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RESEARCH ARTICLES

Development of a surgical guide using open-source software for a dental implant placement

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ABSTRACT

Dental technology has advanced significantly in recent years, particularly with regard to the placement of dental implants to replace lost teeth. One such technology is the use of a dental implant guide as a tool to assist with implant installation. The primary purpose of a dental implant guide is to assist the dentist in placing implants with accuracy and precision to maximize operation success and minimize risk of problems. Dental implant guides customized to each patient's unique tooth and jaw architecture are made possible in large part by digital dentistry. To ensure that the implant is positioned optimally in relation to the patient's teeth and jaw anatomy, customization is important. Using the AutoDesk meshmixer for modeling and manufacturing, a 3D slicer to segment the mandible using a 3D segmentation approach and 3D printing using resin and filament are all part of the dental implant guide design process. To improve precision and customization in the placement of dental implants, this comprehensive strategy makes use of digital dentistry.

Keywords: clinical engineering; digital dentistry; medical 3D design

INTRODUCTION

Losing teeth has aesthetic, psychological, and functional impact, such as chewing, including changes in the teeth and jaw structure.[1,2] Missing teeth are replaced using implants attached to the patient's jawbone. Dental implants provide a reliable and long-lasting solution that restores oral function and improves the aesthetic appearance to its original appearance.[3] The dental implant installation procedure is divided into two methods: flap and flapless.

The flap method is a method of installing dental implants using an open incision. This method requires a high level of skill and expertise, has a higher risk of failure, and can cause significant functional and aesthetic impairment.[4] Failure to install a dental implant can cause perforation of the inferior alveolar nerve, peri-implantitis or infection of the tissue around the implant, and osseointegration failure.[5] This can reduce the success rate of prosthodontic rehabilitation compared to the flapless method, which uses assistive devices adapted to the patient.[6] The flapless technique is a minimally invasive approach for the placement of dental implants utilizing a dental implant guide, hence reducing the time required for the procedure.[7,8]

Designing dental implant guide requires accurate planning and relies heavily on using paid commercial software, which can be prohibitive for small dental clinics or educational institutions. However, using open software such as 3D Slicer, BlueSky Plan, and Autodesk Meshmixer is a more affordable alternative and still produces optimal results. Commercial software has advantages, such as an intuitive interface and comprehensive technical support. Commercial software, however, has significant subscription

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costs, making it provide limited resources and less flexibility in access. In contrast, open software provides more flexible access without having to pay subscription fees. This difference suggests that open software can provide a more affordable alternative that still produces optimal results.[9]

The fabrication of dental implant guides by 3D printing, in conjunction with imaging technology such as cone beam computed tomography (CBCT), has emerged as a crucial method in the planning of dental implant placement procedures as a supplementary diagnostic tool when acquiring panoramic radiography pictures during the diagnosis and treatment planning phase. Moreover, relying solely on panoramic radiography without CBCT can elevate the risk of misdiagnosis by 7%.[10] The application of CBCT for digital modeling as a preliminary phase in tooth and jaw reconstruction can provide a tool for the exact placement of dental implants tailored to the patient's dental and jaw anatomy.[11,12] Dental implant installation aids serve as instruments for dentists, facilitating the procedure by reducing time and enhancing the accuracy and precision of dental implant placement, thereby minimizing complications and improving success rates in dental implant procedures.[13,14]

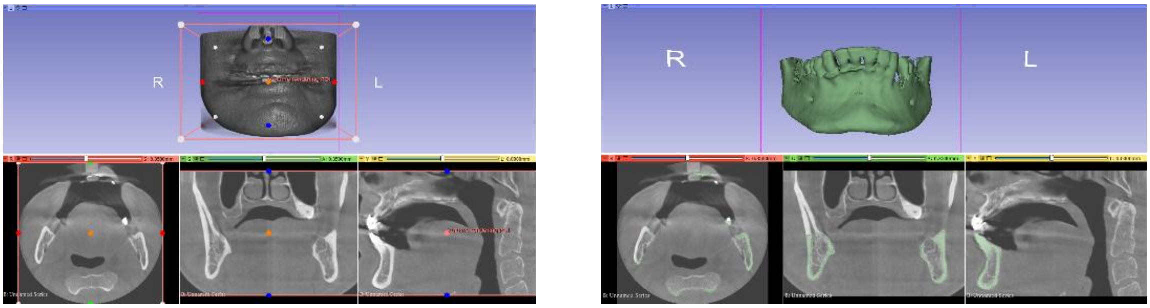
Digital dentistry has several aspects, such as digital imaging using cone beam computed tomography (CBCT) scanning. CBCT is a medical imaging technology for producing 3D images used in treatment planning procedures, virtual simulations, and assisted diagnosis. Oral CBCT data can be projected into one image within a certain range, which provides the dentist with an image of the tissue and anatomy in the patient's mouth.[15] The image produced by CBCT is DICOM data, which can be engineered into 3D data. Digital Imaging and Communications in Medicine (DICOM) is a standard for managing and storing medical images developed by the National Electrical Manufacturers Association (NEMA).[16] DICOM is used to process data with three-dimensional (3D) modeling with the design engineering process using assistance software such as 3D Slicer. A 3D modeling process uses a computer-aided design/computer-aided manufacturing (CAD/CAM) modeling. CAD/CAM technology has become an important part of development in the field of dentistry and other medical fields because it can produce 3D objects with high resolutions that utilize computer technology in their design.[17]

The aim of this research is to maximize the use of digital dentistry in the field of dentistry. Digital imaging technology in dental treatment planning, such as CBCT and 3D modeling using DICOM, becomes the main focus of this research, with the aim of evaluating the use of medical data in the field of digital dentistry, especially in digital imaging and 3D modeling such as integrating CBCT, DICOM, and CAD/CAM in dental treatment planning. The study also identifies innovations in the field of digital dentistry that can improve the diagnosis of dental care for patients.

MATERIALS AND METHODS

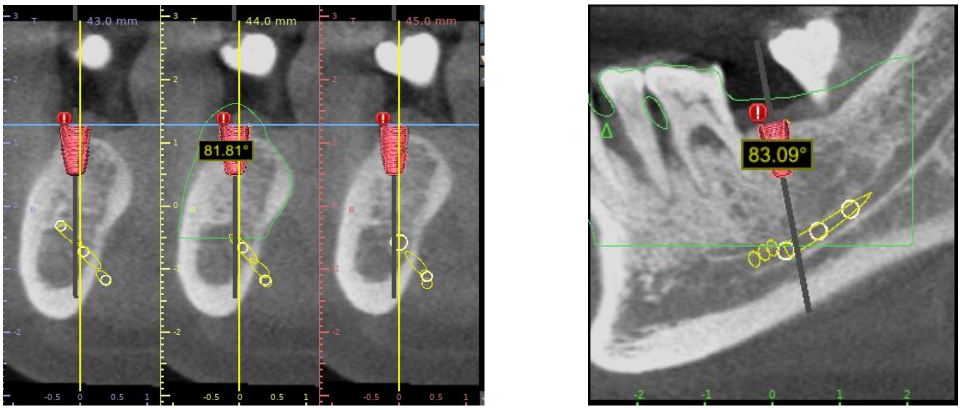
This study utilized CBCT image data from GS Dental Care Surabaya dental clinic, focusing on a 49-year-old male patient with a missing lower left second molar (tooth 37). The CBCT image consisted of 319 slices. The substance employed for the fabrication of dental implant guides was polyurethane acrylate resin (SG100 eSun). This research comprised five principal steps: reconstruction of CBCT images utilizing 3D Slicer software, planning dental implant placement with BlueSky Plan software, designing dental implant guides through BlueSky Plan and AutoDesk Meshmixer, fabricating dental implant guides via a 3D printer (Phrozen Mighty 4K), and measuring angulation using Kinovea software.

The segmentation of CBCT data was performed with 3D Slicer software. The method commenced with the importation of CBCT picture into 3D Slicer software to facilitate segmentation, as shown in Figure 1 (A). The subsequent procedure involved volume rendering and segment editor. In the volume rendering preset, a modification to MR-Default was performed, and then a window value of 4095 was applied with a preset level of 1024. Following the configuration of volume rendering, segmentation utilizing the segment editor was performed by employing the paint tool to delineate many segments in green, subsequently applying the grow from seed function. Upon completion, the initialize function was activated, and the show 3D option was selected to visualize the three-dimensional shape, as shown in Figure 1 (B). Following the segmentation procedure, the resultant objects still exhibited noise. Noise elimination was accomplished with the paint, draw, cut, and erase functions in the segment editor menu. The results of image reconstruction with 3D Slicer software were CBCT images transformed from DICOM format to STL format.



(A) (B)

Figure 1. CBCT Image (A) Volume rendering process (B)



(A) (B)

(C)

Figure 2. Inferior alveolar location from sagittal section (A), coronal/frontal section (B), and panoramic section (C)

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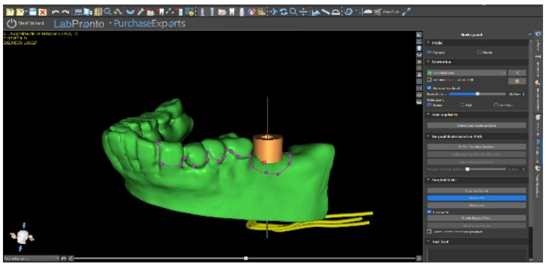


Figure 3. Design process for body and sleeve on dental implant guide

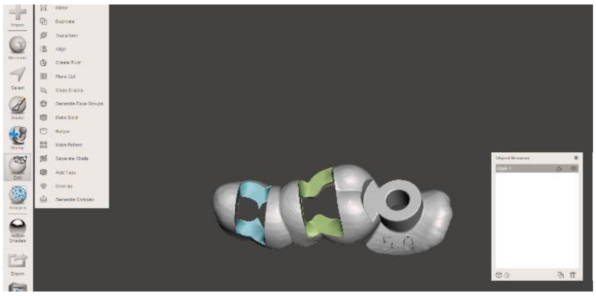
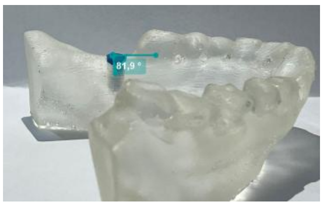


Figure 4. Design process for window on dental implant guide

Table 1. 3D Printing Setup

1. *Quality*	
Layer Height	0,05 mm
2. Layer Count	
Bottom Layer Count	6
Transition Layer Count	4
3. Time	
Exposure Time	3.8 s
Bottom Exposure Time	40 s
4. Delay	
Light-off Delay	6 s
Bottom Light-off Delay	6 s
5. Distance	
Bottom Lift Distance	8 mm
Lifting Distance	8 mm
6. Speed	
Bottom Lift Speed	60 mm/min
Lifting Speed	60 mm/min
Retract Speed	150 mm/min



(A)

(B)

(C)

Figure 5. Measurements of angulation angles utilizing Kinovea software on sagittal (A), coronal/frontal (B), and panoramic (C) cross-sections

$$\bar{x} = \frac{\sum_{i=1}^{n}(y - y_1)}{n} \quad (1)$$

whereas:

$\bar{x}$: differences average

n : number of data

y : angulation on dental implant guide planning

y_1 : angulation on mandible phantom after drilling

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2} \quad (2)$$

whereas:

σ : deviation standard

n : number of data

x_i : differences on each data

$\bar{x}$: differences average

The planning for dental implant placement was conducted by using BlueSky Plan software by importing the patient's CBCT data and reconstruction result files segmented with 3D Slicer. This program facilitates implant planning by identifying the nerve's position in the mandible via the nerve detection tool. Prior to conducting a simulation, it is essential to ascertain the sort of dental implant to be utilized. This study utilized Dentium brand implants of the Implantium type with a diameter of 4.5 mm and a length of 8 mm. This software displayed the position of the inferior alveolar nerve (seen as yellow mark) in a sagittal slice (Figure 2 (A)), coronal/frontal section (Figure 2 (B)), and panoramic section (Figure 2 (C)). The "nerve list" and "detect nerve" features were utilized to determine the angulation angle for dental implant placement based on the reconstructed CBCT data.

The dental implant guide was designed by utilizing BlueSky Plan and AutoDesk Meshmixer software. The objective of utilizing BlueSky Plan software was to generate the body and sleeve for the design of instruments that facilitated the installation of dental implants. The design of the body and sleeve utilized the surgical guidance menu. The draw curve function was utilized to designate the section that would serve as a support for the dental implant insertion instrument. Subsequently, the produce surgical feature was employed to ensure the automatic formation of the body and sleeve components in accordance with the specified portions (Figure 3).

The Meshmixer software was utilized for designing the window section of the dental implant guide. The body and sleeve design outcomes derived from BlueSky Plan served as a reference for constructing the window by using the "meshmix" and "boolean difference" features (Figure 4). The purpose of establishing this window was to enhance visibility and enable verification during dental implant installation procedures performed by a dentist. The output of this software was a design for an implant guide produced in an STL format.

The dental implant guide design that had been developed was printed on polyurethane acrylate resin material (SG100 eSun). The settings for the SLA 3D printer (Phrozen Mighty 4K) used for creating the dental implant guide are presented in Table 1. Following the printing of the dental implant guide, a curing process was conducted by utilizing ultraviolet (UV) radiation for a duration of 60 minutes.

Angulation testing was performed by placing the final dental implant guide to the patient's mandibular phantom for the purpose of dental drilling. The drilling procedure involved placing a drill into the sleeve aperture. Subsequent to drilling, the aperture was filled with plasticine, followed by the acquisition of pictures from sagittal, coronal, and panoramic cross-sections. Angulation angle measurements were conducted with the Kinovea software, as depicted in Figure 5.

The measured angulation angle utilizing Kinovea software was compared to the planned angulation angle from the design phase. Subsequently, the angular discrepancy was determined between the angulation angle of the printed dental implant guide and the design plan of the dental implant guide utilizing equation 1. In addition, the standard deviation was determined by employing equation 2 after the average difference from the three angles had been determined.

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Figure 6. Reconstruction outcomes derived on patient CBCT picture segmentation

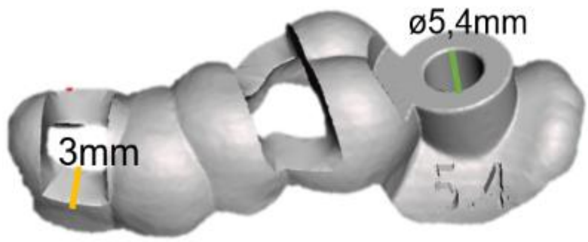

Figure 7. 3D model of dental implant guide design

RESULTS

The segmentation of DICOM CBCT images by utilizing 3D Slicer generated a three-dimensional representation of the patient's mandible. The reconstruction outcomes yielded a mandibular model with enhanced clarity of the dental and jaw architecture, as illustrated in Figure 6. This model served as a benchmark for the creation of the dental implant guide.

Table 2. Results of implant placement simulation

Parameters	Implant placement
Sagittal angulation(°)	81.81°
Coronal angulation (°)	83.09°
Panoramic angulation(°)	80.23°
Diameter (mm)	5.4 mm
Depth (mm)	8 mm

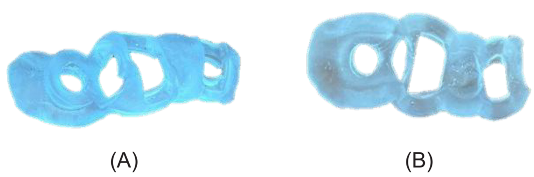

Figure 8. Top view of product results (A) and bottom view of product results (B)

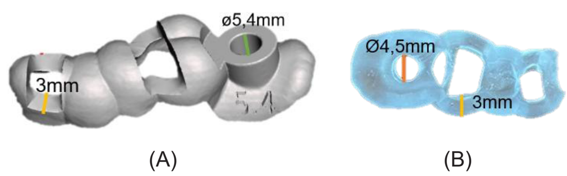

Figure 9. Dimensions in 3D model design (A) and printing results (B)

Table 3. Comparison between planning and actual

Parameter	Planning (y)	Actual (y_1)	Angle Difference ($y - y_1$)
Sagittal Angulation(°)	81.81°	81.9°	- 0.09°
Coronal Angulation (°)	83.09°	83.1°	- 0.01°
Panoramic Angulation(°)	80.23°	81.4°	- 1.17°
Diameter (mm)	5.4 mm	4.5 mm	0.9 mm
Depth (mm)	8 mm	8 mm	0 mm

The design of the dental implant guide started with planning to determine the angulation and depth of the implant. During the planning stage, the hole diameter and depth and the sagittal, coronal, and panoramic tilt angles were obtained as specified in Table 2. The implant location was observable in the sagittal section at an angle of 81.81°, in the coronal portion at 83.09°, and in the panoramic section at an angle of 80.23°.

The dental implant guide was designed by using AutoDesk Meshmixer software with a thickness of 3mm (shown by the yellow line in Figure 7) and a sleeve diameter of 5.4mm (shown by the green line in Figure 7). The design of the

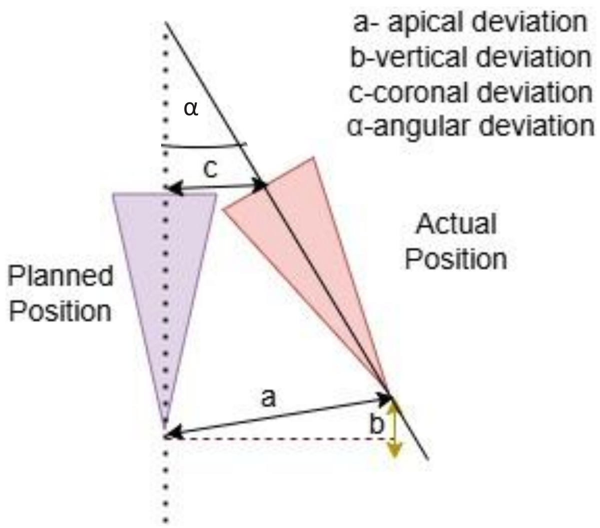

Figure 10. Visualization of accuracy parameters

dental implant installation tool has a window, which functions to increase visibility and facilitate verification when the dentist is carrying out the dental implant installation procedure, and a sleeve that becomes a place to direct the drill and dental implant to be inserted.

The 3D design of the dental implant guide was printed by using an SLA 3D printer (Phrozen Mighty 4K) with polyurethane acrylate dental resin (SG100 eSun) material. The printing process took 2 hours, 54 minutes, and 49 seconds with a volume of resin used of 11.41 mL. Then, a curing process was carried out by using ultraviolet (UV) light on the 3D printer printout for 30 to 60 minutes to increase its mechanical strength. The resulting dental implant guide weighed 12.5 grams. The result of the dental implant guide printing is shown in Figure 8.

The sleeve of the dental implant guide was designed by using BlueSky Plan software. The sleeve had an initial diameter of 5.4mm, shown by the green line in Figure 9 (A), with a wall thickness of 3mm, shown by the yellow line in Figure 9 (A). After the 3D printing stage using an SLA 3D printer with a dimensional tolerance of ±0.9mm, the final diameter of the sleeve was reduced to 4.5mm, as shown by the orange line in Figure 9 (B), with a wall thickness of 3mm, as shown by the yellow line in Figure 9 (B). The final diameter produced after the printing process was the diameter that corresponded to the dental implant to be installed, namely the Dentium Implantium type, which had a diameter of 4.5mm and a length of 8mm. the enlargement of the sleeve diameter during the design process aimed to accommodate the tolerance of the SLA 3D printer and produce the correct size.

The printed dental implant guide was attached to the patient's mandibular phantom for drilling simulation. After drilling, the drilled holes in the phantom were filled with plasticine to analyze the angles again using Kinovea software. Table 3 shows the angle, diameter, and depth for installing the dental implant, showing the angle differences in each view in the analysis results using Kinovea software. The angle measurements were obtained using Kinovea software on the sagittal section with an angle of 81.9°, on the coronal/frontal section with an angle of 83.1°, and on the panoramic section with an angle 81.4°.

Table 3 compares the implant planning from BlueSky and the actual from 3D printout. In the sagittal view, the angle difference was -0.09°; in the coronal/frontal view, the angle difference was -0.01°; and in the panoramic view, the angle difference was -1.17° with an average difference of 0.423°. This happened because of the differences in tolerance between implant planning and printout from a 3D printer.

DISCUSSION

The CBCT image reconstruction process using 3D Slicer software provides more precise and accurate modelling of the mandible with tooth and jaw structures to produce a model as an initial basis for planning and designing a dental implant installation guide. The implant planning process using BlueSky Plan software provides accurate results for the determination of the angulation, depth, and position of the implant to be installed based on the CBCT image. It has a feature to detect nerves and several views, including sagittal, coronal, and panoramic views. These views ensure that the position of the implant does not affect the inferior alveolar nerve. There is a difference in the angulation between the results of the implant planning using BlueSky Plan software and the test results using Kinovea software. However, this difference is still within normal limits for installation of dental implants.

The design of the tool for installing dental implants was carried out by using BlueSky Plan software to make the body and sleeve parts of the tool and using Autodesk Meshmixer software to make the window part. The design of the dental implant installation guide aimed to increase visibility and facilitate the dentist's verification when carrying out dental implant installation procedures. The sleeve on the dental implant installation guide was made with a diameter of 5.4 mm with a tolerance of ±0.9 mm, thus allowing the design of the dental implant installation guide to fit the dental implant to be installed, namely Dentium Implantium, with a diameter of 4.5 mm.

Dental implant installation guides are printed using a 3D printer with the SLA method (Phrozen Mighty 4K), which has high accuracy and resolution by forming layer by layer and hardening when exposed to ultraviolet (UV) light until the entire object is formed (18). Dental resin with a polyurethane acrylate composition (SG100 eSun) is used as the material. The printing results of the dental implant installation guide had a dimensional tolerance of ±0.9mm, and this dimensional change is due to the photopolymerization process, resulting in a dimensional tolerance on the 3D printer (19). After the printing, the printed results are cured by using ultraviolet (UV) light for 30 to 60 minutes to enable their crosslinking network to increase mechanical strength.[20]

The mold was attached to the patient's mandibular phantom, then a drilling simulation was carried out. The hole resulting from the drilling process was filled with dark colored plasticine to simulate the dental implant being installed. Dark colors are chosen to facilitate visualization when measuring tilt angles. The standard angulation for installing dental implants is 90°, 80°, 75°, and 65°, and dental implant installation is said to be good if the angulation of the dental implant is more perpendicular to the horizontal surface.[21] The average angle difference obtained was 0.423°. The standard deviation obtained from the calculation was 0.647°, indicating a normal threshold with a slope tolerance of a minimum of 0.38° and a maximum of 3.03°.[22] The calculation results of the standard deviation show how significant the differences among the three angles are between the planned and the actual results, which in this study amounted to -1.17°.

The angular deviation, coronal deviation, apical deviation, and vertical deviation were also measured as accuracy parameters of the dental implant guide as seen on Figure 10.[23] The angular deviation is the angular difference between the planned and actual positions in coronal cross-sections. Based on Table 3, it is known that the resulting angular deviation is 0.01°, the resulting apical deviation is 0.0014 mm, and the vertical deviation is 0.0002mm. Coronal deviation cannot be measured because the magnitude is too small.

The use of open software such as 3D Slicer, BlueSky Plan, and AutoDesk Meshmixer makes the process of designing and manufacturing dental implant guides possible. CBCT data is integrated to allow the anatomical structure of the teeth and jaw to be visualized, and dental implant placement can be planned better and more accurately. Using open software has the advantage of having lower costs and not paying monthly subscription fees to use the software, thereby minimizing expenses, especially in small dental clinics.

CONCLUSION

The research results show that digital technology, including open software such as 3D Slicer, BlueSky Plan, and AutoDesk Meshmixer, can produce good accuracy in the design of dental implant guides. This study has limitations, such as a shrinkage in the sleeve size of the dental implant installation tool due to tolerances during printing.

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CONFLICT OF INTEREST

The author(s) declare that they have no conflict of Interests.

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