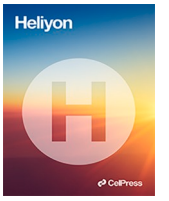
Heliyon 9 (2023) e16168

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon



Case report

Digital fabrication of complete dentures using a combination of additive and subtractive manufacturing technologies

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ARTICLE INFO

Keywords:
Complete dentures
CAD/CAM
Case report
Digital

ABSTRACT

Fabrication of complete dentures in the traditional way is a labor-intensive and time-consuming method. This article reports a series of novel digital methods for impression making, design and fabrication processes for complete dentures. It is highly anticipated that this novel method could improve the efficiency and accuracy of the design and fabrication of complete dentures.

1. Introduction

It is well accepted that complete dentures are the first choice for mostly edentulous patients. However, the complicated processes in the fabrication of conventional complete dentures contribute to human processing errors and inaccuracies [1,2].

With the development of digital technologies in recent years, the fabrication of complete dentures has shown better accuracy and efficiency than dentures manufactured by conventional techniques [2,3]. However, some protocols should be improved. For example, some complete denture systems use the 1-step impression technique, which may improve efficiency but lacks accuracy and border extension compared with the traditional method [4]. Even if the metal base or framework can be fabricated automatically, the injection molding technique is essential for making final complete dentures, which is itself a labor-intensive process. Furthermore, in some cases, fractures occur at the attachment area of the resin to the metal base plates, where the stress is concentrated.

Therefore, to simplify the traditional protocol and eliminate fractures caused by stress concentration in complete dentures, a novel digital method was proposed. A custom tray and diagnostic dentures were first designed to make impression and occlusal relationships accurately and efficiently. The final complete dentures with new structures were designed and fabricated by the selective laser melting (SLM) method, which shows good accuracy and avoids fracture.

2. Clinical report

A 50-year-old male with edentulous dentition presented to the Department of Prosthodontics at Stomatological Hospital, ** Medical University, requesting complete dentures to restore masticatory function. An oral examination showed that the alveolar ridge was mildly absorbed [Fig. 1A, B]. Prior to clinical treatment, informed consent was obtained from the patient, and the following clinical procedures were approved by the Institutional Review Board of the Hospital.

First, a novel maxillary tray was made with occlusal rims in the posterior area, and grooves were shaped on the rims [Fig. 2A].

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https://doi.org/10.1016/j.heliyon.2023.e16168
Received 11 January 2023; Received in revised form 28 April 2023; Accepted 9 May 2023
Available online 11 May 2023

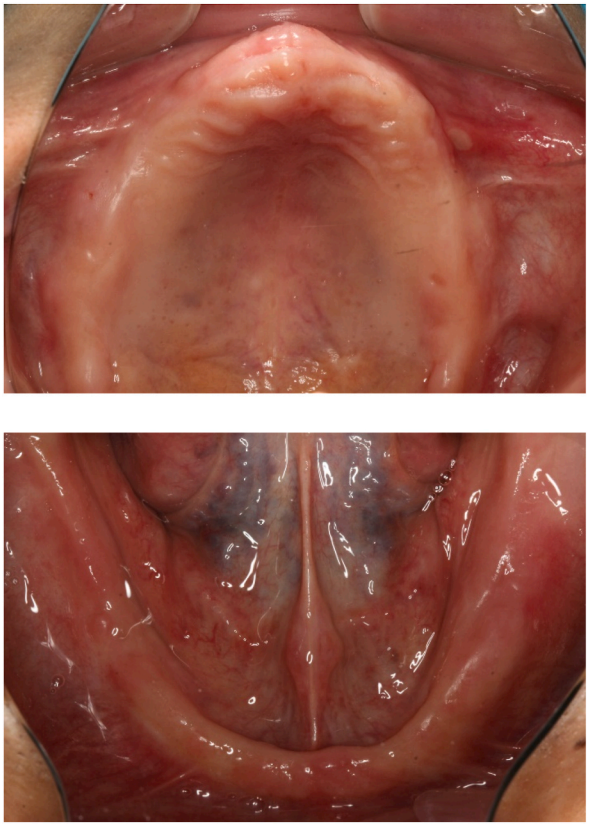

Fig. 1. Unrestored, edentulous condition of the patient. A, Maxillary edentulous arch. B, Mandibular edentulous arch.

Then, a silicon impression material was injected on both the maxillary tray and the occlusal rims. The novel maxillary tray was inserted, and the patient was instructed to bite directly on the mandibular alveolar ridge with an appropriate vertical distance, thus acquiring a primary maxillary impression with a jaw relationship record [Fig. 2B]. Next, the primary mandibular impression was made with the silicon impression material. The obtained preliminary impressions and jaw relationships were scanned (Dental System D900, 3Shape) and saved in standard tessellation language (STL) format. With the overlapping method, primary digital casts with primary jaw relationships were constructed [Fig. 3A]. Based on this, digital diagnostic dentures [Fig. 3B] were designed and fabricated with polylactic acid by the 3-dimensional printing (3DP) method [Fig. 3C].

On the second visit, the diagnostic dentures were inserted into the patient's mouth to verify the interocclusal relationship, stability and aesthetics. The borders of the diagnostic dentures were then functionally molded, and the closed-mouth technique was applied to make definitive impressions and interocclusal relationships with a soft polyether impression material [Fig. 3D]. With a digital scan, the final digital casts were built, and virtual complete dentures were designed [Fig. 4A]. After that, with CAD software, the data of teeth were partially removed with the cut back function, and the amount of the removed part was determined according to the standard tooth preparation. Next, new base plates with abutment structures and crowns were formed, respectively. Moreover, in the aesthetic zone, a rough surface was created on the labial side for aesthetic reconstruction [Fig. 4B, C]. With the selective laser melting method, novel titanium alloy base plates were fabricated and annealed by heating and holding at 800 °C for 4 hours, then slowly cooling in an argon environment. After removal of the supports and polishing, the base plates were finished [Fig. 5A, B]. The resin crowns were milled and bonded on the base retainers. The gingival shape was reproduced by bonding the ceramage gum color on the rough surface to complete the dentures. The dentures were delivered to the clinic on the third visit [Fig. 6]. An experienced dentist assessed the quality of fit of the complete dentures in the patient's mouth according to recommended standard practice, and the dentures were finally fitted for the patient functionally. And a satisfactory aesthetic effect was also achieved [Fig. 7A, B]. After 3 years, the patient re-visited to the clinic and routine examination was undergone. The dentures were in good hygiene status, except for small amount of tea stain on the margin of gingiva [Fig. 8(A-D)]. And the dentures still showed favorable esthetics [Fig. 9A] and retention after 3-year wearing [Fig. 9B].

3. Discussion

This article describes a novel method in impression making, design and fabrication of complete denture with digital method. With a newly designed custom tray, the primary impression with suitable occlusal relation is recorded and reconstructed digitally. Based on

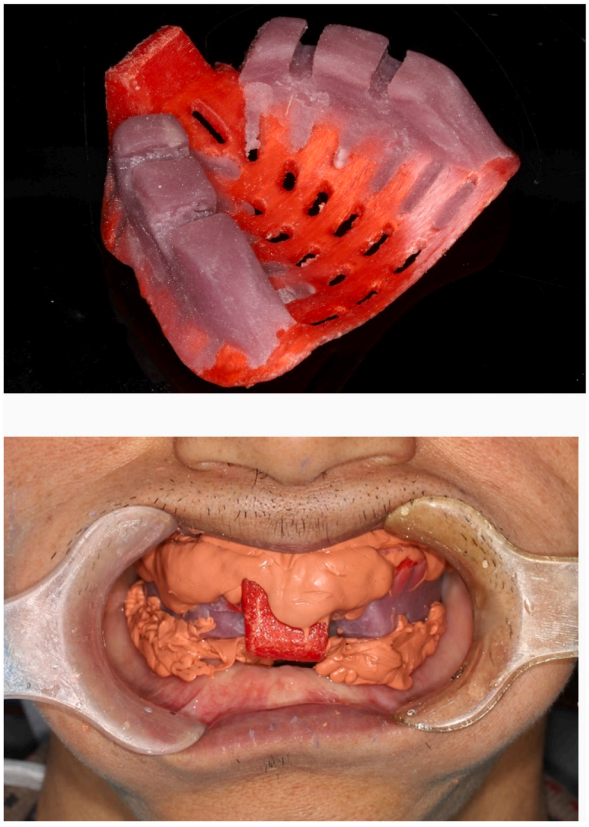

Fig. 2. Design of a novel impression tray and make impression with primary occlusal relationship. A, The novel impression tray with occlusal rims. B, Make impression with primary occlusal relationship.

this, a pair of diagnostic dentures is digitally designed and fabricated. With diagnostic dentures, the final occlusal relation and aesthetic effect could be evaluated and confirmed. In addition, the diagnostic dentures are also be used as custom tray with border molding technique, and the definitive impression was finally made by closed mouth impression technique. In this way, the margin of the impression tray and the true position of the labial and buccal flanges can also be recorded [5]. Moreover, the application of a closed mouth impression is similar to the surface of the mucosa when masticating food with a definitive denture. Therefore, in this way, the fit of the complete dentures could be improved, causing minimal tenderness [6].

Selective laser melting (SLM) technology is becoming increasingly widely used in fabricating frameworks or base plates of removable dentures due to its ability to produce complex-shaped metal objects directly from CAD data [7–9]. However, traditional manual steps, including waxing, tooth arrangement and flasking, are needed, which may lead to quality vibration of the final dentures. Therefore, in this article, based on digital complete dentures with stable occlusal relationships, the tooth data were cut back evenly in CAD software according to the standard tooth preparation protocol, and a novel base plate with abutment structures was reconstructed. Next, the crowns were digitally designed and fabricated with accurate occlusion, and traditional manual errors in waxing were avoided as much as possible. Additionally, to improve the aesthetic, the labial parts of the metal base plate were roughly designed, and ceramage gum was bonded to mimic the gingival shape and color.

As we know, for past decades, the acrylic resin is still widely used as base plate of complete denture for the convenience of operation and repair. But the weak mechanical strength sometimes led to fracture. Therefore, because of low density, high specific strength and good corrosion resistance, titanium base plate is used extensively in complete dentures. However, defects and inaccuracy generated in the traditional lost-wax-casting technique call for new methods. With the application of SLM, several studies have demonstrated that the mechanical properties and microstructure of additive manufacturing components are better than those obtained using conventional casting procedures, indicating SLM fabricated titanium base plates are appropriate for clinical use denture [10–12].

For this patient, the complete dentures with titanium alloy base plates showed excellent retention. In addition to the accurate impression made using the closed mouth technique, the application of SLM may be another important reason. Unlike the casting process, additive manufacturing of SLM fabricates titanium alloy by layering thin layers of metal powders, which leads to superior precision and fitting accuracy [13,14].

In addition, cost-effectiveness is also a very important factor that should be concerned. Despite the cost of SLM fabricated titanium alloy base plate is higher than that of acrylic resin base plate. But the time we spent during CAD/SLM process can be shorten to 1–2 hour in CAD and 7–8 hour in SLM. The whole process saved much time compared to the traditional labor-intensive process including

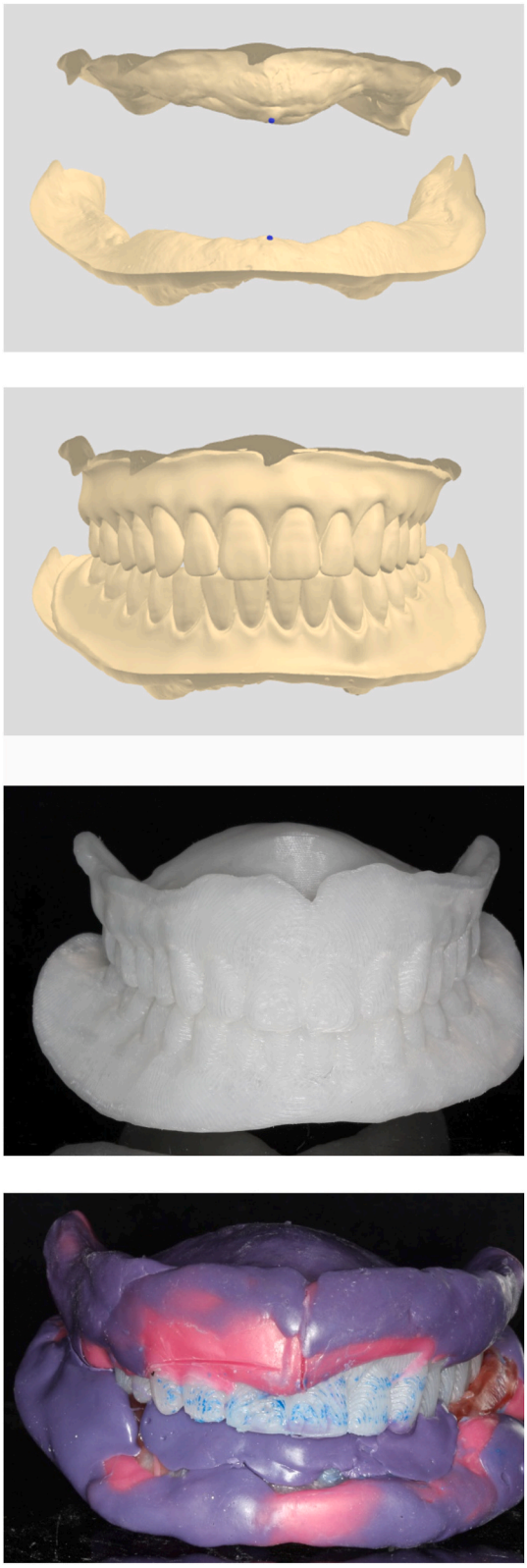

Fig. 3. Digital design and fabricate diagnostic dentures, and make the definitive impression with closed mouth technique. A, Primary digital impression. B, Digital design diagnostic dentures. C, Fabricate resin diagnostic dentures with 3DP method. D, Make the closed mouth impression with diagnostic dentures.

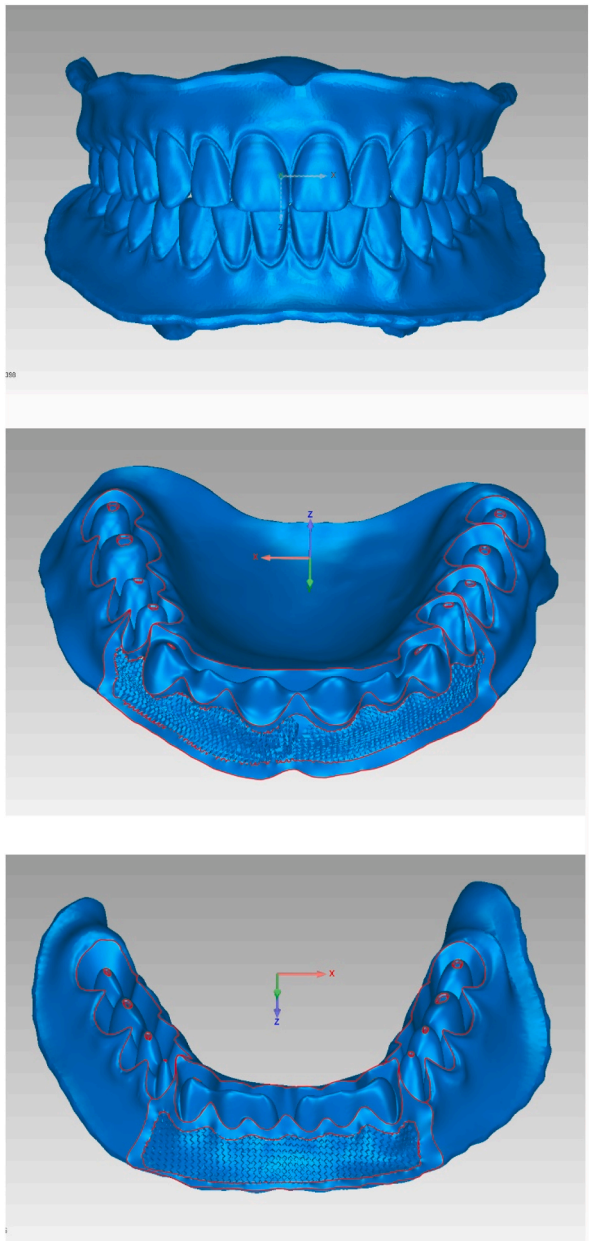

Fig. 4. Design of digital complete dentures and base plates. A, Digital complete dentures. B, Maxillary base plate with abutment structures and rough surface. C, Mandibular base plate with abutment structures and rough surface.

Fig. 5. Fabricate the titanium alloy base plates with abutment structures by the SLM method. A, Maxillary base plate. B, Mandibular base plate.

Fig. 6. Fabricate the final complete dentures by bonding milled crowns on the abutments and ceramage gum on the rough surface.

wax-making, investing and casting, which always takes two to three days to complete. It is believed that the SLM method will become more efficient and economical with concomitant reductions in cost in the future.

Furthermore, with absorption of alveolar ridge, relining/rebasing is sometimes used in clinic to seal the gap between inner surface of the base plates and alveolar ridge mucosa. In this case, the pure titanium alloy base plates were digitally designed and fabricated with SLM method. With pure titanium alloy base plate, less chance of fracture can be achieved but is difficult for resin bonding on the smooth titanium alloy surface. Therefore, before relining/rebasing, several small holes could be drilled on the inner surface of the titanium alloy base plate. Thus, the rebasing resin can be strongly bonded on the surface of the titanium alloy base plate. Also, sand blasting will improve the bonding strength between resin and base.

The hygiene maintenance of the complete denture is another important issue to be considered. For this patient, except for the

Fig. 7. Deliver the novel complete dentures to the patient. A, Dentures in the mouth. B, Front view of the patient with dentures.

routine operation on denture, a denture cleaning tablet is daily used to reduce the adhesion of microorganisms. Besides, SLM method may also play an important role in anti-bacterial adherence. Researchers found the better bacterial resistance of SLM fabricated titanium specimens than that of casting and milling titanium, because SLM group had more TiO_2 percentage (40.82%) than the casting (34.41%) and milling (34.74%) groups. And TiO_2 could effectively reduce the adhesion of microorganisms [15,16]. In a word, it is highly anticipated that SLM should an ideal process to produce titanium base plates for dentures.

4. Conclusion

This article describes a novel digital method for the design and fabrication of a complete denture with efficiency, accuracy and aesthetics.

Author contribution statement

All authors listed have significantly contributed to the investigation, development and writing of this article.

Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Fig. 8. Hygiene condition of complete dentures after 3-year wearing. A, Occlusal view of upper complete denture. B, Front view of upper complete denture. C, Occlusal view of lower complete denture. D, Front view of lower complete denture.

Fig. 9. Clinical examination of complete dentures after 3 years wearing. A, Front view of the patient with dentures. B, Favorable retention of complete dentures.

Acknowledgements

This work was supported by the Project of National Clinical Research Center for Oral Diseases (No. LCB202007).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e16168.

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