A Preliminary Report of Designing Removable Partial Denture Frameworks Using a Specifically Developed Software Package

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This article reports on a method to digitally survey and build virtual patterns for removable partial denture (RPD) frameworks using a new three-dimensional (3D) computer-aided design/computer-assisted manufacturing (CAD/CAM) software package developed specifically for RPD design. The procedure included obtaining 3D data from partially dentate casts, deciding on the path of insertion, and modeling the shape of the components of the frameworks digitally. The completed model data were stored as stereolithography (STL) files, which are commonly used in transferring CAD/CAM models to rapid prototyping technologies. Finally, metal RPD frameworks were fabricated using a selective laser melting technique. *Int J Prosthodont 2010;23:370–375.*

Computer-aided removable partial denture (RPD) framework design is time consuming and complicated when using general three-dimensional (3D) design software because of the variety of RPD components and their irregular shapes. It is not feasible to fabricate RPDs using the computer-aided design/computer-assisted manufacturing (CAD/CAM) method without suitable dedicated software. Nevertheless, until recently, no software specifically for the design of RPD frameworks was available. Williams et al[1] and Eggbeer et al[2] reported on a CAD/CAM method to design and fabricate RPD frameworks. In their studies, however, a special device (a force feedback sculptor) was necessary, which yielded a relatively high cost of manufacture.

The aim of the current study was to introduce the principle of a specifically developed software package (the Tang Long CAD system) that makes the designing of RPDs efficient and provides the possibility of fabricating RPDs using the CAD/CAM technique.

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Materials and Methods

Data Capture and Processing

Two dental casts (one maxillary, one mandibular) of partially dentate patients were scanned using a 3D cross-section scanner (CXM-I, Aibraces), which has been used in orthodontics for many years. The nominal tolerance of the scanner is 0.050 mm according to the manufacturer's specifications, and it meets the accuracy requirement of dental cast scanning for RPD design. After data processing, the surface of each dental cast was digitally obtained by means of a cluster of points outlining the surface, called a point cloud (Fig 1), which was then imported to the Tang Long CAD system.

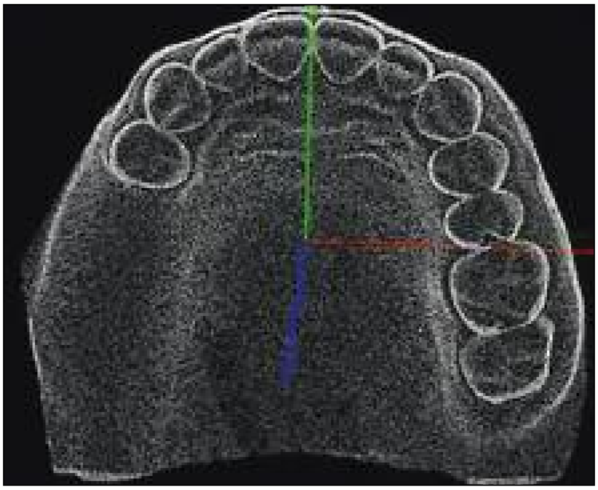

Fig 1 Point cloud (a 3D cluster of points outlining the surface) of a scanned maxillary partial dentate cast.

Fig 2a Survey lines of the entire dentition identified by the program. A straight line was drawn in the center of the dentition. Blue = buccal survey line; red = lingual survey line.

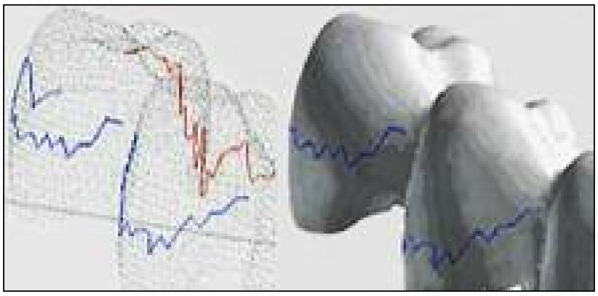

Fig 2b Close-up of Fig 2a. Survey lines **(right)** on the solid digital model and **(left)** on the point cloud.

Deciding the Path of Insertion

It is necessary to decide the path of insertion digitally so as to create the computerized RPD framework according to the principles of RPD design. First, the point cloud of just the teeth was removed from the entire point cloud manually. Then, a straight line was drawn in the center of the point cloud perpendicular to the occlusal surface, representing the predefined path of insertion. The distances between the line and the individual points of the pint cloud were calculated by the computer program. The closest lingual point and farthest buccal point to the straight line at different angles were discerned and connected. Thus, the survey lines were produced electronically (Fig 2). This process was completed automatically and instantaneously. According to the survey lines, the user could then decide whether the predefined path of insertion was ideal or not. If the survey lines were not ideal, the direction of the straight line could be adjusted easily until the survey lines were satisfactory. The new direction of the straight line was the final path of insertion. Thus, the path of insertion could be determined and modified conveniently in an electronic manner. After the final path was decided on, the z-axis was modified to be the same as the straight line in the interest of reducing memory requirements.

For clinical application, the clinician could use the traditional method to hypothesize the RPD design on the diagnostic cast and then prepare the teeth in the oral cavity, take a second impression, and obtain the final cast. After the final cast is scanned, the computing described above can begin. The software can also be used to identify the required modifications of the tooth surfaces for the selected path of insertion, if the preliminary cast is scanned and put into the software program.

Framework Design

The entire framework was designed using the point cloud data to meet the requirement of fitting the human anatomy. Generally speaking, three steps comprised the design process: deciding the contour of the component, building the tissue surface, and creating the polished surface.

For occlusal rests, circumferential clasps, and lingual bars, the basic contour was preset. The location of the component must be selected and its form modified and sized with the tools the program provides. The tissue and polished surfaces are then built automatically.

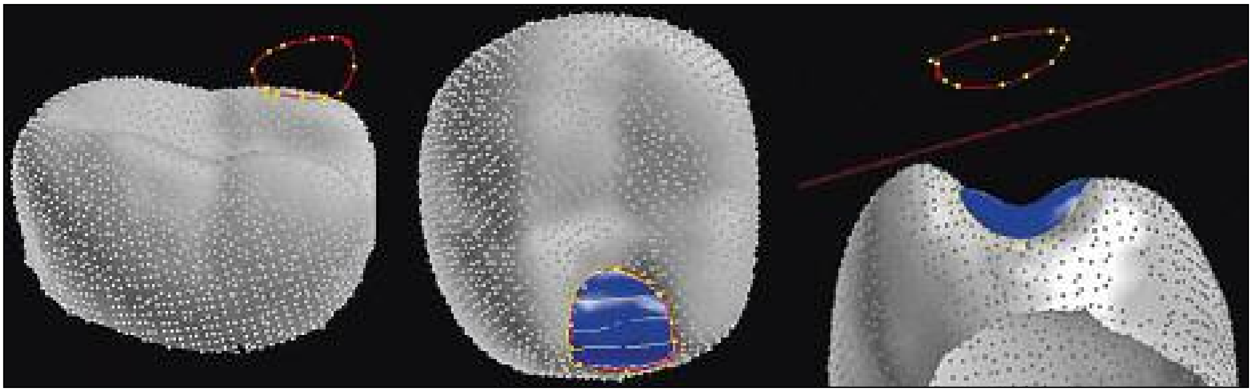

Fig 3 Design process of occlusal rest points. **(left)** A preset red circle was drawn above the occlusal rest seat. **(center)** Occlusal view. The outline of the red circle was projected onto the point cloud of the abutment tooth. The shape of the outline could be adjusted by moving the yellow control point on the red circle. The tissue and polished surfaces were generated automatically. **(right)** Proximal view of the occlusal rest. The curvature of the polished surface was continuous with that of the tooth surface in the surrounding area.

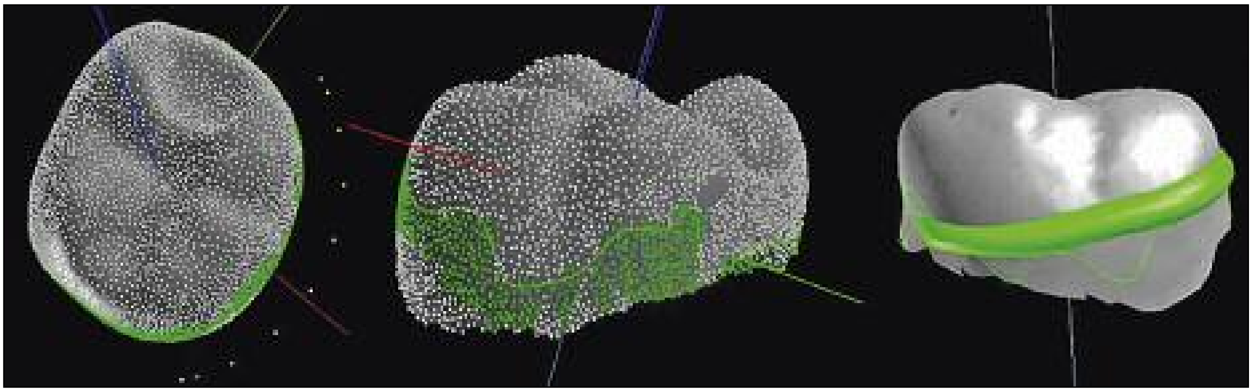

Fig 4 Building process of a clasp. **(left)** Control points surrounding the abutment tooth. The shape and location of the clasp could be modified by adjusting the control points. **(center)** The point cloud within the undercuts of a certain depth (0.5 mm in this case) is shown in green. **(right)** The generated digital clasp model.

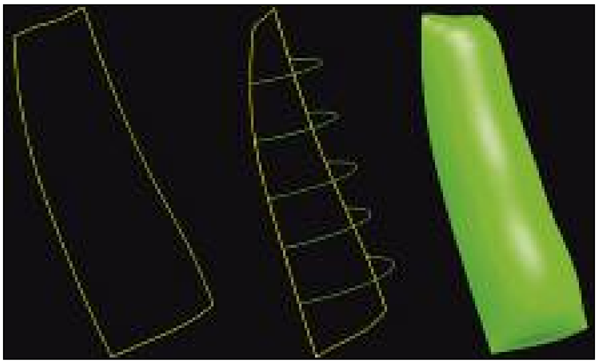

Fig 5 Creation of the polished surface of a minor connector. **(left)** Outline of a minor connector. **(center)** Default cross section. **(right)** Polished surface generated using the component outline and the default cross section as restrictions.

Figures 3 and 4 show the design process of the occlusal rest points and the clasp. For clasps, points at the undercut area of a certain depth (default value: 0.5 mm) were highlighted to determine clasp termination. The results of the accuracy analysis of the tissue surface of the occlusal rest provided by the software showed that the longest distance between the tissue surface and the point cloud was 0.11 mm and the average distance was 0.03478 mm. This means that the tissue surface and the point cloud are a high-precision match. To model other components, the user needs to define the contour by referring to the point cloud because the shapes of these components differ greatly depending on the patient. The tissue surface was built using the points within the contour as restrictive terms. The polished surface can be built using the component outline and the default cross section as restrictions. Figure 5 shows the building process of the polished

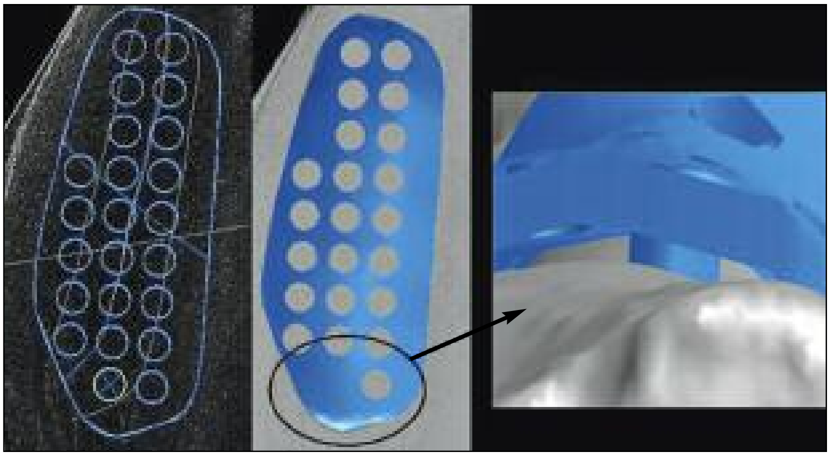

Fig 6 Digital model of the polymeric retention framework and tissue stop.

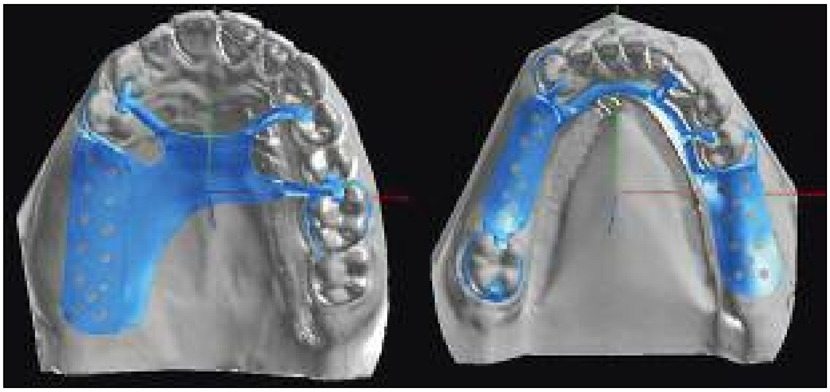

Fig 7 On-screen photographs of two RPD frameworks being created.

surface of a minor connector. The shape of the cross section can be modified with the tools provided by the program. For the polymeric retention framework, relief is created by offsetting the tissue surface (default value: 0.5 mm). The radius of the holes of the polymeric retention framework and the minimum distance between holes were preset so that the computer could decide the location of all holes in accordance with the constraints. The location of the tissue stop requires manual selection (Fig 6).

To avoid undercuts during this process, a central line was built on the point cloud parallel to the z-axis. Then, the distances between the central line and the individual points in the surrounding area of the central line were calculated in the same manner as was the path of insertion. If the lower point was farther away from the central line than the upper one at the same angle, the x- and y-coordinates of the lower point were adjusted to be the same as the upper one. Thus, the components avoided entering the undercut area.

Results

RPD frameworks of the two scanned partially dentate casts were designed easily with the new design module (Fig 7). The entire design process took approximately 30 minutes for each framework. The completed models were stored as STL files, which are commonly used in transferring CAD/CAM models to rapid prototyping technologies.

Fig 8 **(left)** Virtual RPD framework and supports prepared for building. **(center)** Metal frameworks emerging from the SLM machine. **(right)** The RPD frameworks fit to the casts.

Discussion

The new design module based on the Tang Long CAD system was developed specifically for designing RPD frameworks. The software has a user-friendly interface and is easy to use. In this procedure, it takes the clinician only a few minutes to survey the model electronically. The scanned data can then be transferred to a remote laboratory for framework design.

An example of one of the drawbacks of this software is that it is impossible to discern automatically the edge of the rest seat on the point cloud because the program cannot differentiate between points. Nevertheless, the edge of the rest seat could be discerned visually, because the scanned model can be rotated and viewed clearly from any angle on the screen, just as with the real physical cast.

Selective laser melting (SLM) technology is based on CAD/CAM design, which has attracted great attention among researchers for its rapid fabrication of high-precision metal parts with different materials and shapes.[3,4] To manufacture the virtually designed RPD framework, the authors are exploring developing an SLM machine with the appropriate parameters for RPD framework fabrication. The finished CAD/CAM data were imported into the SLM machine. Supports were added to the RPD model using Geomagic (Raindrop) to help conduct heat away from the build area and to prevent movement during the building procedure. The metal RPD framework was built successfully using this technique, and the RPD frameworks were deemed to have a satisfactory fit by visual inspection (Figs 8 and 9) and pressurizing the framework to detect whether there was movement, methods used on a daily basis when fitting RPDs to patients. To assess more objectively the accuracy of fit of RPD frameworks, the authors are exploring methods of scanning the completed frameworks for comparison with the original build in the virtual environment. The time it took to fabricate one framework was less than 1 hour. However, the optimization of the processing parameters has not been completed and research is still underway.

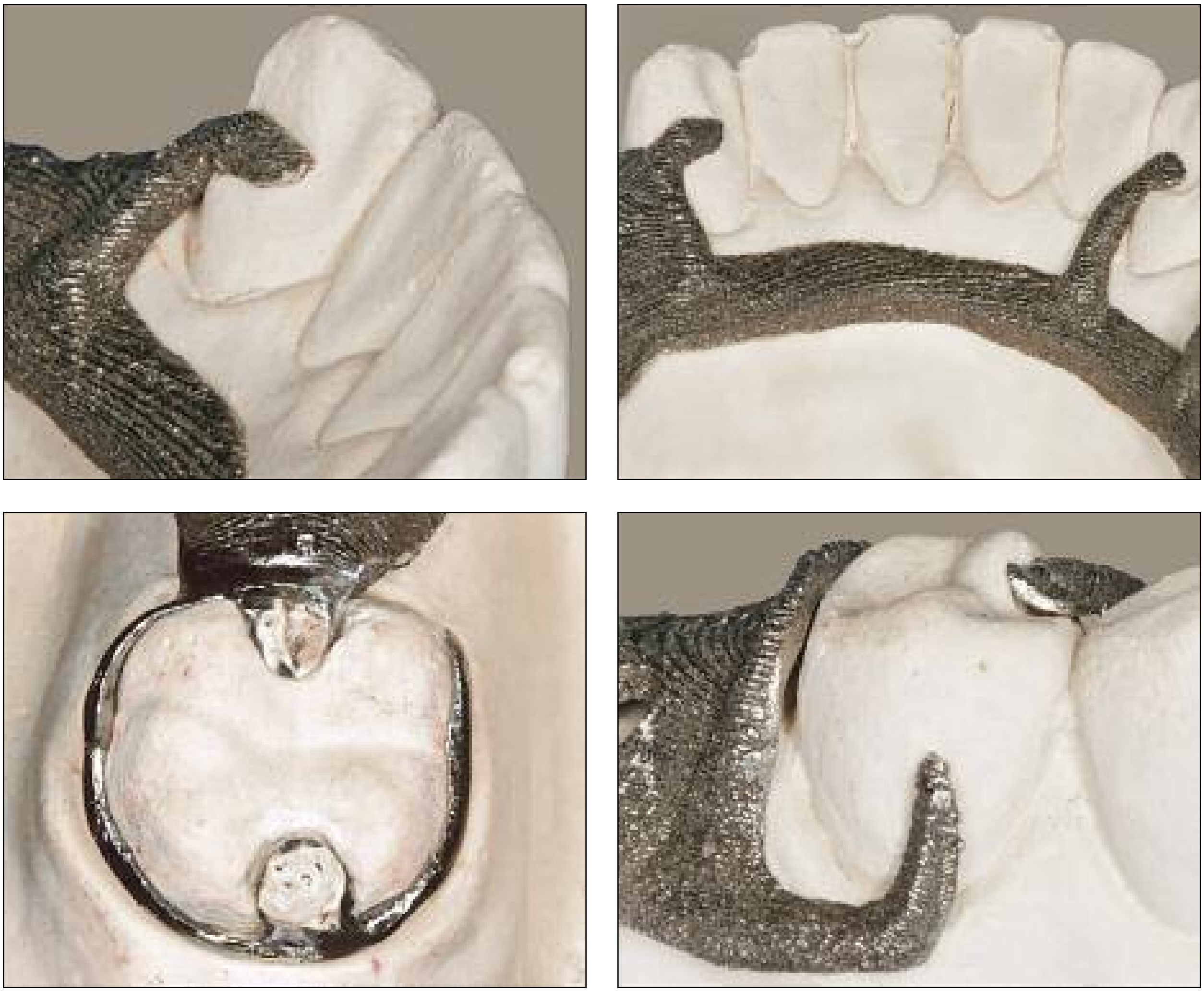

Fig 9 Close-up views of the metal RPD framework fit to the original mandibular cast.

Conclusion

The generation of RPD frameworks was analyzed. In practical application, the operation is much simpler than explained here; the software "fills in the spaces" between components. However, every component needs to be modified using the tools the software provides to meet RPD design requirements and obtain a satisfactory shape. The current technique has saved many conventional complicated and time-consuming procedures and makes the design of an RPD simpler and faster. It could therefore gain new clinical applications. However, further studies are necessary to validate and prove the effectiveness of the software described.

Acknowledgments

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