Rapid Prototyping Mandible Model for Dental Implant Surgery Simulation

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ABSTRACT

The dental implant surgery results usually depend on dentists' clinical experiences and judgments. Most implant surgery utilizes the software to process pre-operation planning and simulation. Hence, this research intended to apply the rapid prototyping (RP) technique to build real mandible model for implant surgery simulation. Unlike other simple mandible RP models, vessels and nerves pathways are demonstrated in our model to help dentists to avoid false drillings on them. Besides, orientation pillars for surgical guide are included in the model. Moreover, for comparison's purpose, the platforms of placing indexing balls are also integrated. Computed tomography (CT) data of mandible were first converted to a CAD model with vessels, nerve, orientation pillars, and indexing platforms by a medical imaging processing software. RP technique was then utilized to obtain a real 3D model for pre-operation planning, surgical guide fabrication, and surgery simulation. The mandible model helped to drill holes on the traditional surgical guide by a 5-axis CNC drill press and it also drilled into the mandible model. Besides, the dentist simulated the drilling process in the dental implant surgery on the mandible model. Both drilled RP mandible models were CT-scanned and compared with the designed implant locations and angles. The errors are within acceptable region. Our approach has been successfully demonstrated in dental implant's pre-operation planning and simulation, which will help to increase the successful rate and safety of dental implant surgery.

Keywords: rapid prototyping, dental implant, mandible model, surgery simulation.
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1 INTRODUCTION

The introduction of the concept of osseointegration by Branemark [1] started the era of the dental implants. Osseointegration has become the basic requirement in dental implant nowadays and more concerns fall on reducing osseointegration time and optimizing the implant location and angle. The surgical guide, defining the locations and angles of drilling holes, was created to fulfill these needs. With the surgical guide, the surgical wounds are minimized, and the operation time and healing time can be shortened. Besides, Rapid Prototyping (RP) models have been applied to various surgery planning [2-5]. According to Erickson's survey in 1999[6], with assistance of a real 3D model, the operation time can be reduced 17-60%. RP techniques were also utilized to fabricate surgical guide and implant's angle errors were evaluated. In Vrielinck's research [7], the angle errors for zygoma and pterygoid implants were 5.14 and 10.18 degrees respectively. Sarment *et al.* [8] in 2003 compared the Stereolithography (SLA) surgical guide with the traditional one, and showed the SLA one reduced the angle error from 8 to 4 degrees. In clinic practice, most implant surgery still only utilizes the software to process pre-operation planning and simulation. There is no mandible RP model available in the literatures to include vessels and nerves pathways in it for better surgery planning and simulation. Hence, in this research, RP technology is adopted to build a real mandible model to have vessels and nerves pathways, orientation pillars for surgical guide, and platform for indexing balls. In addition to surgery planning and implant design, the model was used to aid hole-drilling of a traditional surgical guide on a 5-axis CNC drill press and to conduct surgery simulation by a professional hand-held drilling instrument by the dentist. The drilled results on the mandible models are compared with the original designs to evaluate the feasibility and performance of our approaches.

2 MANDIBLE CAD MODEL CONSTRUCTION

This research takes CT-scanned images to convert to 3D solid CAD model for rapid prototyping application. A medical image processing software, Mimics (Materialise, Belgium), was adopted to handle the job. Patients' dental CT data in DICOM format (.dcm) were input into Mimics. Before further processing the images, the function of "Profile Lines" was used to evaluate patient's bone density (Fig. 1). This will help not only to understand if the patient is suitable for dental implant, but also to determine the thresholds for image segmentation. The suitable threshold values were then set and the software would automatically select areas within the threshold range. Since only certain mandible portion is used in our application, the function of "Crop Mask" was used to limit the image processing within the required region, which would reduce editing time later.

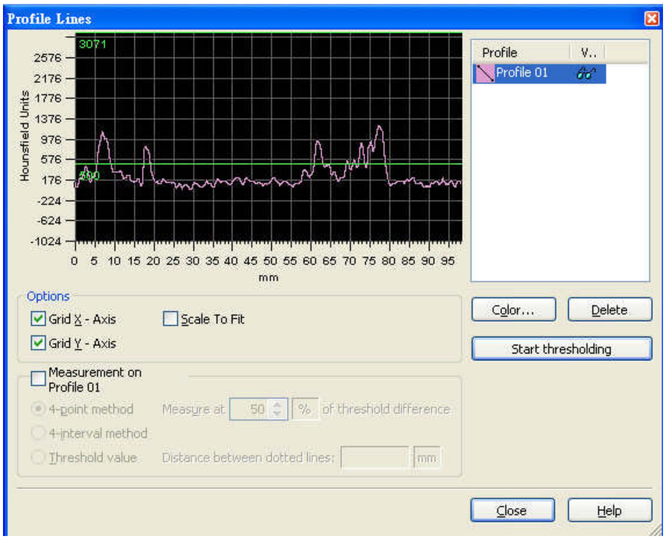

Fig. 1: "Profile Lines" to show bone density.

After initial automatic handling works by the software, we need to check and manually edit each image carefully in Mimics to remove noises and clarify the ambiguous areas. The noises are mainly from the scattering effect due to the existence of indexing balls and plates, while the boundary areas of the mandible tend to introduce ambiguity. These are inevitable in CT images and can be eliminated by well-trained users. Since balls and plates for indexing were included in the CT images, they also needed to be chosen in different layer and subtracted from the selected mandible areas by Boolean operation. Vessels and nerves pathways can be also seen in CT images. Their existence in the mandible model will help dentists to avoid false drilling in implant design and simulation and in the actual surgery. Hence, they were segmented (Fig. 2) and subtracted from the mandible area in each image. Besides, the surgical guide would need orientation pillars for placing. So, three orientation pillars were added in each image (Fig. 3). Moreover, for verifying the surgery simulation results, indexing balls will need to be placed in the mandible model as well. Therefore, a platform (Fig. 4) for indexing balls placing was integrated to ensure the final mandible model and CT images after-simulation will have the same coordinates for comparison. At last, the mandible images with vessels and nerves pathways, orientation pillars, and the indexing platform were converted to a mandible CAD model in STL format and ready for RP fabrication. Since each image was carefully edited, the resultant STL file would not need extra cleaning process. The errors caused by the images editing are usually greater than the errors from the RP process we used. Since the drilled results and implant designs are compared within CT images, the impact of image editing errors is not evaluated in this study.

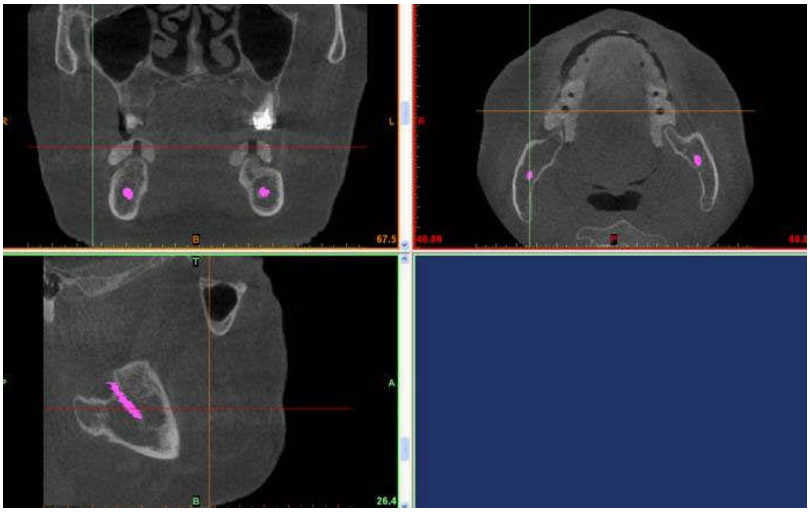

Fig. 2: Segmentation of vessels and nerves pathways.

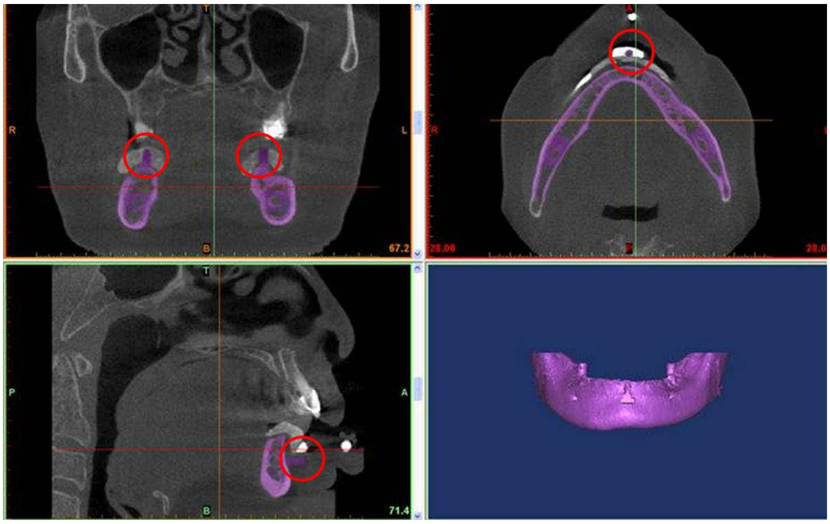

Fig. 3: Image with added orientation pillars (circled by red lines).

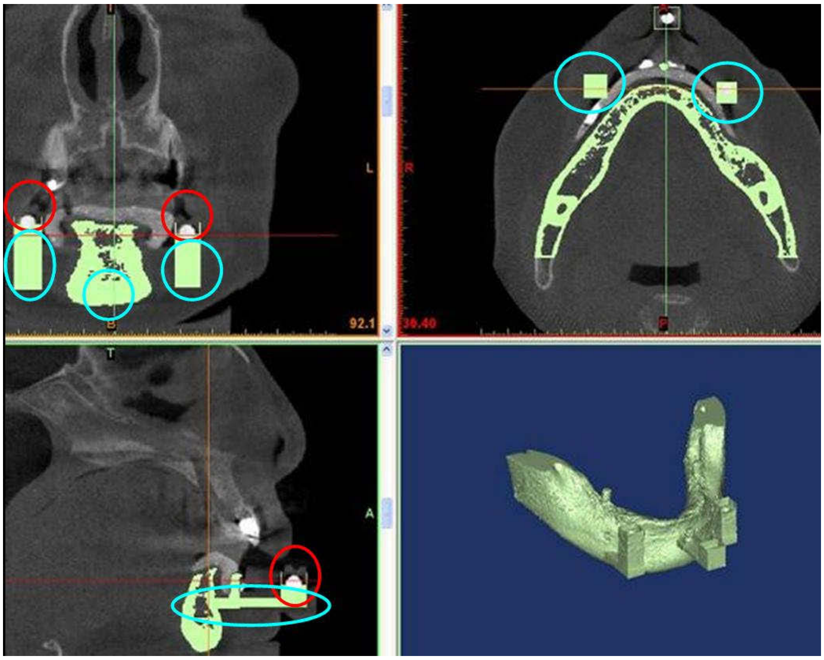

Fig. 4: Images with indexing platform (circled by blue lines) and indexing balls (circled by red lines).

A commercial RP system, Objet's EDEN 330 (Objet Geometries, Inc., Israel), was used to generate mandible models. Objet's PolyJet™ process jets photopolymer in ultra-thin layers (16μm) layer by layer and the layer is cured immediately after jetting by UV lamps behind the print-head. The support material is gel-like and can be removed mechanically. Comparing with other commercial 3D RP printers under similar price range, Objet's system has the advantages of resolution and surface finish. A mandible model needed about 99g model material and 100g support material, spending 6 hours in layered processing. The post processing of removing support material was done by hand cleaning first to remove most support material and then placing in a 2% NaOH solution under one-hour ultrasonic cleaning. In order to clean the support material in the small pathways of vessels and nerves, metal wire was used before placing the model in the NaOH solution. After cleaning, the pathways of vessels and nerves were dyed in red for better demonstration (Fig.5). The completed mandible model is shown in Fig. 6. This model can be used immediately for dentist to plan surgery strategies, to design surgical guide avoiding false drilling on the vessels and nerves pathways, to explain the surgery to the patients, to assist the fabrication of surgical guide, and to perform the surgery simulation. In the following sections, the details about assistance of surgical guide fabrication and surgery simulation of drilling will be explained, and the results will be compared with the expected designs.

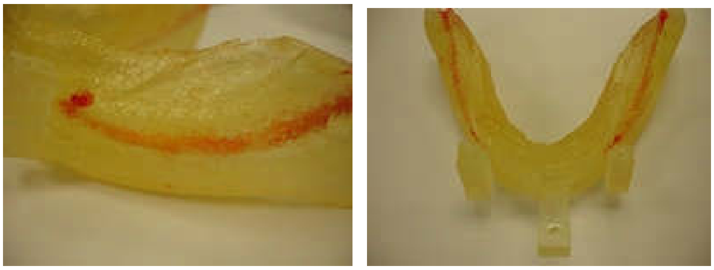

Fig. 5: Dyed vessels and nerves pathways.

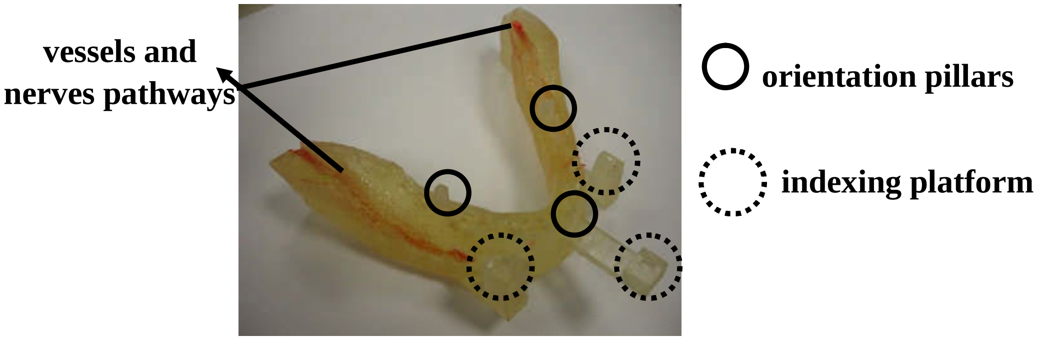

Fig. 6: The completed mandible model.

3 THE AIDS OF SURGICAL GUIDE FABRICATION

A surgical guide in dental implant can help the dentist to drill holes on the patient's bone in accordance with the pre-operation planning. The traditional surgical guide fabrication by dentist replicates patient's dental impress to obtain the shape of a surgical guide and then holes for implant are drilled on it at planned locations. To reduce the errors during drilling process, a 5-axis CNC drill press was developed by National Taiwan University of Science and Technology and National Defense Medical Center (Taipei, Taiwan). The RP mandible model provides a base and index for the surgical guide drilling. Since the mandible model obtained in the previous section did not include gum, a layer of resin was extruded into the gap between the surgical guide and RP model to imitate gum before drilling (Fig. 7). After the resin is cured, the surgical guide is removed if the drilling is not performed immediately to prevent further deformation of the gum. The Fig. 8 shows the cured gum with RP mandible model.

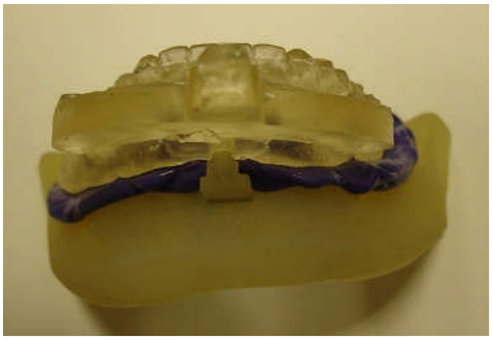

Fig. 7: Extrude resin between surgical guide and RP mandible model to obtain gum.

Fig. 8: Cured gum with RP mandible model.

A dental implant planning software, ImpantMax (Saturn Imaging Inc., Taiwan), was conducted by the dentist to arrange the locations and angles of implants. The three indexing balls ensure that the mandible model with surgical guide, the drill press, and implant design in ImpantMax software have the same index. Fig. 9 shows the mandible model with surgical guide fixing on the drill press after 3-point indexing and origin locating. In this particular case, the drill press drilled 6 holes (numbering 46, 45, 41, 31, 35, and 36) through the surgical guide and also drilled into the necessary depths in the mandible model with the hole size of 3 mm (Fig. 10).

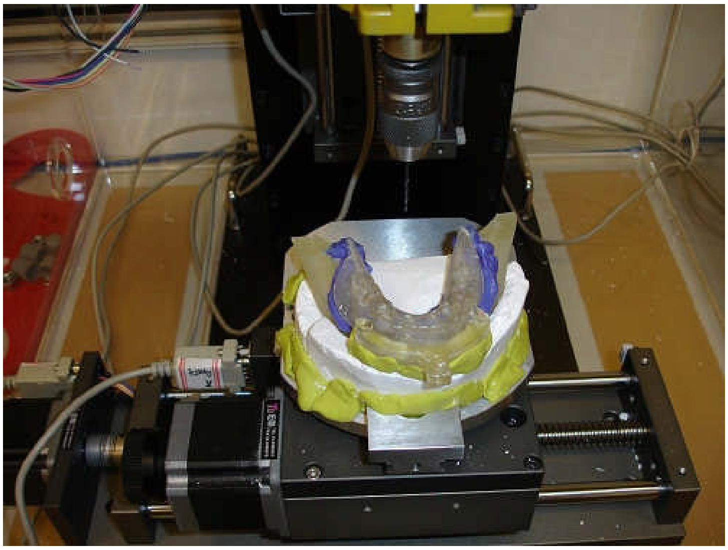

Fig. 9: Mandible model and surgical guide fixing on the drill press after indexing and origin locating.

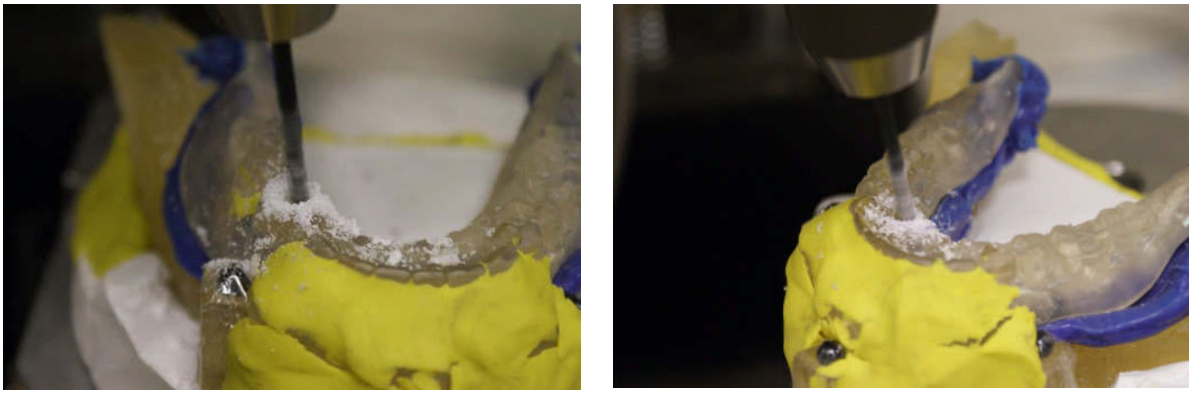

Fig. 10: Drill #45 (left) and #41 (right) holes on the 5-axis CNC drill press.

4 SIMULATION DRILLING IN SURGERY

The RP mandible model can also be used in surgery simulation. Stacking the RP mandible model together with the surgical guide, dentists can simulate and practice drilling process to avoid mistakes in the real surgery and discover possible problems. The case illustrated here took a mandible model with integrated gum in the RP model. The surgical guide was self-designed with required holes and built by the RP process. A hand-held dental surgery instrument, Implantmed (W&H, Austria) (Fig. 11), was used to perform drilling simulation. The dentist used three sizes (2.1, 2.5, 3.0 mm) of drill bit sequentially to enlarge the hole gradually. Six holes with the same locations (numbering 46, 45, 41, 31, 35, and 36) as previous section were drilled into the mandible model. Fig. 12 shows the sequence of drilling the hole of location #35.

Fig. 11: Implantmed dental surgery instrument.

Fig. 12: Sequences of surgery simulation to drill #35 hole: (a) Drilling by 2.1mm drill (left), (b) Drilling by 2.5mm drill (middle), and (c) Drilling by 3mm drill (right).

5 DRILLED RESULTS VERIFICATION

Drilled mandible models by 5-axia CNC drill press (model I) and by hand-held Implantmed (model II) were CT-scanned and loaded the CT images into ImplantMax for comparison. The three indexing balls were placed on each model during the CT scanning to determine the same coordinates for both models and the designed implants in the ImplantMax. Since the Objet's model material was not clear in CT images, aluminum tubes were placed in the drilled holes to make comparison easier. The CT-scanned drilled models are shown in Fig. 13. Using the functions in ImplantMax, we could obtain the average errors of five measurements between drilled results and the designs in Mesial angle, Buccal angle, Total angle, Mesial offset, Lingual offset, and Total offset. Total offset is the square-root of the sum of squared Mesial offset and squared Lingual offset. Tab. 1 and 2 are the average errors at different drilled locations for model I and II..

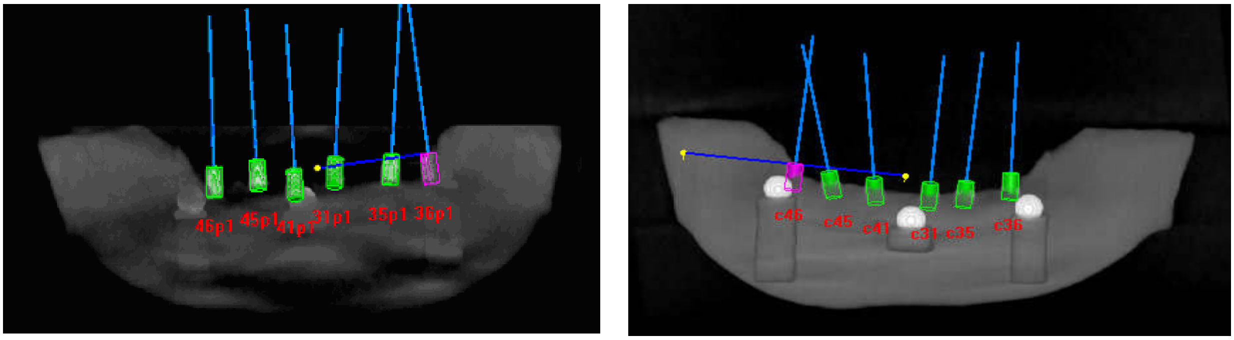

Fig. 13: CT-scanned images: (a) 5-axia CNC drilled model (left) and (b) Implantmed drilled model (right).

Tab. 1: Average errors at different implant locations for the 5-axia CNC drilled model (model I).

Implant #	Mesial Angle (deg)	Buccal Angle (deg)	Total Angle (deg)	Mesial offset (mm)	Lingual offset (mm)	Total offset (mm)
46	1.14	0.77	1.38	0.64	0.84	1.06
45	0.07	2.02	2.02	1.97	0.11	0.78
41	2.28	0.50	2.34	0.33	0.46	0.57
31	2.55	1.01	2.74	0.84	0.81	1.17
35	2.27	0.47	2.32	1.00	1.17	1.55
36	1.61	0.05	1.61	1.40	0.74	1.59
Average	1.65	0.80	2.06	1.03	0.68	1.12
S.D.	0.93	0.67	0.50	0.58	0.36	0.40

Tab. 2: Average errors at different implant locations for Implantmed drilled model (model II).

Implant #	Mesial Angle (deg)	Buccal Angle (deg)	Total Angle (deg)	Mesial offset (mm)	Lingual offset (mm)	Total offset (mm)
46	0.68	1.27	1.44	0.29	0.34	0.46
45	0.17	1.43	1.44	0.27	0.33	0.42
41	1.12	1.01	1.52	0.27	0.02	0.27
31	1.6	0.27	1.63	0.50	0.23	0.56
35	1.61	0.69	1.79	0.32	0.26	0.41
36	0.87	1.52	1.74	0.26	0.29	0.39
Average	1.01	1.03	1.59	0.32	0.25	0.42
S.D.	0.56	0.49	0.16	0.09	0.12	0.10

For model I, the total angle range is 1.38~2.74 degrees with the average of 2.06 and standard deviation of 0.5. Model II's total angle range is 1.44~1.79 degrees with the average of 1.59 and standard deviation of 0.16. If total offset is considered, model I has the range of 0.57~1.59 mm with the average of 1.12 and standard deviation of 0.40, while model II has the range of 0.27~0.56 mm with the average of 0.42 and standard deviation of 0.10. In both models, the errors are within acceptable regions for implant surgery and better than those in the literatures. Therefore, it is proven that our approaches can be utilized successfully in dental implant surgery simulation. The errors and standard deviations of model I are slightly larger than those of model II. If the precision of the 5-axis drill press can be improved, the results can be comparable to hand-drilled data. Besides, because the hand-held drilling was done by the experienced dentist with professional tool, the accuracy and precision of model II were satisfying. If we look into specific implant locations, the maximums of total angle and total offset for two models were varying, but the minimums are identical. The minimal total angle happened at #46 and the minimal total offset happened at #41 for both models.

6 CONCLUSIONS

This research successfully integrated the vessels and nerves pathways, orientation pillars for surgical guide, and platform for indexing balls in the RP mandible model. The model can help dentist to plan surgery, to design implants, to drill holes on the traditional surgical guide by a 5-axis CNC drill press, and to simulate surgery sequences by a professional hand-help drilling instrument. The drilled mandible models were CT-scanned and compared with the original designs. The errors are within acceptable regions in practice and are better than those in the literatures. Our approach has been proven feasible and performed promising in dental implant's pre-operation planning and simulation. It can be applied to other dental implant cases in the future to increase surgery successful rate and reduce the operation time and healing time.

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