Preliminary Clinical Application of Removable Partial Denture Frameworks Fabricated Using Computer-Aided Design and Rapid Prototyping Techniques

Hongqiang Ye, DDS, PhD[1*]/Jing Ning, BDS[2*]/Man Li[3]/Li Niu, BS[4]/Jian Yang, DDS, PhD[5]/
Yuchun Sun, DDS, PhD[6]/Yongsheng Zhou, DDS, PhD[7]

Purpose: The aim of this study was to explore the application of computer-aided design and rapid prototyping (CAD/RP) for removable partial denture (RPD) frameworks and evaluate the fitness of the technique for clinical application. ***Materials and Methods:*** Three-dimensional (3D) images of dentition defects were obtained using a lab scanner. The RPD frameworks were designed using commercial dental software and manufactured using selective laser melting (SLM). A total of 15 cases of RPD prostheses were selected, wherein each patient received two types of RPD frameworks, prepared by CAD/RP and investment casting. Primary evaluation of the CAD/RP framework was performed by visual inspection. The gap between the occlusal rest and the relevant rest seat was then replaced using silicone, and the specimens were observed and measured. Paired *t* test was used to compare the average thickness and distributed thickness between the CAD/RP and investment casting frameworks. Analysis of variance test was used to compare the difference in thickness among different zones. ***Results:*** The RPD framework was designed and directly manufactured using the SLM technique. CAD/RP frameworks may meet the clinical requirements with satisfactory retention and stability and no undesired rotation. Although the average gap between the occlusal rest and the corresponding rest seat of the CAD/RP frameworks was slightly larger than that of the investment casting frameworks ($P <$ .05), it was acceptable for clinical application. ***Conclusion:*** RPD frameworks can be designed and fabricated directly using digital techniques with acceptable results in clinical application. *Int J Prosthodont 2017;30:348–353. doi: 10.11607/ijp.5270*

[1]*Lecturer, Department of Prosthodontics, School and Hospital of Stomatology, Peking University, National Engineering Laboratory for Digital and Material Technology of Stomatology, Beijing Key Laboratory of Digital Stomatology, Beijing, China.*

[2]*Graduate Student, Department of Prosthodontics, School and Hospital of Stomatology, Peking University, National Engineering Laboratory for Digital and Material Technology of Stomatology, Beijing Key Laboratory of Digital Stomatology, Beijing, China.*

[3]*Dental Technician, Dental Laboratory Center, School and Hospital of Stomatology, Peking University, Beijing, China.*

[4]*Dental Technician, Beijing Liaison Dental Technology, Beijing, China.*

[5]*Lecturer, Department of Prosthodontics, School and Hospital of Stomatology, Peking University, National Engineering Laboratory for Digital and Material Technology of Stomatology, Beijing Key Laboratory of Digital Stomatology, Beijing, China.*

[6]*Assistant Professor, Center of Digital Dentistry, School and Hospital of Stomatology, Peking University, National Engineering Laboratory for Digital and Material Technology of Stomatology, Beijing Key Laboratory of Digital Stomatology, Beijing, China.*

[7]*Professor, Department of Prosthodontics, School and Hospital of Stomatology, Peking University, National Engineering Laboratory for Digital and Material Technology of Stomatology, Beijing Key Laboratory of Digital Stomatology, Beijing, China.*

These authors contributed equally to this work.

Correspondence to: *Dr Yongsheng Zhou, Department of Prosthodontics, Peking University School and Hospital of Stomatology, 22 ZhongguancunNandajie, Haidian District, Beijing, PR of China, 100081. Fax: 86-10-62173402. Email: kqzhouysh@hsc.pku.edu.cn*

Removable partial denture (RPD) is an important conventional treatment method for partially edentulous arches, one of the most common diseases in prosthodontics. Computer-aided design and computer-aided manufacturing (CAD/CAM) techniques have been applied in the field of dentistry for the past three decades. Development of CAD/CAM techniques in the area of RPD was slow in the earlier years because there was no specific software to support it and the CAM techniques relied exclusively on subtractive methods. The current dental CAD/CAM systems are not applicable for fabricating complex metal RPD frameworks because the techniques used therein are subtractive manufacturing methods such as grinding, cutting, and milling processes that may cause deformation or breaking at thin or narrow areas during manufacturing. In recent years, rapid prototyping (RP), an additive material manufacturing technique, has developed rapidly in dentistry to fabricate frameworks of different prostheses, including RPDs. Commonly used RP techniques are stereolithography (SLA), three-dimensional printing (3DP), selective laser sintering (SLS), selective laser melting (SLM), and fused deposition modeling (FDM).[1] RP has gradually been introduced in digital manufacturing research for RPDs as it can fabricate products of any shape

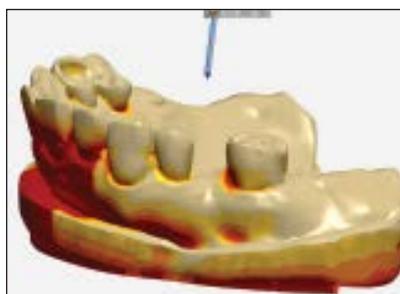Fig 1   Three-dimensional digital cast of the master cast.

Fig 2a   Digital surveying. Depth of the undercut area was marked using different colors.

Fig 2b   Filled undercut areas (translucent pink) and trimmed clasp shoulders.
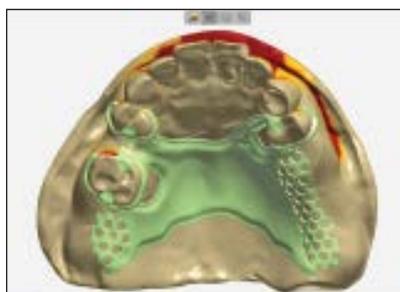

Fig 3a   Designed framework meshes.

Fig 3b   Designed major and minor connectors, clasps, and occlusal rests.
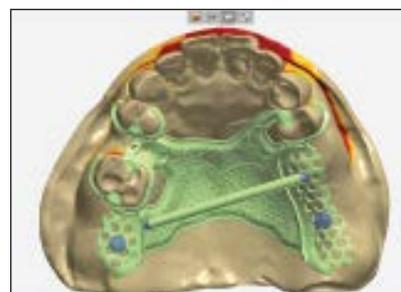

Fig 3c   Designed external and internal finishing lines, tissue stops, and support structures.

designed by CAD, overcoming several problems encountered during subtractive material manufacturing. Recent studies have focused either on the development of a dedicated CAD software for RPDs or on the feasibility of RP to prove that CAD/RP techniques can be used to design and manufacture resin RPD frameworks[2–5] or for direct fabrication of metal RPD frameworks[6–8] evaluated using stone casts; however, few clinical studies have evaluated these techniques in patients.

Several researchers believed that a combination of CAD and RP would be compatible and efficient.[5–7] Digital manufacturing methods have the advantage of better fit, a shorter production period, and less labor and deviation.[9] However, there is no clinical evidence to support the idea that the fitness for clinical application of CAD/RP metal RPD frameworks is better than that of traditional casting RPD frameworks. This study presents a clinical process for digital design and manufacture of metal RPD frameworks and evaluates their fitness for clinical application compared with investment casting RPD frameworks.

Materials and Methods

Patients with dentition defects requiring RPDs were selected. After tooth preparation as per clinical requirements, impressions were recorded using silicone impression materials, and stone casts were created and disinfected. 3D digital casts of the master casts were acquired using a lab scanner (D800, 3Shape) and were clear and integrated, containing all anatomical structures required for RPD (Fig 1). Digital surveying was completed using the CAD software (Dental System, 3Shape), which provided accurate positioning for RPD components. At a certain direction of the path of insertion, a survey line could be made automatically and the depth of the undercut could be marked in different colors. Thereafter, the undercut areas were filled virtually and the clasp shoulders were trimmed where the clasps engaged (Fig 2). With the aid of digital surveying, RPD framework components such as clasp, rest, and minor and major connectors were designed according to the principles of RPD framework.[10] The entire framework design was formed after all components were combined together (Fig 3). Certain support structures were added to avoid deformation of the framework during fabrication. The 3D data of the RPD framework were exported as a stereolithography (STL) file and imported into an SLM RP system (M270, EOS), which was used to directly manufacture cobalt-chromium alloy (Wirebond C+, Bego) RPD frameworks. After removal of support structures and polishing, the final RPD frameworks were fabricated (Fig 4).

The finished CAD/RP frameworks were seated on stone casts for primary evaluation of fitness.

To evaluate fitness for clinical application, 15 patients who required RPDs were selected. The following inclusion criteria were used: *(1)* at least one

Fig 4 Cobalt-chromium alloy framework directly fabricated using the rapid prototyping system.
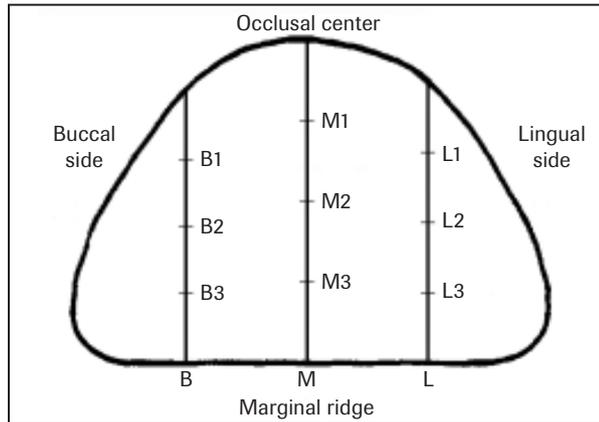

Fig 5 Well-seated framework.

Fig 6 Schematic diagram of a silicone specimen showing the sections and measured points.
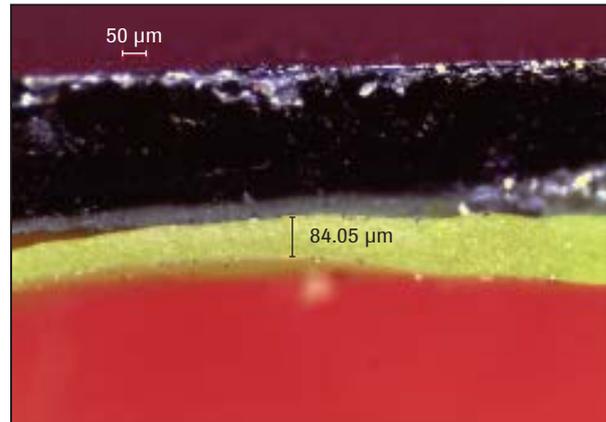

Fig 7 Fixed section of a silicone specimen showing measurements.

premolar or molar for occlusal rest preparation; *(2)* mobility of abutment teeth ≤ Class II and alveolar bone loss less than half of the tooth root; *(3)* no tooth defects, endodontic or apical diseases, or periodontal diseases (in case of history of any, records of successful treatment were ensured); and *(4)* healthy oral mucosa and soft tissues. Exclusion criteria included the following: *(1)* partially edentulous arch with jaw bone and soft tissue defects; *(2)* patients with mental disabilities or those who could not take care of themselves or who may swallow the denture; and *(3)* patients who were unsuitable for RPDs for reasons other than the aforementioned. Ethical approval was granted by the School of Stomatology (PKUSSIRB-2012045), Peking University, and all patients provided informed consent.

Following tooth preparation, two impressions were recorded for each patient using the same silicone impression materials by the same dentist, and two master casts were poured by the same technician. One master cast chosen randomly was used to prepare a digital cast for designing and manufacturing an RPD framework using the CAD/RP technique (test group). The other master cast was used to fabricate an RPD

framework using the conventional investment casting technique (control group). Both frameworks were tried-in by the same prosthodontist, who was blinded to whether the frameworks came from the control or test group, in clinic. When the frameworks were well seated after certain adjustments, clinical fitness evaluations were initiated (Fig 5).

Visual inspection and a pressing test were used for qualitative evaluation of clinical fitness. The qualitative evaluations were performed by three prosthodontists who were not involved in the fabrication of the frameworks and were blinded to whether the frameworks came from the test or control group. Differing views among the three investigators were resolved by majority. The visual inspection method, proposed by Frank et al,[11] included the following components: *(1)* whether all rests were seated; *(2)* whether all rigid elements touched the teeth; and *(3)* that the major connector did not impinge on the underlying soft tissue and had no visible relief space > 1 mm. For the pressing test, a cement plugger was held on the occlusal rest perpendicular to the occlusal plane, and any detectable movements observed while applying appropriate pressure on the rest were noted.[11]

There is no standard method for quantitative evaluation of clinical fitness of an RPD framework. Stern et al[12] and Dunham et al[13] have proposed similar approaches to quantify the space between the rest and the rest seat, which can reflect the clinical fitness of RPD frameworks. Accordingly, the investment casting RPD framework was used as the control to quantitatively evaluate the accuracy of the CAD/RP RPD framework by following the methods described by Stern et al[12] and Dunham et al.[13] Light body silicone impression material (Light Flow, Heraeus Kulzer) was injected around the tissue contact surfaces of the occlusal rests. Thereafter, slight pressure was applied on the RPD framework to ensure that it was well seated, and the pressure was maintained until the silicone material polymerized. Silicone gap specimens were collected and stored in an appropriately sealed bag at room temperature for measurement. Silicone gap specimens were collected from all patients from both groups. All specimens were observed under the low-power objective lens of a stereomicroscope (M125, Leica) to record the number of specimens with one or more pierced holes. When a hole was detected in a specimen, the corresponding rest was considered to contact the tooth. Specimens were sliced into quarters in length along the sagittal plane (from mesial to distal) under the stereomicroscope. Buccal cross sections were selected for measurement and marked as B, M, and L (buccal, mesial, and lingual) sections (Fig 6). These sections were fixed on a gallium arsenide (GaAs) wafer (type N, Tebo Technology), and the measuring surfaces were placed parallel to the cross sections of the GaAs wafer (Fig 7). Fixed sections stood upright in the bracket, ensuring that the measuring surface was parallel to the stereomicroscope objective lens. Photographs and measurements were recorded using ZoomBrowser software (Canon). Three points on each quartered section were selected as test points and named B1, B2, B3, M1, M2, M3, L1, L2, and L3 (from occlusal center to marginal ridge). The thickness of each test point was the average value of the three measurements.

The average of the nine test points was recorded as the average thickness of the silicone specimen. Specimens that contained one or more pierced holes (at low magnification) or one or more of the nine test points with a thickness of ≤ 50 μm at high magnification were defined as specimens containing contact point, which meant that the corresponding occlusal rest contacted the tooth.[12] The number and proportion of such specimens were recorded. Every silicone specimen was divided into three zones from mesial to distal to compare differences in gap thickness between the occlusal rest and the rest seat among the zones. The zone closest to the occlusal center was named Zone C, the thickness of which was the average thickness of B1, M1, and L1. The zone closest to the marginal ridge was named Zone R, the thickness of which was the average thickness of B3, M3, and L3. The zone between Zones C and R was Zone M, the thickness of which was the average thickness of B2, M2, and L2. The difference in gap thickness among the zones and the difference in gap thickness within each zone were compared.

All statistical analyses were conducted using SPSS 20 (IBM). Analysis of variance was used to compare the difference in gap thickness among different zones in both groups. Paired t test was used to compare the average thickness and distributed thickness of different zones between the two groups.

Results

RPD frameworks were designed quickly and effectively and were directly converted into cobalt-chromium alloy frameworks using the RP technique. All CAD/RP frameworks were easily seated on stone casts after certain adjustments, showing good fitness, suitable retention, and desired stability.

A total of 15 patients, 6 men and 9 women, with ages that ranged from 41 to 79 years, were selected for this study. In the 15 cases, 6 maxillary RPDs and 9 mandibular RPDs were involved, including 8 cases of Kennedy Class I, 3 cases of Kennedy Class II, 3 cases of Kennedy Class III, and 1 case of Kennedy Class IV. A total of 40 occlusal rests were included for 15 RPD frameworks.

All 15 CAD/RP RPD frameworks met the clinical requirements when tested on corresponding patients as all rests were seated well and all rigid components appropriately contacted the relevant teeth. Moreover, the major connectors did not press underlying soft tissues and left no visible space of > 1 mm. Furthermore, there were no detectable movements while applying pressure to the occlusal rests using a cement plugger.

Among the occlusal rest silicone specimens obtained from the CAD/RP framework, 42.5% of the specimens contained a gap of < 50 μm, indicating that the occlusal rest contacted the tooth. Correspondingly, 72.5% of rests in the control group contacted the teeth.

The average thickness of silicone specimens of CAD/RP frameworks was 174 ± 117 μm (range: 41 to 546 μm), whereas the corresponding thickness of conventional RPD frameworks was 108 ± 84 μm (range: 17 to 369 μm). Paired t test showed statistically significant differences in the average thickness of silicone specimens between the two groups ($P = .003$). The average thickness of silicone specimens of CAD/RP frameworks was greater than that of investment casting frameworks.

Table 1 Average Thickness of Silicone Specimens of Different Zones and Intra- and Intergroup Differences

Group	Zone C (mean ± SD, μm)	Zone M (mean ± SD, μm)	Zone R (mean ± SD, μm)	P (ANOVA)
CAD/RP	165 ± 112	180 ± 125	178 ± 123	.855
Investment casting	108 ± 84	110 ± 93	104 ± 87	.948
P (paired t test)	.005	.004	.003	

Zone C = zone near the occlusal center; Zone M = middle zone; Zone R = zone near the marginal ridge.

There were no significant differences in the occlusal rest gaps among Zones C, M, and R in both groups (test group, P = .885; control group, P = .948). In each zone, the occlusal rest gap of the test group was greater than that of the control group (Table 1).

Discussion

The CAD/CAM technique for RPD fabrication has rapidly developed since RP was introduced in the field of dentistry. Williams et al[5] designed and manufactured a resin RPD framework using the CAD/CAM technique in 2004, which was converted into a metal framework using the investment casting technique and seated well on a cast.[5] In 2006, the same team designed and fabricated a cobalt-chromium alloy RPD framework using the CAD/RP technique, which was tried-in in the patient.[6] Bibb et al[7] and Han et al[8] used the CAD/RP technique to directly fabricate cobalt-chromium alloy RPD frameworks. However, although metal RPD frameworks have been designed and fabricated using the CAD/RP technique, few studies have reported clinical application and evaluation of such frameworks. In this study, RPD frameworks designed and fabricated using the CAD/RP technique were applied in a clinical setting, and the clinical results were evaluated.

To date, few studies have discussed the clinical fitness and accuracy of RPDs, particularly the quantitative evaluation, owing to the complexity of structures, the variety of component materials, and the wide variety of designs. To the knowledge of the present authors, no commonly accepted criteria exist for RPD frameworks. Therefore, a visual inspection and a pressing test, commonly accepted in clinical practice and used previously,[11] were used to evaluate clinical fitness of RPD frameworks. In addition, gaps between the occlusal rest and the rest seat were duplicated using silicone impression material for quantitative evaluation, as in studies conducted by Stern et al[12] and Dunham et al.[13] For the investment casting RPD framework, Stern et al's study indicated that 79% of occlusal rests contacted the teeth,[12] whereas 24% of occlusal rests contacted the teeth according to Dunham et al's study.[13] In the present study, 72.5% of occlusal rests of investment casting frameworks contacted the teeth, which was similar to that reported by Stern et al[12]; moreover, 42.5% of occlusal rests of CAD/RP frameworks contacted teeth, which was greater than that reported by Dunham et al[13] and lower than that reported by Stern et al[12] for investment casting frameworks. Stern et al reported an average gap thickness of 69 to 387 μm between the occlusal rest and the rest seat,[12] and Dunham et al reported an average thickness of 193 ± 203 (range: 0 to 828) μm for investment casting frameworks.[13] In the present study, the average gap thickness was 108 ± 84 μm (range: 17 to 369 μm) for investment casting frameworks and 174 ± 117 μm (range: 41 to 546 μm) for CAD/RP frameworks. Thus, the fitness of occlusal rests of investment casting frameworks in this study was similar to that reported by Stern et al.[12]

No significant differences were observed among different zones in either group, suggesting that the gap between the occlusal rest and the rest seat was relatively uniform; this was inconsistent with the findings of Stern et al[12] that the marginal ridge zone exhibited better fitness.

Conclusions

Within the limitations of the present analyses, RPD frameworks can be designed and fabricated directly and effectively using the CAD/RP technique, with acceptable results in clinical application. Although the average gap between occlusal rest and rest seat of CAD/RP frameworks was slightly larger than that of investment casting frameworks, CAD/RP frameworks may meet the requirements for clinical application. More clinical trials and further improvement in the CAD/RP technique should be performed in the future.

Acknowledgments

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