Technical Report

Visualizing and fabricating a reduction guide for circumferentially parallel guiding planes with computer-aided design and computer-aided manufacturing technology

Chia-Yuan Hu, DDS, MS[a]
Szu-Han Chen, DDS, MS[b]
Tsung-Chieh Yang, DDS, PhD[c*]

[a]Attending Staff, Department of Dentistry, National Taiwan University Hospital, Taipei, Taiwan
[b]Attending Staff, Division of Prosthodontics, Department of Dentistry, National Taiwan University Hsin-Chu Hospital, Hsinchu, Taiwan
[c]Associate Professor, School of Dentistry, National Taiwan University and National Taiwan University Hospital, Taipei, Taiwan

[*]Corresponding author:
Tsung-Chieh Yang
National Taiwan University, School of Dentistry, No 1, Chang-Te Street, Taipei 100, Taiwan
Tel : +882-2-23123456 ext 67718
Email: yangtc@ntu.edu.tw

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Abstract

The preparation of appropriate parallel surfaces in accordance with tooth morphology influences the clinical performance of a partial removable dental prosthesis (RDP). Well-designed guiding planes that are prepared accurately around the abutment tooth ensure the stability of an RDP. We have created a novel reduction guide to design and fabricate continuous circumferential and parallel surfaces around abutment teeth by using computer-aided design and computer-aided manufacture (CAD/CAM). In conclusion, with help of CAD/CAM technology, design and production of a guiding plane reduction guide could be more precise and predictable.

Key words: guide plane, RDP, CAD/CAM, reduction guide

Introduction

A stable removal dental prosthesis (RDP) resists displacement due to functional, horizontal, and rotational stress.[1] Stability is a critical factor in patient satisfaction.[2] The stability of a partial RDP depends on well-designed guiding planes on the abutment teeth with two or more vertically parallel surfaces.[1,3,4] The intentionally prepared surfaces are usually placed on buccolingual curves according to the contour of the abutment teeth and 1.5–5.0 mm in occlusogingival height.[5-7] However, preparing continuous circumferential and parallel planes on abutment teeth is always challenging because of the morphology of the teeth. Conventionally, guiding planes are prepared freehand and verified on models,[6,7] assisted by reduction guides[8-14] or intraoral surveyors.[15,16] Computer-aided design and manufacturing (CAD/CAM) technology has also been used to design and manufacture reduction guides to prepare guiding planes for partial RDPs.[17-20] While digital technology allows more accurate and repeatable processes to design and prepare straight planes for an RDP, providing continuous circumferential and parallel planes around abutment teeth remains difficult. These clinical problems are overcome in this article by evaluating the path of insertion and survey line, analyzing areas of guiding planes, and fabricating a device for circumferential guiding plane preparation using CAD/CAM technology.

Methods

1. Survey the study model to determine the path of insertion of the RDP with the attached pin index using a laboratory surveyor (Dental Surveyor, Tungsheng Co., Tapipei, Taiwan; Fig.1).
2. Scan the study model to create a standard tessellation language (STL) file with a laboratory scanner (E3, 3 shape, Copenhagen, Denmark) and import it into CAD software (Autodesk Meshmixer, Autodesk, San Francisco, USA) . Create and combine a cylindrical object aligned with the pin index on the study model for ease of orientation; it is challenging to assign the same direction to the face normal from the top of the pin after scanning since the pin's surface is irregular at microscopic scale of the mesh (Fig. 2). Align the orientation of the study model by cylindrical object with the positive z-axis of the world coordinate to facilitate later dimensional adjustment of the object in the x- and y-axes.
3. Build a columnar 3D object as a reduction guide for the RDP abutment tooth. Two methods are presented for this process. The first method labels the abutment tooth (Fig. 3A) and selects the visible area from the top view using the selection modify function to define the area above the survey line (Fig. 3B). Care must be taken to ensure that no face normal without positive orientation in z-axis is selected. Otherwise, an overlapped or inverted normal would be encountered during the extrusion process, leading to processing errors. Use the selection modify function to optimize and smooth the border of the selected surface and extrude it as a 3D columnar object, and adjust the column dimension in the x- and y-axes for a suitable range of the guiding plane circumferentially exposed between the column and the model (Fig. 3C and 3D). The second method uses several small 3D round or elliptical cylindrical objects to approximate the range of the reduction guide of the 3D columnar object like in the first method (Fig. 4A and 4B). Combine all the small round or elliptical cylindrical objects with the Boolean union to simplify the process in the next step.

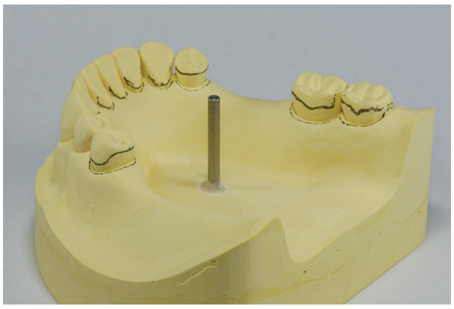

Figure 1.
Attach a pin to the study model to indicate the path of insertion.

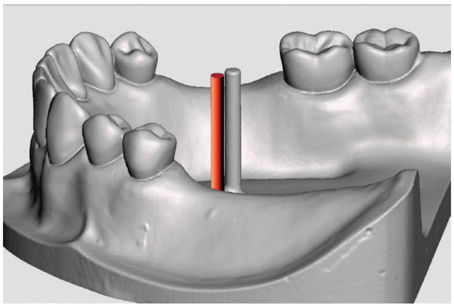

Figure 2.
Place a cylinder next to the pin on the standard tessellation language (STL) model for easy alignment.

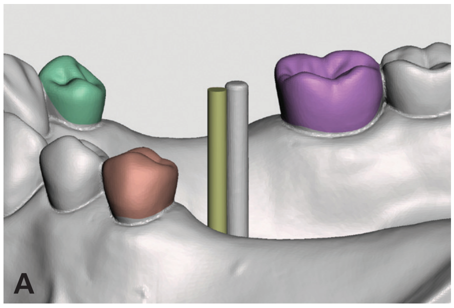

Figure 3A.
Select abutments.

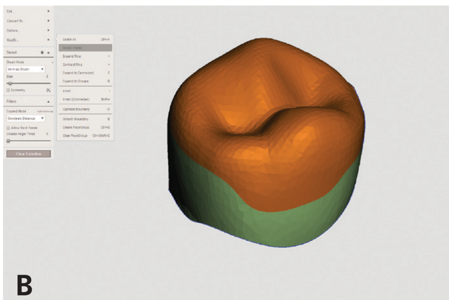

Figure 3B.
Select the visible portion from the top view above the survey line.

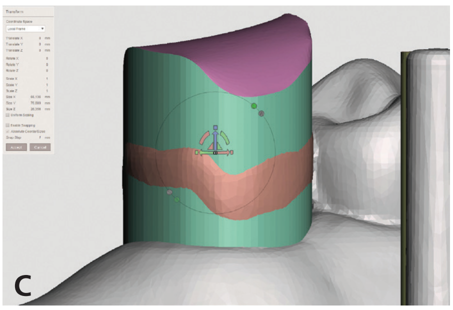

Figure 3C.
Flatten the selected area and extrude a column for guiding plane range adjustment in the x- and y-axes.

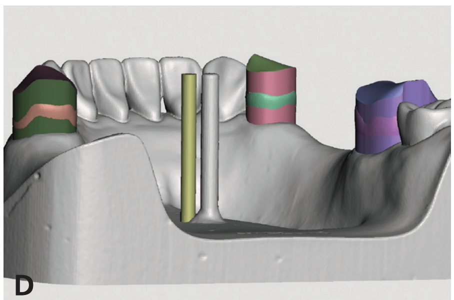

Figure 3D.
Prepare all columns.

4. Process the reduction guides from the designed 3D columnar objects and the study model using the Boolean difference (Fig. 5). Please make sure to remesh the columnar object and adjust the mesh density to closely match that of the study model in the wireframe view. This step helps to reduce any edge discrepancies caused during the Boolean operation. In addition, unchecking "Auto-Reduce Result" in the Boolean function box could avoid morphological changes around the object border during Boolean processing in Meshmixer. Select and remove the remaining portion below the guiding plane.
5. The parts of the guides on the abutment teeth are connected with an object extruded from the study model to increase the accuracy of the reduction guide positioning on the teeth. Additionally, some windows are incorporated on the occlusal surface of the reduction guide to confirm full seating on the teeth (Fig. 6A).
6. Prepare the output STL reduction guide model in the processing software (Phrozen 3D, Phrozen Tech Co., Hsinchu, Taiwan) to orient the tissue surface of the model away from the build plate, add and arrange printing supports (Fig. 6B), slice into printing layers, and output in the 3D printer format. Fabricate the reduction guide with printable resin (DD guide, Enlighten Materials, Taipei, Taiwan) using a 3D printer (Sonic, Phrozen Tech Co., Hsinchu, Taiwan; Fig.7).
7. After removing all printing support and checking the fit on the study model, the reference plane on the reduction guide is painted black (Fig. 8) for easier discrimination and as a contact indicator during guiding plane preparation.

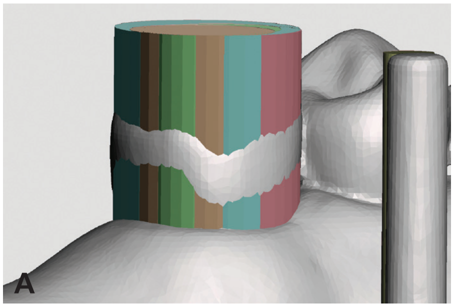

Figure 4A.
Another method to make columns uses round and elliptic cylinders.

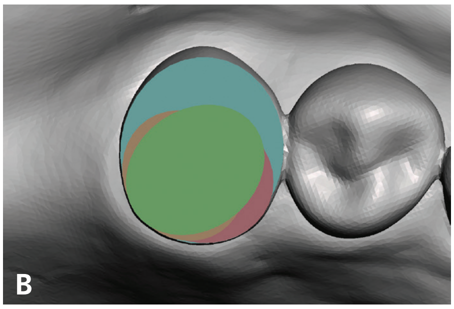

Figure 4B.
The top view shows a column formed by four cylinders.

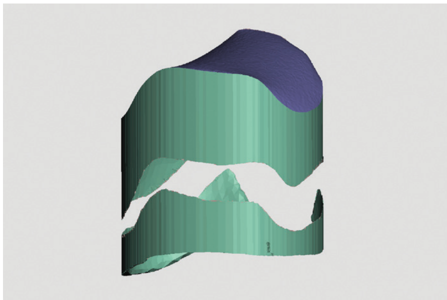

Figure 5.
A reduction guide is formed by the Boolean difference between the column and the study model. The lower portion is removed later.

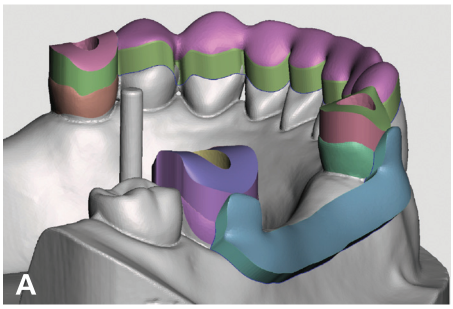

Figure 6A.
Connect designed reduction guides.

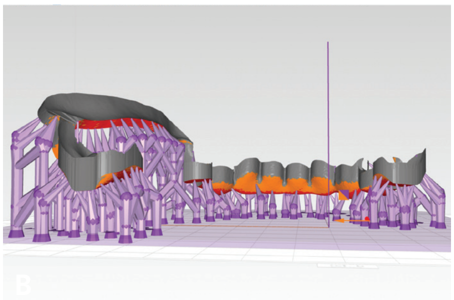

Figure 6B.
Orient reduction guide and apply printing support in Phrozen 3D.

Figure 7.
The finished reduction guide on Typodont.

Figure 8.
The reference plane of the reduction guide is painted black for better visualization.

Discussion

The fabrication of guiding planes improves the stability of an RDP and its resistance to displacement due to horizontal or rotational stress.[3,4] The number of parallel surfaces in a partially edentulous ridge should be maximized to increase the quality of stabilization[4] especially in situations when few abutment teeth remain. Additionally, establishing parallelism between distant teeth without the help of a device is challenging.[18]

Conventionally, an acrylic resin block molded on the occlusal surface of the model's abutment teeth and processed with a three-axis milling machine mounted on a survey machine is used for reference to reduce the guide plane.[4,11] The milling process is performed on both the resin block and the stone model. This process cannot be reversed if the surfaces are over-prepared.

With the aid of digital technology, the morphology of the abutment teeth could be evaluated from the x-, y-, and z-axes separately, and the region of the guide plane could be determined more explicitly. Currently, many dental digital design software are on the market that can perform similar functional operations. However, if we do not want to invest too much in professional software, Meshmixer is freeware worth considering, although its development was discontinued in 2021.

The Boolean operation is one key operation in every 3D modeling software. In dental design software, the Boolean operations are integrated and concealed into the design process. The Boolean operations encompass merging, subtracting, or intersecting digital objects, necessitating the mesh of manipulated objects to be manifold, devoid of inverted face normals, and exhibit closely matched mesh face density. Consequently, our approach involves a meticulous selection of the guide area and the remeshing of objects during the procedural steps. Being an experimental basic 3D modeling software, Meshmixer has limited debugging and error-proofing capabilities. Therefore, when the objects undergoing Boolean operation cannot be adequately prepared, alternative robust software becomes a viable option for simplifying the workflow. Moreover, all the steps in our demonstration could be substituted with any other software featuring similar functions, provided that the same orientation is maintained and potential quality changes in the digital model during transitions between software applications are addressed.

Based on its relatively low cost, versatile forming capabilities in multiple directions, and ability to capture fine details, we used a masked stereolithography 3D printer to fabricate the guide. The resin printing material is brittle and flexible, necessitating careful consideration of structure thickness and strength during model construction. Moreover, the 3D printing process is technically sensitive, with the dimensional and morphological accuracy of the product being influenced by various factors such as printing support arrangement, setting of printing parameters, and post-processing procedures such as washing, curing, and support removal. Consequently, using a dental model as a fitting standard before intraoral use is advantageous. When higher mechanical strength is imperative, making a guide by milling resin blocks becomes favorable.

This method is more likely to create continuous circumferential and parallel surfaces around the abutment teeth, avoid over-preparation of tooth structure, and approach the goal of a single path of insertion for the RDP. However, since the guide rests on the teeth, the accuracy of the guide plane's preparation depends on factors such as the number, mobility, and distribution of the teeth involved. When dealing with a limited number of teeth, it is advisable to incorporate a structure with greater soft tissue coverage into the preparation guide's design. Additionally, we used inspection windows and transparent materials for this case to ensure proper attachment of the preparation guide to the abutment tooth. It is recommended that all essential components on each abutment tooth be connected into a single cross-arch unit to enhance the manageability of the guide. We can more effectively attain our objectives of well-prepared guide planes through meticulous design and material handling.

Conclusion

Using CAD/CAM technology, a reduction guide for continuous circumferential and parallel guiding planes according to the morphology of the abutment teeth can be fabricated precisely and predictably for an RDP.

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