Custom fabrication of try-in wax complete denture

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Abstract

Purpose – The use of removable complete dentures is a selectable restorative procedure for edentulous patients. To improve the fabrication quality and efficiency of removable complete dentures, this paper aims to introduce a new method to fabricate customized wax complete dentures with additive manufacturing. This process uses complementary digital technologies, and allows faster and better manufacture of complete dentures.

Design/methodology/approach – In the study, a dental scanner was used to obtain surface data from edentulous casts and rims made by the dentist. A parameterized three-dimensional graphic database of artificial teeth was pre-established. Specialized computer-aided design software was used to set up the artificial dentition and design the esthetic gingiva and base plate. A selective laser sintering machine was used to transfer the data from stereolithography files into a wax base plate with location holes for each artificial tooth.

Findings – Under this method, a set of wax base plates with 28 location holes available for the placement of the artificial teeth were designed and fabricated within 6 h. The try-in wax dentures fitted the patient's mouth well, besides occlusion relationships. Then, the occlusion relationships can be adjusted manually to achieve a balanced centric occlusion.

Originality/value – This method can be used to design and fabricate wax try-in removable complete dentures semi-automatically and rapidly; however, the algorithm for the occlusion contact design needs to be improved.

Keywords CAD, Rapid prototyping

Paper type Research paper

1. Introduction

China has more than 10 million edentulous patients (Qi, 2008). Complete denture implants have benefited many systematically healthy edentulous patients who can afford them, although the removable complete denture is still the primary solution for most edentulous patients.

It is commonly known that the different levels of experience and craftsmanship among technicians designing and fabricating complete dentures can result in variable treatment results. It is difficult to train each technician to master the same high level of experience and craftsmanship. However, use of the latest computer-aided design and computer-aided manufacturing (CAD/CAM) dental technologies allows for this possibility. Over the past 20 years, the benefits of applying digital technologies to dental clinical practice have indeed been proven (Yuan *et al.*, 2014; Rudolph *et al.*, 2007; Tinschert *et al.*, 2004; Richard, 2012). Using CAD/CAM for the design and manufacture of removable complete dentures makes it possible for complete denture experts to describe in great detail many of their more complicated techniques to other technicians. The high level of experience and craftsmanship of skilled technicians can then be dutifully repeated, even in remote areas of the country, to the benefit of any edentulous patient.

Lü *et al.* defined the teeth dentition curve with the power function $Y = A|X|B$ and created a "surrounding box" for the three-dimensional (3D) data of each artificial tooth (Lü *et al.*, 2006). Robot fingers were then used to position artificial teeth one-by-one onto a wax rim. No base plate was designed and fabricated in their study. Maeda *et al.* used a 3D laser scanner to obtain 3D data of artificial dentition and a base plate made by a dental technician (Maeda *et al.*, 1994). Additive manufacturing technology was applied to fabricate the individual flask of the complete denture, and the final

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complete denture was then finished after traditional packing. Selective laser sintering (SLS) is often used to generate conceptual models, precision and functional prototypes, master patterns for tooling and production parts for direct manufacturing (Lü *et al.*, 2006). In addition, SLS is used for the fabrication of surgical guides (Haese *et al.*, 2012). The physical process can involve full melting, partial melting or liquid-phase sintering. Depending on the material, up to 100 per cent density can be achieved with material properties comparable to those made using conventional manufacturing methods. A layer thickness of approximately 80-100 μm was ideal for developing a removable complete denture wax base plate. In the past few years, selective laser melting technology has also been used in several applications in dentistry. It has been used successfully for fabricating dental implants (Mangano *et al.*, 2012a; 2012b). Sun *et al.* explored the use of CAD software for designing a removable complete denture (Sun and Wang, 2009). Digital methodology and traditional denture materials were effectually combined to make a final removable complete denture, aided by CAD and additive manufacturing technology. However, a denture designed in this manner cannot be tried-in before the final fabrication, and trying-in is known to be a very important step in achieving a complete denture with the best fit. Our research describes the application of digital methods to the design and fabrication of a try-in removable complete denture for an edentulous patient.

2. Materials and methods

2.1 3D data acquisition

In the study, dental casts and wax occlusion rims of an edentulous patient were used. The patient had visited the Prosthodontics Division, Peking University Hospital of Stomatology (Beijing, China), and had undergone restorative treatment to receive removable complete dentures. The patient had undergone extraction of all teeth more than 3 months earlier and had well-rounded residual ridges.

Individualized impression trays were fabricated. Alginate impressions were then created and poured with die stone (i.e. scannable stone) to obtain the edentulous dental casts. Unnecessary portions of the casts were trimmed so that blind sections could be minimized during the subsequent 3D surface-scanning process. Record bases and occlusion rims were fabricated by using the conventional method (Feng and Xu, 2005).

To record the jaw relation, the maxillary record base was first placed into the patient's mouth and the occlusal plane was defined on the maxillary occlusion rim by using the Fox occlusal plane indicator (Feng and Xu, 2005). The mandibular record base was placed into the patient's mouth and the vertical dimension was determined by using the rest position method. The centric relation was then determined by using several direct interocclusal records and registered by using an interocclusal record material (LuxaBite; DMG Chemisch-Pharmazeutische Fabrik GmbH, Hamburg, Germany).

Using a D700 dental scanner (3Shape A/S, Copenhagen, Denmark), the following five steps were used to obtain 3D data of the crests and rims, and their respective spatial relationships:

1. Spray a layer of diffuse reflective powder on the upper and lower rims.
2. Scan the upper cast and rim (Data set I).
3. Scan the lower cast and rim (Data set II).
4. Scan the upper and lower rim in a centric relation as a whole (Data set III).
5. Register Data sets I, II, and III using Geomagic Studio 2012 software (3D Systems, Morrisville, NC, USA).

The casts recorded the anatomic shape of the edentulous alveolar crests and the post-dam zone that had been carved by the dentist in advance. The rims recorded the vertical distance and centric relationship, the position of the occlusal plane, the facial midline, the fullness requirements of the upper lip and other information. After 3D scanning and registration, a clear image of the surface morphology in a centric relation as required for the CAD process was obtained (Figure 1).

2.2 Denture CAD

2.2.1 Manual steps

The 3D data were input into specialized CAD software (Sun and Wang, 2009). Three points (one point must be the intersection point between the centric line of the upper rim and the incisal edge; all three points must not form a line) on the occlusal portion of the upper rim were defined, and the marginal lines of the base plate were created based on the data from the upper and lower edentulous 3D models. During the operation, the 3D models could be zoomed, rotated and translated freely, allowing the creation of the occlusal plane and marginal lines.

2.2.2 Automatic steps

Based on the occlusal plane data, the specialized CAD software can analyze the 3D shape of the crests and rims and determine their spatial relationships. Two curves on the tips of the upper and lower crests were constructed. The artificial teeth dentition curves, the fullness mark on the surface of the upper anterior teeth and the main direction of the crests were created. The artificial teeth were set up one-by-one. The proximal contacts were checked and adjusted to be near zero. The marginal gingiva and the polished surface of the base plate were created, and the root shape appeared indistinct on the polished surface. The surface inside the marginal lines was taken as the tissue-side surface of the base plate. A customized palatal wrinkle map was copied and transferred to the polished surface of the upper base plate. Finally, the 3D models of the base plates were finished with 28 tooth location holes. The internal surface of each location hole was a conjugate of the corresponding artificial tooth (Figure 2). If the spatial position or the orientation of any tooth required fine adjustment, a computer mouse and keyboard could be used to assist the operator (Figure 3).

2.3 Three packaging base plate data for additive manufacturing

The 3D data of the base plate were packaged using Geomagic Studio 2012 software. Small gaps in the complete denture data stereolithography file must be filled to achieve watertightness, which is absolutely vital for effective additive manufacturing.

Figure 1 The registration process of the upper and lower edentulous alveolar crests and rims and their spatial relationships

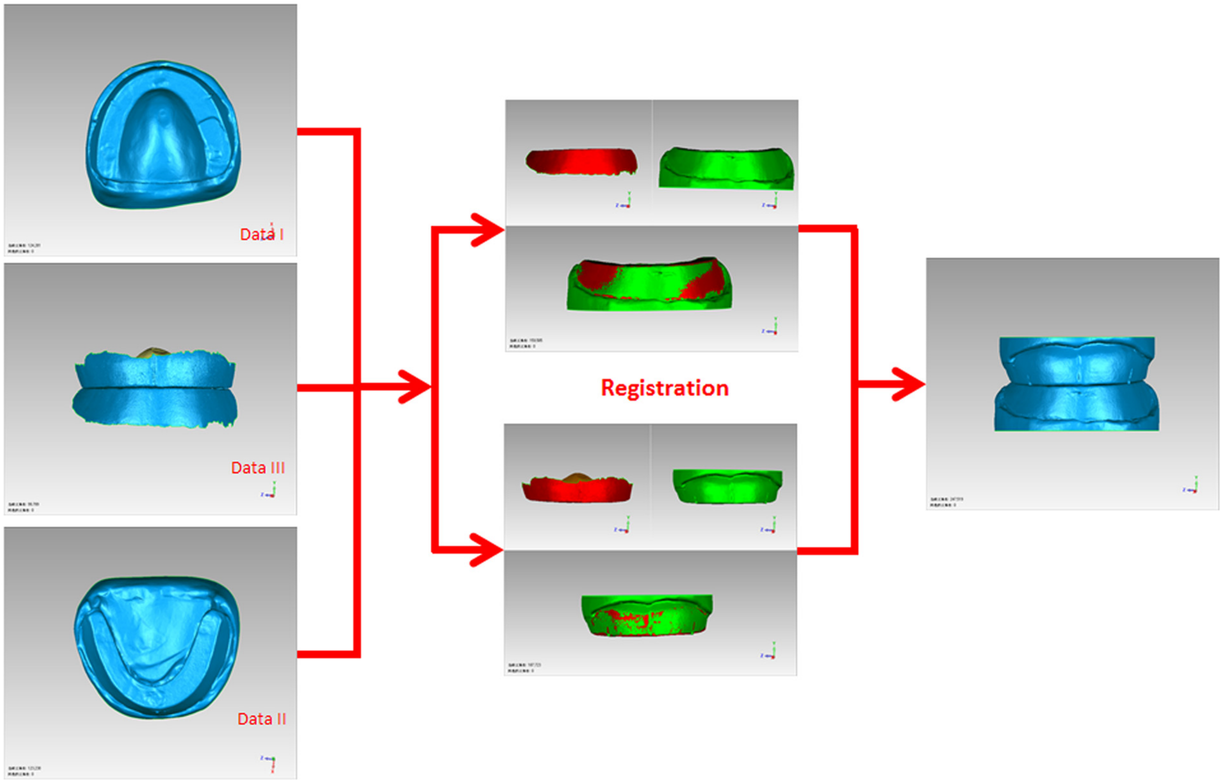


Figure 2 The procedure for the automatic design of complete denture

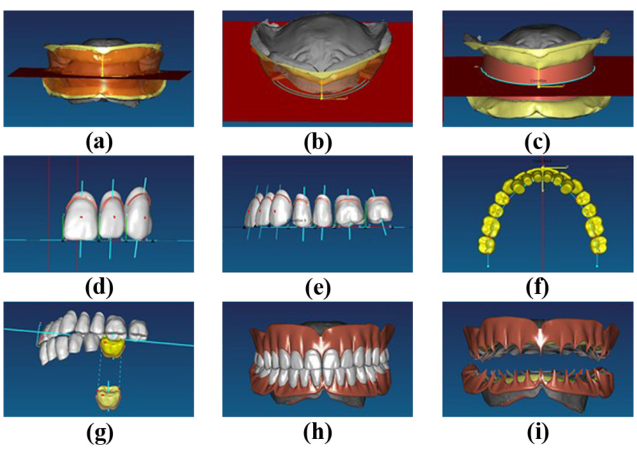
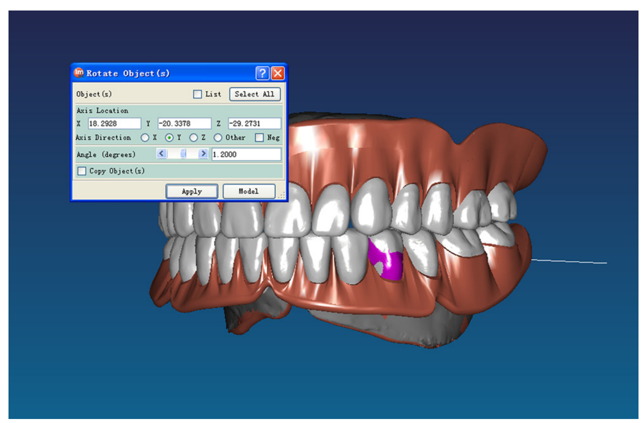


Figure 3 The manual micro-adjustment of the spatial position and orientation of any tooth is possible



2.4 Fabrication of the try-in wax base plate with a selective laser sintering machine

An AFS 360 automated fabrication system (Beijing Long Yuan Co., Beijing, China), a type of SLS machine with a laser power of 30-50 W, a resolution of 300 × 450 dpi, a layer thickness of 80–300 μm, a scanning speed of 2000 mm/s and a forming speed of 60-100 cm^3/h, and Magics RP data processing software (Materialise, Leuven, Belgium), were used to fabricate the wax base plate using a high-performance wax powder that has been proven suitable for transient or short-term use in the oral cavity without any toxic effects to humans. The fabrication accuracy of the whole system is about 100 μm. The CAD data were translated and printed on a physical, customized base plate of complete denture with 28 tooth location holes. The artificial teeth were then manually inserted into the base plate location holes.

2.5 Try-in of the wax base plate

The wax base plates with the artificial teeth were tried in the patient's edentulous casts and intraoral crests. After some adjustments, the final denture was made using a traditional handcrafting method (Feng and Xu, 2005).

3. Results

Using this method, two wax base plates (for the upper and lower jaw) with 28 location holes available for the placement of artificial teeth were designed and fabricated. The finished plates were a good fit for the edentulous casts. The artificial teeth were manually inserted into the location holes. The try-in wax dentures fitted the patient's mouth well, besides occlusion relationships (Figure 4). Then, the occlusion relationships can be adjusted manually to achieve a balanced centric occlusion.

4. Discussion

The AFS 360 (Beijing Long Yuan Co.) is a type of SLS machine that utilizes proprietary processes to fabricate physical objects using input from CAD files or 3D scanning and sculpting devices. SLS, a laser-based additive manufacturing technique, is achieved using mirrors to direct a high-power laser at a substrate that consists of a fine layer of powdered material. The beam creates a melt pool where it hits the powder, and the powder particles fuse together. After each cross-section is scanned, the powder bed is lowered by one layer of thickness, and a new layer of material is applied on top. The process is repeated until the part is completed (Zein *et al.*, 2002).

Because the rims were made of a semi-translucent red wax, they had to be covered with a layer of diffuse reflective powder before scanning. The powder layer was very thin (approximately 20 μm); however, it added a measure of scanning error to the 3D surface of the rims.

The D700 dental scanner (3Shape A/S) is not specially designed for edentulous casts and rims. When setting up the casts and rims for fixation to the device, maintaining their stable occlusal relationship is difficult, and therefore allows room for error.

The D700 dental scanner (3Shape A/S) can achieve a precision of approximately 20 μm, which is sufficiently accurate for single object scanning, but not necessarily sufficiently accurate to achieve the most precise relationships between the casts and their respective rims and between the upper and lower rims during 3D data registration. The iterative closest point algorithm technique was used for registration. It calculates the closest points between two 3D objects, establishes a corresponding transformation matrix and iteratively transforms the points. The iteration is stopped upon reaching a certain convergence condition (Besl and McKay, 1992). The iterative closest point algorithm has one basic requirement: there should be sufficient overlap in areas with specific geometric characteristics. However, in our study, the overlapping area was primarily on the base of the plaster casts, which was not very geometrically specific. A preliminary study demonstrates an inside error less than 100 μm.

Figure 4 A try-in of the complete wax dentures in the patient's mouth

CAD software specialized for removable complete denture design can help to realize a highly accurate Spee's curve and fullness for the upper dentition (Haese *et al.*, 2012); however, data interference at the occlusal areas of the 3D dentition resulted in poor occlusal contact of the posterior teeth. It is important to virtually check and adjust the occlusal contact conditions. In the near future, this will be a point of focus for our follow-up work.

There are some requirements for wax material additive manufacturing in fixed restorations, although the technology and material have developed relatively slowly. The fabrication accuracy of the machine used in this study is only approximately 80-100 μm. When the wax material solidifies from its liquid form, it undergoes a change in size. More error is introduced as the object size increases. The 3D size of the base plate for the removable complete denture is somewhat large; therefore, the accuracy of its fabrication is particularly susceptible to error.

The roots of some artificial teeth were so long that they penetrated through the base plate. Therefore, the excess length was ground down before they were finally fixed in the location holes of the wax base plate. After undergoing manual grinding, some teeth lost their stability in the location holes. Furthermore, the additive manufacturing wax base plate was so fragile that it was not easily manually adjusted. Therefore, a new wax powder with improved plasticity and esthetics than the type used in this study should be developed and the accuracy of the machine should be improved.

In the near future, more accurate methods for automatic tooth type selection to meet customized requirements will be developed. A virtual articulator and customized balance occlusion algorithm will thus be developed. A new additive manufacturing machine for tooth-colored resin will be used to fabricate artificial dentition after adjusting the virtual occlusion. Clinical experiments will be performed to verify the possible advantages of this method.

5. Conclusions

The try-in wax removable complete dentures can be designed and fabricated with CAD software and the SLS method, which reduce the time of fabrication and improve the fabricating accuracy compared with traditional manual fabrication methods.

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