25	15.53	25	17.15	25	17.9

DISCUSSION

Several key points identified on the basis of the sample test results for all the samples printed using the FDM machine include the small dimension, which also affects the weight of the materials printed. Regarding the printing time, most of the samples require more time to be finished when the models are printed using 50% infill materials than the printing time estimated with the software. However, 100% infill materials are printed faster than the printing time estimated with the software. This finding may be attributed to the need of 50% infill to be shaped, so the geometry makes the printing time to be longer than the estimated time. The printing time of 100% infill is longer than that of 50% infill.

In the weight test, all the samples with 100% infill are strong enough to hold the weights of 10, 15, and 20 kg. A certain weight is used on the basis of our test data. In particular, 20 kg is the minimum weight at which a

2.4 reconstruction plate with a size of 40 mm starts to bend. A different result is observed in 50% infill 3D material samples, that is, HIPS is the weakest in holding the weight. Conversely, PLA can hold the weight given. The same result is also found in the drop test. In this test, each sample is attached to the weight is dropped from a height of 1 m. All 100% infill materials can hold the weight without any changes or even a crack and a break. By contrast, PLA in the 50% infill group has the strongest durability in holding the weight dropped from a height of 1 height, but ABS and HIPS show the same condition under which a crack and even a break appear from the test.

In the drilling test, a common metal fissure bur usually used in oral and maxillofacial surgery is utilized, and the maximum depth of the bur is set at 25 mm. The 50% infill samples are examined, and the results indicate that the bur can penetrate (25 mm) through the material at the optimal depth without any melting residue in all the samples. However, in 100% infill materials, all the samples cannot have an optimal depth of the bur, and some melting residues adhere to the fissure bur.

Most of these conditions may occur because of the properties of the materials. ABS, PLA, and HIPS may have different specification materials from those in the software database, although the difference is small. The printing condition also has a role in printing. For instance, if room temperature that surrounds the printing machine is high, then the risk of having a distortion is smaller. Conversely, if the room temperature that surrounds the printing machine is too low, then distortion, such as warping at the bottom layer of materials, occurs. Other conditions, such as mechanical problems in machines whose nozzle may have melted residues, can affect the filaments to be extruded; furthermore, a preheated printing bed with an unstable temperature may influence the construction at the bottom layer.[14]

Regarding the accuracy of the 3D printed model and compared with the 3D model data on software has been proven reliable, although technologies in the future will have a great role in manufacturing more accurate and precision result.[5,15] As for this research result, the properties of new materials, such as HIPS, are similar to those of ABS, but the former are better than the latter. Conversely, their properties differ from those of PLA. Using HIPS for 3D printing is considered new, so further research on its mechanical properties because this material shows potential for the replacement of ABS materials.

Other previous data or studies reveal the same result as distortion occurs in 3D printing; however, under clinical conditions, 3D printing has slight affects, but this technology can still be accurately used as guidance (Deeb et al., 2017).[16] Sivasankaran et al. (2015) found that infill density affects the mechanical properties of materials, but other factors, such as microstructure patterns of printed models, also influence the strength of their material properties.[13] In the present research, a hexagonal shape is the only type of the microstructural geometry of all the same materials produced.

Lay et al. compared some materials, such as ABS, PLA, and Nylon 6, and observed that the physical and mechanical properties of 3D printed materials are affected by the infill density and viscosity of materials.[10] In our research, the viscosity of the materials is not analyzed because the research tool is limited, and the testing device used here is a modified form of the testing machine utilized in other studies. However, the mechanical properties and principle of the test are considered the same. Previous studies also included a tensile strength test, which is not performed in our study to examine the complete mechanical properties of the 3D materials.

CONCLUSION

Many 3D printing materials are commercially available, and each material has unique advantages and disadvantages. With the development of 3D technology, new materials have emerged. However, for surgical use, a surgeon should determine the appropriate 3D printing materials as surgical guidance.[4] In the present study, the accuracy and strength of popular 3D materials are examined using in-office 3D software. Testing these 3D materials mainly allows us to choose ideal 3D printing materials and fabrication methods, so it will guide a surgeon in choosing one. Choosing appropriate 3D materials guides surgeons in making 3D models and consequently prevents surgical complications caused by misplaced implants or cutting. The accuracy, strength, weight, and durability of PLA are better than those of the two other tested materials; however, other factors, such as printing time and total cost, should be considered.[17]

CONFLICT OF INTEREST

The authors declared no conflict of interest.

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