Direct Fabrication of Three-Dimensional Printing Parts Made from Polymethyl Methacrylate for Biomedical Applications

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Abstract - The materials supplied with freeform fabrication machine are generally designed for industrial works and cannot be implanted directly to the body. Therefore, the use of available freeform fabrication (Three dimensional Printing) machine to fabricate medical implants by these materials is impossible. Medical implants usually made from bone cement or PMMA (Polymethyl Methacrylate) can not directly fabricate by 3DP machine. Therefore, tooling is needed to convert from Rapid Prototyping model into implant by using silicone or plaster molds. This method has many steps and long manufacturing time. These cause an extra cost of the implants. This study is aimed to formulate the suitable polymethyl methacrylate based powder for directly fabricated in three dimensional printing machine.

Keywords- Three-dimensional Printing (3DP), Polymethyl Methacrylate Implants, Biomedical.

I. INTRODUCTION

SOLID freeform fabrication is a technology that can fabricate complex-shaped, three-dimensional parts directly layer by layer using 3D computer data. This technology is very useful in biomedical applications to fabricate 3D physical objects from digital image data acquired either from a CAD software, computed tomography (CT) scan or magnetic resonance imaging (MRI). The objects can be then used for pre-operative planning tools and production of patient models or customized implants [1-2].

Three dimensional printing (3DP) is one type of freeform fabrication machine that additively builds three dimensional parts by using inkjet printhead to jet a liquid media to bind the powder together layer by layer.

In the case of medical implant fabrication, implants can be designed digitally to fit the host site and aesthetically correct for individual patient prior to the surgery.

The 3DP model is fabricated and employed as a pattern of the desired implants to create silicone or plaster moulds for further casting by biomedical materials. One of the frequently used materials is polymethyl methacrylate such as bone cement or dental acrylic [3]. This is due to materials for freeform fabrication machine is not designed for medical applications. If the biomedical materials could be fabricated directly from a machine, the steps of generating moulds are omitted and extra cost of molds is saved. In addition, the risk of model damage from handling during casting step could be reduced.

This study is aimed to formulate the suitable polymethyl methacrylate based powder for used in three dimensional printing machine focusing on the cranio-maxillofacial reconstruction.

Fig. 1 Schematic diagram of 3D-Printing

Fig. 2 The conversion of graphical data into personalized implant
II. MATERIALS AND METHODS

A. Materials
Polymethyl methacrylate was purchased from Lang Dental, Ltd., USA. Materials used as binder are maltodextrin (Shandong Duqing, Inc., China) and polyvinyl alcohol (Sigma-Aldrich, USA). These materials were supplied in the form of powders with particle size ranging 80-100 microns.

B. Specimen Preparation
A mixture of raw materials with various percentage of raw materials, Table 1, was prepared by initially stirring in a plastic bag and then thoroughly mixed by a mechanical blender. The mixture was then loaded in the 3DP machine (Z400, Z Corporation, USA). Rectangular bars (80 mm. x10 mm. x4 mm) were printed using a layer thickness of 0.175 mm. Water was used as a binding liquid in all formulations.

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<th>Table 1. MATERIALS FORMULATION</th>
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C. Freeform fabrication by 3D-Printing machine

1. Create three dimensional model
2. Convert the model to STL format
3. 3D-printing machine
4. Slice the STL file into thin cross-sectional layers
5. Construct the specimen one layer atop another
6. Clean and finish the specimen

The input for three dimensional printing is a graphical file that has been converted into standard STL format. Software in the 3DP system slices the STL model into a series of horizontal cross sections and later, the specimens will be constructed by 3DP machine.

D. Dimensional measurement
Dimensions in width, thickness and length of green structure fabricated by 3DP machine were measured by a vernier caliper (Mitutoyo machine) with the reading resolution of 0.01 mm. and recorded.

E. Apparent density
Apparent density was determined by measuring all dimensions of the specimen by a vernier caliper (Mitutoyo, Japan) with the reading resolution of 0.01 mm. Volume was calculated by multiplying width, thickness and length. The weights of specimens were measured by a digital balance (Mettler Toledo PB4002-S, Switzerland) with the reading resolution of 0.001 grams. Density was then calculated by dividing the weight by the volume.

F. Flexural Testing
Flexural tests were performed on a universal testing machine (Instron 4502, USA) equipped with a 10 kN load cell. All the tests were carried out according to ASTM D790 at 23 °C and 50 % RH, using three point bending method and a constant crosshead speed of 1.9 mm min⁻¹. The reported data are the average values from five replicates.

III. RESULTS AND DISCUSSION

The average errors of the fabricated samples compared to the designed computer graphic are shown in figure 4.
IV. CONCLUSION

The results show that polymethyl methacrylate parts were directly fabricated successfully by 3DP. It could be concluded that binder content affect the formability of polymethyl methacrylate parts. Although increasing binder content increased the flexural properties of the parts, too high or too low amount of binder led to the dimensional errors of the parts. Thus the suitable amount of binder should be chosen to optimize between strength and dimensional control. It was observed that the optimum formulation for the best mechanical results was determined to be 40% PMMA, 60% binder (50% maltodextrin and 10% PVA), and the formulation for the best dimensional results consisted of 70% PMMA, 30% binder (20% maltodextrin and 10% PVA). These structures can be further developed as cranio-maxillofacial implants and a variety of other biomedical applications.

REFERENCES

