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Full Length Article

# Accuracy in dental surgical guide fabrication using different 3-D printing techniques

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ABSTRACT

Accuracy in dental prosthesis plays a significant role. Surgical guides are widely used for accurate positioning of dental implants. Designing of guides using modern software is useful in achieving precision; however, translation of these images into actual fabricated parts can be achieved using Three-dimensional (3-D) printing. Conventionally, guides were fabricated using vacuum forming technique which leads to several dimensional inaccuracies. Computed Tomography (CT) images of patients with missing teeth are modeled to design surgical guide using Computer Aided Design (CAD) / Computer Aided Manufacturing (CAM) software which is then combined with surface scan files in Standard Tessellation Language (STL) formats to design the guide. In this work, surgical guides have been 3-D printed using different technologies like Material Jetting technology (MJT), Vat photopolymerization (VP) and Material extrusion (ME). Depth, diameter, Area and Volume of the printed guides have been calculated using vernier caliper and scan measurements. These dimensions have then been compared with the dimensions obtained from software modeled images. Least error has been found for the guides fabricated using MJT. The experimental work in this paper, hence, suggests MJT be the most preferred printing technique due to its superior accuracy for printing dental prosthesis like aligners, implants, and crowns, etc.

## 1. Introduction

The field of dentistry includes the replacement of missing teeth and their supporting structures with artificial prosthesis anchored into the jawbone. Here the artificial root that replaces the natural root of the tooth is known as a dental implant. Implants are metal posts or frames surgically positioned into the jawbone beneath the gums. Some of the research studies in this field are as follows:

Eufinger et al. 1995 reviewed the CAD/CAM techniques for pre-operative modeling of the implant based on CT data. It was concluded that the reconstruction of craniofacial bone defects with individual implants based on CAD/CAM manipulated CT data proved to be superior to conventional methods of cranioplasty [1]. Hence, the desire to perform low risk and accurate surgery led to the discovery of computer-aided surgical planning [2]. Bindl et al. 2005 evaluated the internal and marginal fit of molars and found that CAD/CAM techniques show the same accuracy as conventional techniques. They analysed that the conventional fabrication techniques such as slip-casting and heat-pressing gave a slightly better marginal fit for the slip-cast than for the heat-pressed copings [3]. Daniel et al. 2005 evaluated the concept including a treatment planning procedure based on CT scanned images and prefabricated fixed prosthetic reconstruction for immediate function of upper jaw using flapless surgical technique. They found that each prosthesis was functional in this case [4]. The 3-dimensional model of surgical guide allows the surgeon to visualize the site of surgical bone prior to implant placement and improve the placement of implant. The inputs required for this procedure were in the form of CT and STL files for both upper and lower jaws [5]. Balshi et al. 2006 described a procedure using medical imaging and computer technology to virtually place dental implants and construct surgical template for connection of implant. In this case, identification of the bone anatomy in relation to the teeth before surgery allowed the surgeon to place implants in areas where the implant-bone interface could be maximized [6]. Also, Nascimentor et al. 2008 gave a capacity analysis of Selective Laser Sintering (SLS) and three-dimensional printing (3-DT™) models to for reproduction of craniomaxillary anatomy with a dimensional error.

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They used Invesalius software to segment CT images using thresholding and converted them to STL format. Thereafter these STL files were converted to 3-DP™ and SLS using rapid prototyping. Finally, linear measurements were made using electronic caliper and data was analysed for performance using descriptive statistics to compare the samples using statistical t-test. Analysis showed that 3-DP™ model had a lower final costing than SLS model. However, SLA printed model was found to be most expensive. But prototypes of SLS have higher precision in dimensions and accuracy of reproduction than 3-DP™ prototypes [7]. Similarly, Ibrahim et al. 2009 presented an analysis study of capacities of SLS, 3-DP™ and PolyJet™ models to reproduce the anatomy of the mandible and find their dimensional errors. They started with the acquisition of CT images from a dry mandible and performed manipulations on it using Invesalius software and converted them to STL format. These files were then converted into SLS, 3-DP™ and PolyJet™ printed models. Here also analysis showed that SLS prototype had the most exceptional dimensional accuracy amongst the three prototypes. But cost analysis showed that 3-DP™ technique had the lowest final cost [8]. In this field, the fabrication of the surgical guide templates is based on CAD/CAM technology which solves three major challenges of restoration, appearance, and accuracy [9]. Thereafter, Figliuzzi et al. 2012 gave a procedure for fabrication of implants using direct laser metal forming. MIMICS was used as a 3-D reconstruction software to construct a 3-D projection of the roots and MAGICS was used to prepare the STL files to design the implant [10].

Further, Margreet et al. 2012 presented a study for validation and reproducibility for dental models using intraoral scanners. They initially scanned the dentition using chair side oral scanner. These scanned files were then corrected for missing data by computer programs and were converted into digital models by using software such as Orthoproof. Finally, the files were converted to 3-D printed models using the 3-D printer with 3 M ESPE algorithm. The measurements of dentition and stereolithographic models were performed using a digital caliper and that of the digital models were performed using the Digimodel software. Measures used for the analysis were widths of teeth, transversal distances, skull segments, dimensions of stereolithographic and digital models. According to the analysis, differences were clinically insignificant. The standard values used for analysis were the mean measurements of the skulls with cut offs for segments of 0.2 mm, widths of mesiodistal of 0.1 mm, arch discrepancies and transversal distances of 1.0 mm and discrepancies in tooth size of 1.5 mm [11].

Later, Hazeveld et al. 2013 developed a rapid prototyping approach with its significance to create replicas of plaster models. In this study authors initially scanned the plaster models to form 3-D Surface models in STL format using dual sensor laser scanner. They then transformed these STL files to physical models using 3-D rapid prototyping methods such as a jetted photopolymer, digital light processing, and 3-D printing. Height and width measurements of these models were carried out by using a digital caliper. On analyzing the performance of the proposed approach mean difference for measurements of clinical crowns were recorded as 0.04 mm for the digital light processing models, -0.02 mm for jetted photopolymer models and 0.25 mm for the 3-D printing models. Similarly, for the width of teeth, systematic mean differences were -0.05 mm for digital light processing model, -0.08 mm for jetted photopolymer models and -0.05 mm for the 3-D printed models. But this study lacks its performance in some cases due to distortions in STL files after conversion and manipulation [12].

Also, Parthasarathy, 2014 reviewed the recent trends of custom implants and 3-D modeling in craniofacial reconstruction. This was concluded that custom implants for the reconstruction of craniofacial defects gained importance due to better performance [13]. To analyze existing approaches Marro et al. 2016 reviewed innovations on the application of 3-D printed objects using medical imaging data. It was concluded that 3-D printing combined with medical imaging could be successfully used to create anatomical models to assist surgeries [14]. Recently, Thakur et al. 2017 presented a review of approaches used for extraction and modeling of tooth/teeth from x-ray and CT images. The paper concludes with challenges and approaches to deal with these challenges [15]. In case of dental prosthesis, 3-D printing techniques are beneficial for designing of dental prosthesis like aligners, implants, crowns, etc. These designs are based on printing techniques such as Stereolithography (SLA), SLS, Fused Deposition Modelling (FDM) and PolyJet. SLA prints 2D layers of the photoreactive resin material in successive layers by using ultraviolet light. In SLS printing laser melts the bed of powder to apply and get the shape of the 3-D model. In FDM printers, a polymer wire filament deposits on the predefined locations according to the shape of the model [11]. On the other hand, PolyJet system works by addition of photopolymer resin layers which builds detailed models with smooth surfaces [16].

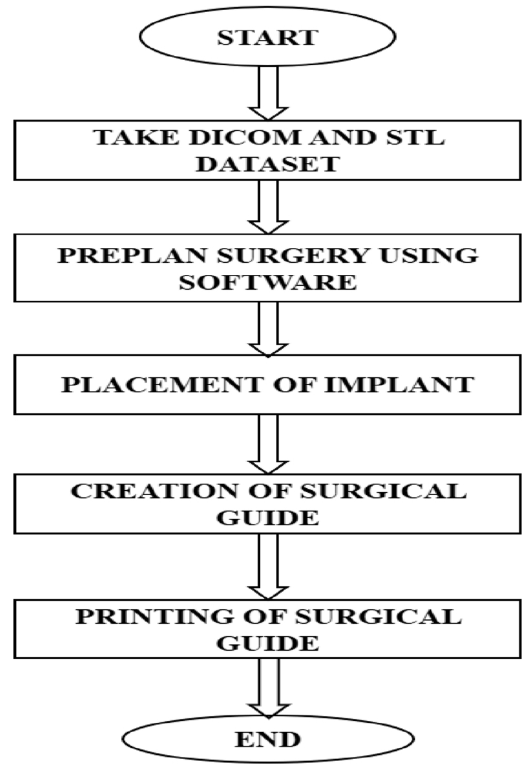


**Fig. 1.** Procedure for developing a surgical guide and preplanning the implant surgery.

In the proposed work, both CT scan and surface scan are used due to better accuracy than the conventional designing technique which uses only CT scans. MJT and VP printing techniques are used to print the models of materials Durus White and Grey Resin respectively. Durus white is a material similar to polypropylene which offers a variety of features like flexibility, strength, and appearance. Whereas, the surgical guide made of Grey resin uses a laser to polymerize photosensitive resin, producing higher-resolution printed objects with complex geometry [17]. Also, Poly Lactic Acid (PLA), Acrylonitrile butadiene styrene (ABS) and Polyethylene Terephthalate Glycol (PETG) are printed using ME which begins with a software process which processes an STL file by mathematically slicing and orienting the model for the build process. ME uses a small temperature-controlled extruder to force out a thermoplastic filament material and deposit the semi-molten polymer onto a platform through a layer by layer process. The designed object is fabricated as a three-dimensional part based on the precise deposition of thin layers of the extrudate [18].

PLA is a linear aliphatic biodegradable polyester, produced by ring opening of lactic acid monomers and lactides using fermentation of sugar feeds, corn starch or cassava roots. This is commonly used in biomedical applications due to its remarkable mechanical properties such as tensile strength, surface quality and creation of high-resolution