ISSN NO. 2320-5407

Journal homepage: http://www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH

RESEARCH ARTICLE

Novel 3D Modeling Technique of Removable Partial Denture Framework Manufactured by 3D Printing Technology

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Manuscript Info

Manuscript History:

Received: 25 July 2014
Final Accepted: 29 August 2014
Published Online: September 2014

Key words:
Digital RPD manufacturing, RPD 3D modeling, 3D printing, Prototyping.

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Abstract

The objective of the present study was to digitize the removable partial denture framework construction using a combination of simplified novel modeling technique and a 3D printing prototyping technology. A partially edentulous stone cast was selected representing mandibular Kennedy class I. The cast was optically scanned using desktop structured light scanner and the generated 3D model data was be exported as STL file then imported to universal reverse engineering software. The cast was digitally surveyed according to the selected path of insertion then all undesirable undercuts were selected, removed and blocked by flat surfaces. A stress releasing design for mandibular class I Kennedy was considered then the components were drawn and cut, as a thin shell, from a 3D model duplicate. Each component was offset outside the 3D model surface to a distance equivalent to its required relief. The framework volume was then created by thickening the shell surface followed by smoothening. Finally, the framework was fine-tuned using sculpt tool. The final framework 3D model was generated layer by layer using the 3D printer machine. The final framework was checked on the stone cast for error and fitness. The final outcome of the current technique produced precise and well-fitted removable partial denture framework using simplified, rapid yet accurate technique of modeling.

Introduction

Removable partial denture is an indispensable treatment option for certain situations. Although various materials and techniques were developed in the laboratory dental field, the conventional metallic removable partial denture manufactured by lost wax technique is still used. This old technique is successful however it's inherited drawbacks. The conventional technique is time consuming, requires multiple steps and technique-sensitive. It should be noted that, more steps used, more chance for errors and ill-fitting denture (Phoenix, et al., 2008). (Rudd & Rudd, 2001a, 2001b, 2001c) reviewed and categorized 243 errors possible during the fabrication of a removable partial denture. Their three-part articles are considered a very good guide for all practitioners, students, and laboratory technicians to review all possible errors and recognize their solutions. They clarified that avoiding errors by good technique is easier than their treatment. In addition, they confirmed that errors are cumulative and so may result to denture remake.

Nowadays, the CAD CAM technology became one of the most important developments happened in the dental field at the twenty-one century. The manufacturing of dental restorations and devices using CAD CAM subtractive behavior was successful in many situations and so used widely in tooth or implant-supported fixed prosthodontics and operative dentistry. Consequently, all dental labs started to shift their services to the digital manufacturing where less material consumed, saving time and effort and capability of mass production (Beuer, et al., 2008; Kapos et al., 2008; Strub, et al., 2006).

Further, the additive rapid prototyping technologies can fabricate organic complex configurations which were very difficult to be milled with subtractive method. Consequently, it is suitable for human anatomy structures and highly-detailed prosthetic appliances such as removable partial denture (RPD), complete denture, maxillofacial prosthesis and implant surgical guide stents (Beuer et al., 2008; Ciocca & Scotti, 2004; Kurtulmus, et al., 2008; Sun, et. al., 2009). This innovative method relied on what is called "Layered manufacturing" where a 3D standard triangulation language (STL) file of an object decomposed into cross-sectional layer representations and then an automated fabrication machine will receive the numerical inputs of these configurations to form the prototype. In this way, additive methods are more advantageous and many problems, usually accompanied milling, can be easily overcome. The ability of the additive prototyping technique to create minor details such as undercuts, voids, and complex internal geometries which is lack even in milling machines with multiple-axes (Azari & Nikzad, 2009).

RPD frameworks could be fabricated by prototyping indirectly using polymer powders through 3D Printing technology or directly using metal powder through Direct Laser Sintering technology (Bibb, et al., 2006; Venkatesh & Nandini, 2013). 3D printing is a unique prototyping technology it differs from other rapid prototyping methods in two important aspects. The first distinction is the relatively low cost of machines and materials. The second major difference is that 3D printers seamlessly integrate with computer-assisted design (CAD) software and other digital files like magnetic resonance imaging (Berman, 2012).

To enrich the digital manufacturing of the RPD many companies of the dental products invested a lot of money in CAD modeling softwares to get their own specialized one and facilitate the digital steps of RPD production for both dentists and technicians. However, one of the main obstacles that add cost to the digital manufacturing of the RPD framework is the cost of the modeling software that enable surveying, block-out of the undercut and designing the components (Schwab, 2014; SensAble, 2014).

(Bibb et al., 2006; Williams et al., 2006) used a specialized CAD modeling software and a haptic device in conjunction with various prototyping technologies to produce RPD framework. The outcome product was very promising and resulted in RPD frameworks that are comparable in terms of accuracy, quality of fit and function to the conventional technique used in the dental technology laboratory. They also mentioned that digital designing and manufacturing enable excellent values in terms of reproducibility, time saving and reduced materials consumption than the traditional technique.

(Eggbeer, et al., 2005) succeeded to use common CAD modeling software to design RPD framework over a 3D scanned cast. They confirmed that from the actual effectiveness, the quality and precision of fabricated RPD framework could completely meet the clinical needs, though sometimes it required minor adjustment to fit the patient's mouth perfectly.

Furthermore, (Han, et al., 2009) extended the previous experience by using a customized new three-dimensional 3D computer-aided design/computer-assisted manufacturing CAD CAM software package developed specifically for RPD design for digitally survey, remove undercuts and build virtual patterns for removable partial denture frameworks. Finally, metal RPD frameworks were fabricated using a selective laser melting technique. They claimed that their software procedures were simple but suggested further studies to validate and prove the effectiveness of the software described.

Moreover, (Wu et al., 2012) relied on using CAD and NURBS modeling software to design RPD frameworks on a modified 3D scanned cast. The model was digitally surveyed, undercut was removed, and then relief space was generated. Based on their idea, they recommended creation of the universal component library in the future to enable both dentists and technicians to customize various components that fit their RPD. (Lang & Tulunoglu, 2014) reviewed many articles represented digital technique and reported that as with any innovative technology, clinical studies to support its use must be undertaken. They also added that currently no clinical outcomes research has been published to support the use of CAD/CAM RPDs.

The present study was conducted to offer new and simplified RPD modeling technique in order to facilitate digital manufacturing of the rapidly prototyped denture. Neither special dental software package nor specialized hardware input devices were required.

Materials & methods

Cast selection and scanning

A silicone-based replica of mandibular class I Kennedy classification (missing 36, 37, 46, and 47 teeth) was poured by hard stone material using vacuum mixing machine. After cast hardening and removal, the cast was checked for air bubbles.

The cast was fixed on the scanner table and was scanned using desktop structured-light 3D scanner (Kavo scanner pro, Kavo Dental, Germany). The measurement precision of the scanner was 20 μm with an absolute ratio 1:1. The 3D model was aligned and the polygon mesh was tuned automatically. Finally, the 3D model was exported as STL file format, (fig.1A, and B).

RPD Design planning

The simplest design of a class I mandibular RPD was selected with a default strategy of stress-releasing design. The design included all essential components that fulfill support, retention, bracing, reciprocation, and connection. Two free-end saddles connected with lingual bar were selected according their structural specifications. In addition, two RPI clasps were added on the abutment teeth (35 and 45) included mesial rests, proximal plates, and I-bar retentive arm. Additional rests were added on the distal side of the neighboring teeth (34 and 44). Finally, occlusal rests were connected to the lingual bar major connector; on each side of the arch, through minor connector.

Cast surveying and modification

The 3D model was imported to a reverse engineering software (Geomagic Studio 2012, Raindrop, Research Triangle Park, NC, USA) followed by selecting the lateral view to see the side of the model. The path of insertion of the RPD was selected through anterior tilting of the 3D model in the sagittal plane. The model view was then shifted to top view where the entire model undercut areas became invisible. Using the select all visible order followed by inverse selected, the entire undercut areas became selected as red highlighted, (fig.2).

All selected areas were then removed and filled with flat areas free of undercuts except for small areas of undercut used for clasp retention on the buccal surface of the abutment teeth (specified as desirable undercuts). The cast was ready at this step to draw the predetermined design directly on the model that was duplicated and be used as a medium for RPD components creation, (fig. 3, A&B).

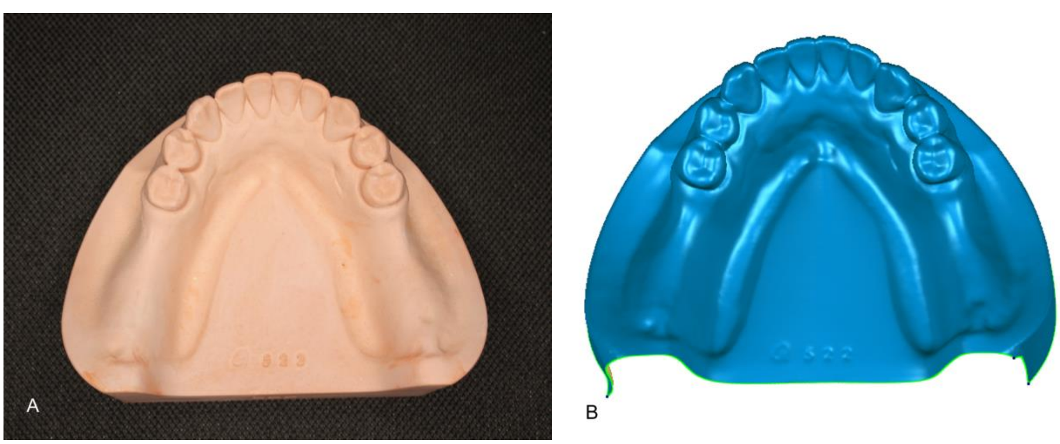

Fig. 1: A; stone cast of the selected studied model representing class I Kennedy. B; 3D model of the cast was scanned using structured-light 3D scanner.

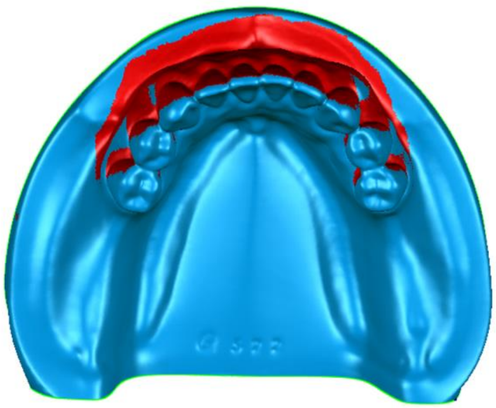

Fig. 2: Undercut areas relative to the proposed path of insertion were selected.

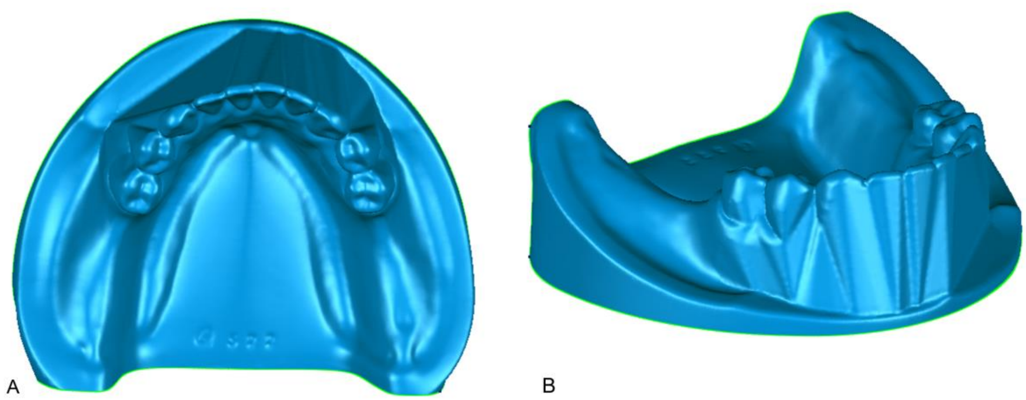

Fig. 3: A, Top and B, isometric views of the model after undercut blockage with flat areas.

Creation of RPD components

A pen-tablet was used as an input device to facilitate designing process. Using the trim with curve tool, simplified shaped-saddles were drawn bilaterally and cut from the model as two thin shells, (fig. 4). The formed saddle shells were then offset outside the model surface by 0.5 mm to represent saddle's relief (i.e. gauge 24 relief wax), (fig. 5).

Using the same concept the lingual bar was drawn with 4 mm width and 3 mm below the free gingival margin and from which two minor connectors were cut one between teeth 34 & 35 and the other at 44 & 45. All connectors were then offset outside the model by 0.25 mm to represent connectors' relief (i.e. gauge 30 relief wax). The I-bar clasps were also cut buccaly according to their configuration using 0.25 mm relief offset. Finally, small parts were cut to connect saddles and lingual bar with extended part forming the proximal plate, (fig. 6).

The next step was converting the surface components into a solid volume. The surfaces were thickened by shell tool to form 2 mm thickness in outside direction. The RPD framework was formed but with sharp angles (90˚) at peripheries, (fig. 7). All sharp angles were then smoothed at peripheries while keeping the framework configuration using smoothing tools, (fig. 8). Finally, some sculpt operations were performed to adjust lower border of the lingual bar, stopper areas at the saddle end and occlusal rest areas, (fig. 9A).

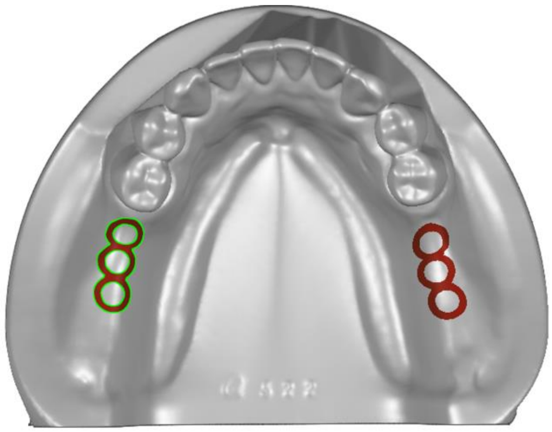

Fig. 4: Saddles were cut from model duplicate as thin surface shell.

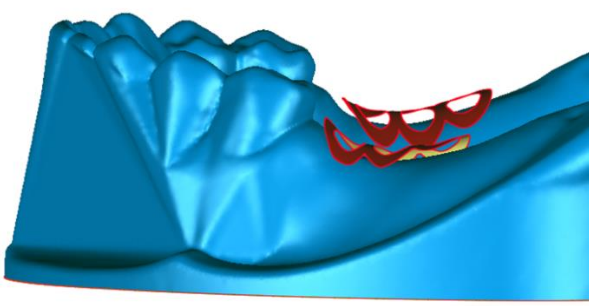

Fig. 5: Saddle shell (in red color) offset by 0.5 mm outside the model bilaterally.

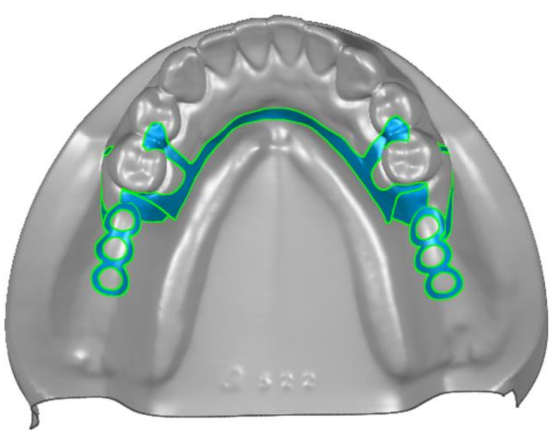

Fig. 6: Full design of the RPD components (blue color) created as thin surface relieved from the model surface.

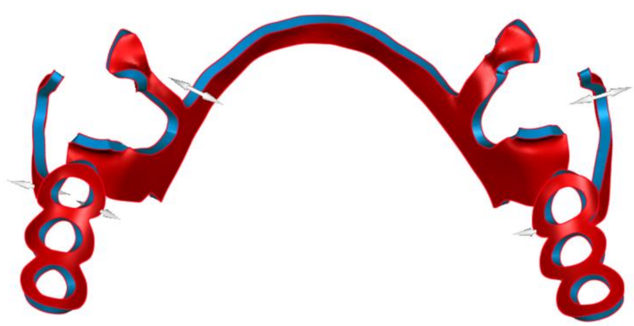

Fig. 7: RPD volume creation from surface using shelling tool, while arrows showed offset direction.

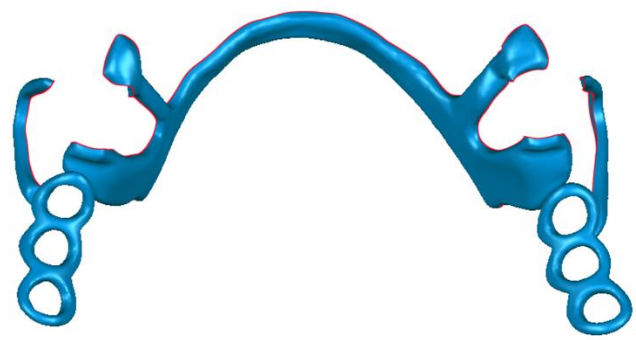

Fig. 8: Smoothening of the sharp angles of the designed framework after creating the volume.

3D printing of the framework

Before 3D printing of the framework, the 3D model was sliced into layers (0.06 mm layer thickness) using the software controlling machine (EOS PSW, EOS RP Tools, EOSTATE, Germany) then production process started by the 3D printing machine (EOS P 396, EOS GmbH, Germany). The CO_2 laser type generated framework from polymer power at 70 watt to sinter the polymer into a solid form with layer-by-layer sequence. The solidified framework was then removed and cleaned, (fig. 9B) ("EOS system data sheet EOS P 396,").

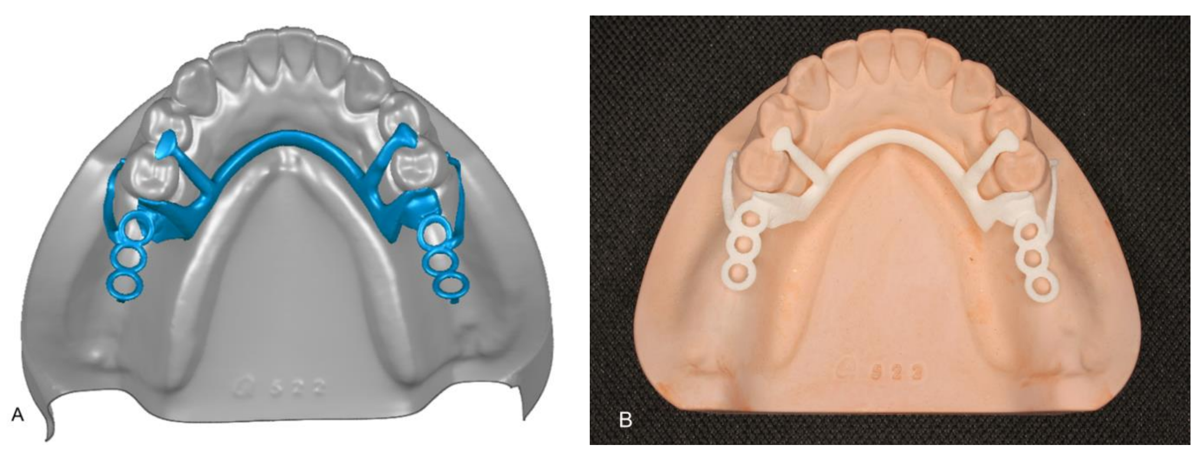

Fig. 9: A; representative of the final 3D model before import to the machine's software. B; 3D printed framework placed on the stone cast

Results & Discussion

The outcome product of the current technique is an accurately well-fitted RPD framework. All procedures used were simple and did not require experienced operator. In addition, the whole steps were timesaving and reduce overall materials consumed during RPD framework production. If a 3D printing service was used, the cost of the RPD prepared from 3D printed framework was approximately equal to those prepared by conventional technique. It should be noted also that 3D printing technology is much cheaper than other rapidly prototyping techniques, (Berman, 2012).

The use of digital surveying was a simple, fast, and precisely determined operation. The role of surveyor and conventional tools like analyzing rod, carbon marker, and wax trimmer were combined into two simple steps; selecting undercuts and blocking them with flat surfaces. Both arbitrary and paralleled block-outs were performed automatically as one-step. Moreover, no need for shaped block-out as its functions becomes unnecessary. This finding coincides with (Wu et al., 2012) and (Han et al., 2009), as they applied digital surveying and block-out and excluded the need of shaped and arbitrary block-out. (Wu et al., 2012) typically used the same reverse engineering software for digital surveying and block-out process while (Han et al., 2009) used a specifically developed CAD modeling software package for the same function. In addition, (Williams, et al., 2004) developed a new plugin written using MATLAB softwares and especially designed for this purpose. On the other hand, (Eggbeer et al., 2005) neglect both procedures during building of their digital framework.

Moreover, the RPD framework components were customized manually through hand drawing. This option is not available as a tool for commercial software (Schwab, 2014; SensAble, 2014). Although this option could require more time to start building components, it enables users to finalize the whole framework in a few minutes. It also facilitates good merging of the designed components.

The use of controlled surface offset using shell tool was used to exchange the conventional virtual creation of relief wax and enable visualization of the relieved space between the cast and the framework. Accordingly, this method facilitated relief process and enabled effective relief at no time. Finally, the use of sculpt and smoothening tool matched the function of adding and removal of wax in the conventional commercial softwares (SensAble, 2014) (Schwab, 2014) (Williams et al., 2006).

The main difference between the current technique of modeling and the (Wu et al., 2012) and (Han et al., 2009) techniques' was the direct use of the 3D cast mesh as a medium for modeling and building the RPD framework in the current technique. On the other hand, their technique required conversion of the 3D model mesh into CAD surface before using a universal CAD modeling softwares. Moreover, they also relied on using surface modeling with their usual building commands like (sweep, loft, extrude .etc.) using sketch planes. This manner of modeling is suitable for solid engineering models and not so, for models with organic or complex shapes that requires more time and effort. Unless the components library; using drag and drop, are considered as in the commercial software, the use of their technique will be impractical and time-consuming.

Based on these findings, the current technique offers a smooth and easy way for simple user. The main concern during using this technique will be the correct and accurate drawing of the RPD components based on the good prosthetic knowledge regarding the mechanical and biological considerations of components configuration and location.

Further studies concerned with clinical application of the present technique are recommended, especially with more complicated designs and cases, and compared to the commercial CAD/RP techniques. Another recommendation is fully digitizing the RPD framework production by the use of direct laser sintering technique (DLS). Although (DLS) technique will be timesaving, it will add more cost to the outcome. Currently, prototyping using metal powders using Titanium, Chromium Cobalt, and Stainless steel are available for rapid prototyping technology. Although, the use of such metal powders for human, through prototyping manufacturing, was not supported by biocompatibility tests (Lang & Tulunoglu, 2014).

Additionally, (Kibi et al., 2009) extended their research to include stress-strain analysis for the CAD RPD before their fabrication which enriched the overall value of the digital manufacturing method. Consequently, once this tool enabled as an ordinary step during digital manufacturing, this technology will be indispensable.

Conclusion

The integrated CAD/RP technique for RPD framework manufacturing becomes a popular successful alternative to the conventional technique. The use of digital model as a base for modeling frameworks after their modification is a successful technique for RPD framework manufacturing. Accordingly, the current technique offers a simple, fast, and precise method for RPD manufacturing. Further clinical trials should be considered to validate their clinical use.

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