Influence of reinforcement bar on accuracy of removable partial denture framework fabricated by casting with a 3D-printed pattern and selective laser sintering

Akinori Tasaka a, c*, Haruna Okano a, Takahiro Shimizu a, Yoshimitsu Kato a, Shizuo Higuchi b, Shuichiro Yamashita a

a Department of Removable Partial Prosthodontics, Tokyo Dental College, Tokyo, Japan
b Wada Precision Dental Laboratories Corporation, Osaka, Japan
c Oral Health Science Center, Tokyo Dental College, Tokyo, Japan

Abstract

Purpose: The purpose of this study was to investigate the accuracy of removable partial denture frameworks fabricated by 3D-printed pattern casting (AM-Cast) and selective laser sintering (SLS) under different conditions with a reinforcement bar.

Methods: A partially edentulous model was scanned with a dental laboratory scanner, and CAD software was used to design the framework. Reinforcement bars (n=0-2) were set on the lingual side of the framework. 3D scanning of the fabricated frameworks by AM-Cast and SLS was performed, and the obtained data were overlapped with the design data. The differences in shape among setting conditions of the bar were statistically compared using the Bonferroni method after the Kruskal–Wallis test.

Results: The ranges in differences of the AM-Cast-0, AM-Cast-1, and AM-Cast-2 were -0.167 to 0.128 mm, -0.101 to 0.105 mm, and -0.185 to 0.015 mm, respectively. The ranges of SLS-0, SLS-1, and SLS-2 were -0.166 to 0.035 mm, -0.182 to 0.049 mm, and -0.138 to 0.038 mm, respectively. Large discrepancies were observed at the joining area of the lingual bar on the right side of the AM-Cast. A significant difference was found between the AM-Cast-0 and AM-Cast-1, and between the AM-Cast-0 and AM-Cast-2.

Conclusions: The setting conditions of the reinforcement bar affected the accuracy of the lingual bar in the AM-Cast; however, no effect was observed on the displacement of the central area of the lingual bar in SLS. Setting a single reinforcing bar on the retentive latticework contributed to improving the accuracy of the lingual bar in the AM-Cast but not the displacement of the central area of the lingual bar in SLS.

Keywords: Removable partial denture, Metal framework, Casting, Selective laser sintering, Reinforcement bar

1. Introduction

Prosthetic treatment using removable partial dentures (RPDs) has become widespread, as it can improve the quality of life of an individual at a lower cost compared to dental implant therapy. RPD wearers account for 13% to 29% or more of the patients who visit a dentist in Europe [1], and 41.7% of all dental patients aged ≥ 75 years in Japan [2]. In North America, the number of partially edentulous patients is expected to rise to 200 million over the next 15 years [3], and the need for RPD is already increasing [4]. However, appropriate fit of dentures is desirable because many patients discontinue wearing RPDs due to poor fit [5].

In the past, the metal framework of a conventional RPD was fabricated by the lost-wax technique; however, human error occurred frequently because the process required significant hand skill [6]. More recently, computer-aided design/computer-aided manufacturing (CAD/CAM) has become increasingly widespread in the fabrication of RPD metal frameworks [7]. To accomplish this, 3D scans are obtained either by scanning a working model with a dental laboratory scanner or by oral scanning with an intraoral scanner, following which the metal framework is designed using 3D data that recreates the oral cavity [8-11]. Computerizing the workflow in this manner has reduced human error and allowed for reproducibility of fabrication [9, 12].

Currently, two main methods are used clinically to fabricate the metal framework for RPD by the CAD/CAM technique [13]. The first of these is a combination of CAD/CAM techniques and the lost-wax method, in which a pattern is shaped using a 3D printer, following which the metal framework is cast [14]. Patterns fabricated using this method are pliable, and must be handled with care due to easy deformation [9]. The second method is the application of techniques for additive manufacturing with metal powder, typically selective laser sintering (SLS), in which the evenly spread out metal powder is melted by thermal energy to directly shape the metal framework [15-17]. One
disadvantage of this method is that the residual stresses during molding could lead to deformation of the object [18]. In particular, major deformation of the central area of the lingual bar has been reported [19]. Presently, this problem is generally addressed by configuring a reinforcement bar in the CAD data in advance to prevent deformation [14, 17, 20]. The reinforcement bar is currently set based on the experience and intuition of the dental technician handling the CAD data, and there is a lack of specific/established design criteria. In the present study, we tested the hypothesis that differences in the setting conditions of the reinforcement bar influenced the accuracy of fit of the metal framework.

The purpose of this study was to investigate the influence of differences in the setting conditions of the reinforcement bar on the accuracy of fabrication, to determine the optimal conditions for fabricating the metal framework of RPDs using the 3D-printed pattern casting and SLS methods.

2. Material and Methods

2.1. Fabrication of the experimental metal framework

The procedures for fabricating the experimental metal frameworks are shown in Fig. 1. A working cast of Kennedy’s Class II modification with missing #35, #36, #46, and #47 (FDI Two-Digit Notation) teeth (MIS3004-L-PL-28, Nissin Tokyo, Japan) was used as the simulation model. In the working cast, rest seats were prepared on the distal occlusal surface of #34, mesial occlusal surface of #37, and the mesial occlusal surface of #45, and a guide plane was prepared on the distal aspect of #34, mesial aspect of #37, and the distal aspect of #45. The working cast was scanned with a 3D dental laser scanner (Smart Big, Open Technologies, Brescia, Italy), following which CAD software (Digistell, Digilea, Montpellier, France) was used to produce the data to design the metal framework (design data). The selected denture retainers were an Akers clasp on #34, a ring clasp on #37, and an RPI clasp on #45. A lingual bar was selected for the major connector. Each clasp had an accessory sprue at the tip to improve the flow of molten metal during casting and prevent deformation due to overhang during metal additive manufacturing. Three setting conditions of the reinforcement bar were considered namely, zero, one, and two reinforcement bars. In the setting condition with one reinforcement bar, the retentive latticework of the left and right edentulous areas were connected by a single bar. In the setting condition with two reinforcement bars, a second bar of the same size as in the one reinforcement bar condition joined the major connector at sites corresponding to #34 and #44. The reinforcement bars were 2.5 mm in diameter.

Fabrication of the framework by 3D-printed pattern casting was performed using a resin pattern (VisiJet M3 Dentcast, 3D Systems Corporation, Circle Rock Hill, SC, USA) shaped by additive manufacturing with a 3D printer (Projet 3510DP, 3D Systems Corporation). The framework was arranged with the occlusal surfaces of the three rests parallel to the baseplate of the 3D printer, such that the framework surfaces that were crucial for conformity faced upward. The support materials were removed using Projet finisher (3D Systems Corporation) after the pattern was formed, and was rapidly transferred to the SLS framework fabrication data onto the corresponding design data which they were digitized by 3D scanning with an ATOS Core 80 scanner (GOM). The SLS frameworks were annealed at 1,000 °C for 30 min after formation, following which shot peening was performed with ceramic powder at a pressure of 3.0 bars. Following removal of the SLS frameworks from the baseplate along with the support materials, they were homogenized for 30 min at 1,150 °C. The reinforcement bars were not removed from any of the metal frameworks or polished.

2.2. Verification of accuracy

The metal frameworks were coated with titanium oxide, following which they were digitized by 3D scanning with an ATOS Core 80 scanner (GOM, Braunschweig, Germany) to obtain the fabrication data. Accuracy was verified by superimposing the AM-Cast and SLS framework fabrication data onto the corresponding design data using the best-fit algorithm of the 3D data evaluation software (GOM Inspect, GOM) to compare differences in shape. The reinforcement bars were not included in the region of interest.

A total of six verification sites were established: the rests for #34, #37, and #45; the center of the lingual bar; and two joining areas where the lingual bar joined the left and right retentive latticework (Fig. 2). At each of these verification sites, five points distributed at equal intervals on the inside of the metal framework were arbitrarily selected, and at each point, the difference value of the fabrication data with respect to the design data was calculated. In addition, these points were set in the same region under all conditions. The mean value of these five points was taken as the representative value at the site. The median was calculated from the representative values of the five frameworks. Accuracy is the ability of a fabrication technique to produce a framework with minimal differences and is represented by the median.
2.3. Statistical analyses

The Kruskal–Wallis test was used to analyze the differences between values at each verification site due to the number of reinforcement bars for both AM-Cast and SLS frameworks. In addition, the Bonferroni adjustment method was used for multiple comparisons. The level of statistical significance was set at 0.05. SPSS (ver. 25 IBM, New York, USA) was used for statistical analyses.

3. Results

Figures 3 and 4 show typical color maps of differences in shape when the design and fabrication data were superimposed. The differences at each verification site on the rests and lingual bar are shown in Tables 1–4. The AM-Cast-2 and SLS-0 data were quoted from the study by Tasaka et al. [19].

The differences at the rest of #34 in the AM-Cast frameworks were 0.078 to 0.148 mm in AM-Cast-0, 0.062 to 0.156 mm in AM-Cast-1, and 0.110 to 0.162 mm in AM-Cast-2, all of which showed inward displacement. No significant difference was found between the setting conditions of the reinforcement bar (Table 1). The differences in the SLS frameworks were 0.024 to 0.050 mm in SLS-0, 0.024 to 0.060 mm in SLS-1, and 0.026 to 0.056 mm in SLS-2, all of which showed inward displacement. No significant difference was found between the setting conditions of the reinforcement bar (Table 2).

At the rest of #37 in the AM-Cast frameworks, the differences were −0.040 to 0.040 mm in AM-Cast-0, −0.004 to 0.026 mm in AM-Cast-1, and −0.016 to 0.032 mm in AM-Cast-2, all of which showed inward and outward displacements. No significant difference was found between the setting conditions of the reinforcement bar (Table 1). The differences in the SLS frameworks were −0.036 to −0.012 mm in SLS-0, −0.028 to −0.010 mm in SLS-1, and −0.020 to −0.002 mm in SLS-2, all of which showed outward displacement. No significant difference was found between the setting conditions of the reinforcement bar (Table 2).

At the rest of #45 in the AM-Cast frameworks were −0.028 to 0.024 mm, −0.028 to 0.034 mm, and −0.122 to 0.026 mm in AM-Cast-0, AM-Cast-1, AM-Cast-2, respectively, all of which showed inward and outward displacements. No significant difference was found between the setting conditions of the reinforcement bar (Table 1). The differences in the SLS frameworks were 0.026 to 0.038 mm, −0.008 to 0.022 mm, and −0.002 to 0.026 mm in SLS-0, SLS-1, and SLS-2, respectively. SLS-0 showed inward displacement, whereas SLS-1 and 2 showed inward and outward displacements. A significant difference was observed between the setting conditions of the reinforcement bar, and multiple comparisons showed a significant difference between SLS-0 and SLS-1 (Table 2).

At the lingual bar central area of the AM-Cast frameworks, the differences were −0.224 to −0.074 mm in AM-Cast-0, −0.082 to −0.042 mm in AM-Cast-1, and −0.084 to 0.004 mm in AM-Cast-2. AM-Cast-0 and AM-Cast-1 showed outward displacement, and AM-Cast-2 showed inward and outward displacements. No significant difference was found between the setting conditions of the reinforcement bar, and multiple comparisons showed a significant difference between AM-Cast-0 and AM-Cast-1 (Table 2).

At the lingual bar central area of the SLS frameworks, the differences were −0.176 to −0.152 mm in SLS-0, −0.190 to −0.174 mm in SLS-1, and −0.154 to −0.120 mm in SLS-2, all of which showed outward displacement. A significant difference was observed between the setting conditions of the reinforcement bar, and multiple comparisons showed a significant difference between SLS-1 and 2 (Table 4).
Table 1. Median, minimum, maximum and interquartile range values of occlusal rests on AM-Cast frameworks (mm). Min=minimum value, Max=maximum value, IQR=interquartile range.

| Rest | AM-Cast | P value | Adjusted P value |
|------|---------|---------|------------------|
|      | 0       | 1       | 2                | 0 vs 1 | 0 vs 2 | 1 vs 2 |
| A    | Median  | 0.112   | 0.106            | 0.114  | 0.765  |        |
| #34  | Min     | 0.078   | 0.062            | 0.110  |        |        |
|      | Max     | 0.148   | 0.156            | 0.162  |        |        |
|      | IQR     | 0.036   | 0.042            | 0.014  |        |        |

Table 2. Median, minimum, maximum and interquartile range values of occlusal rests on SLS frameworks (mm). Min=minimum value, Max=maximum value, IQR=interquartile range. a: Statistically significant differences was found (P < 0.05: Kruskal–Wallis test). Statistically significant difference was in bold (Adjusted P < 0.01: Bonferroni adjustment method).

| Rest | SLS | P value | Adjusted P value |
|------|-----|---------|------------------|
|      | 0   | 1       | 2                | 0 vs 1 | 0 vs 2 | 1 vs 2 |
| A    | Median | 0.036   | 0.056            | 0.036  | 0.153  |        |
| #34  | Min   | 0.024   | 0.024            | 0.026  |        |        |
|      | Max   | 0.050   | 0.060            | 0.056  |        |        |
|      | IQR   | 0.010   | 0.010            |        |        |        |

Table 3. Median, minimum, maximum and interquartile range values of lingual bar on AM-Cast frameworks (mm). Min=minimum value, Max=maximum value, IQR=interquartile range. a: Statistically significant differences was found (P < 0.05: Kruskal–Wallis test). b: Statistically significant differences was found (P < 0.01: Kruskal–Wallis test). Statistically significant differences are in bold (Adjusted P < 0.01: Bonferroni adjustment method).

| Lingual bar | AM-Cast | P value | Adjusted P value |
|-------------|---------|---------|------------------|
|             | 0       | 1       | 2                | 0 vs 1 | 0 vs 2 | 1 vs 2 |
| D Center    | Median  | -0.186  | -0.064           | -0.068 | 0.031\(^{a}\) |         |
|             | Min     | -0.224  | -0.082           | -0.084 | 0.031\(^{a}\) |         |
|             | Max     | -0.074  | -0.042           | 0.004  |         |         |
|             | IQR     | 0.026   | 0.024            | 0.030  |         |         |
| E Left-side | Median  | -0.082  | -0.074           | -0.144 | 0.343  |         |
| Joining area| Min    | -0.136  | -0.250           | -0.394 |        |         |
|             | Max     | -0.024  | 0.018            | -0.038 |        |         |
|             | IQR     | 0.014   | 0.138            | 0.134  |         |         |
| F Right-side| Median  | 0.144   | 0.008            | -0.024 | 0.006\(^{b}\) |         |
| Joining area| Min    | 0.046   | -0.038           | -0.048 | 0.006\(^{b}\) |         |
|             | Max     | 0.174   | 0.022            | 0.010  |         |         |
|             | IQR     | 0.054   | 0.022            | 0.022  |         |         |
Table 4. Median, minimum, maximum and interquartile range values of lingual bar on SLS frameworks (mm). Min=minimum value, Max=maximum value, IQR=interquartile range. a: Statistically significant differences was found (P < 0.05: Kruskal–Wallis test). b: Statistically significant differences was found (P < 0.01: Kruskal–Wallis test). Statistically significant differences are in bold (Adjusted P < 0.01: Bonferroni adjustment method).

| Lingual bar | SLS | P value | Adjusted P value |
|-------------|-----|---------|-----------------|
|             | 0   | 1       | 2               | 0 vs 1 | 0 vs 2 |
| D           | Median | -0.170 | -0.182 | -0.140 | 0.0066 | 0.173 | 0.173 | 0.005 |
| Center      | Min   | -0.152 | -0.174 | -0.120 |         |       |       |       |
|             | Max   | -0.176 | -0.190 | -0.154 |         |       |       |       |
|             | IQR   | 0.008  | 0.014  | 0.024  |         |       |       |       |
| E           | Median | -0.002 | -0.010 | -0.002 | 0.006\(^a\) | 0.590 | 0.005 | 0.173 |
| Left-side   | Min   | -0.010 | 0.008  | 0.016  |         |       |       |       |
|             | Max   | 0.014  | 0.020  | 0.028  |         |       |       |       |
|             | IQR   | 0.004  | 0.008  | 0.002  |         |       |       |       |
| F           | Median | -0.018 | -0.004 | -0.002 | 0.031\(^b\) | 0.173 | 0.005 | 0.590 |
| Right-side  | Min   | -0.030 | -0.014 | -0.010 |         |       |       |       |
|             | Max   | -0.012 | 0.002  | 0.006  |         |       |       |       |
|             | IQR   | 0.008  | -0.008 | 0.004  |         |       |       |       |

At the left-side joining area of the lingual bar in the AM-Cast frameworks, the differences were −0.136 to −0.024 mm, −0.250 to 0.018 mm, and −0.394 to −0.038 mm in AM-Cast-0, AM-Cast-1, and AM-Cast-2, respectively. AM-Cast-0 and AM-Cast-2 showed outward displacement, and AM-Cast-1 showed inward and outward displacements. No significant difference was found between the setting conditions of the reinforcement bar (Table 4). The differences in the SLS frameworks were −0.010 to 0.014 mm in SLS-0, 0.008 to 0.020 mm in SLS-1, and 0.016 to 0.028 mm in SLS-2. SLS-0 showed inward and outward displacements, whereas SLS-1 and 2 showed inward displacement. A significant difference was observed between the setting conditions of the reinforcement bar, and multiple comparisons showed a significant difference between SLS-0 and SLS-2 (Table 4).

At the right-side joining area of the lingual bar in the AM-Cast frameworks, the differences were 0.046 to 0.174 mm in AM-Cast-0, −0.038 to 0.022 mm in AM-Cast-1, and −0.048 to 0.010 mm in AM-Cast-2. AM-Cast-0 showed inward displacement and AM-Cast-1 and 2 showed inward and outward displacements. A significant difference was observed between the setting conditions of the reinforcement bar, and multiple comparisons showed a significant difference between AM-Cast-0 and AM-Cast-1, and between AM-Cast-0 and AM-Cast-2 (Table 4). The differences in the SLS frameworks were −0.030 to −0.012 mm, −0.014 to 0.002 mm, and −0.010 to 0.006 mm in SLS-0, SLS-1, and SLS-2, respectively. SLS-0 showed outward displacement, and SLS-1 and 2 showed inward and outward displacements. A significant difference was found between the setting conditions of the reinforcement bar, and multiple comparisons showed a significant difference between SLS-0 and SLS-2 (Table 4).

4. Discussion

Most previous studies on the accuracy of fit of metal frameworks measured the rests and the major connector [21–25]. The present study also focused on the rests, which are the most important parts for accurate fit of the metal framework, and the major connector, which is believed to exhibit the greatest amount of deformation during metal additive manufacturing. To date, many studies have used silicon impression material to measure the gap between the working cast and the metal framework to evaluate accuracy of the fit [14, 20, 21, 24]; however, it is not possible to evaluate the direction of displacement by this method. In the present study, the design and fabrication data were superimposed in three dimensions, thus allowing evaluation of the direction of displacement. The measurement error of the 3D data evaluation software used in the present study was 0.012 mm and 0.015 mm when measuring the points and surfaces, respectively.

The present study showed smaller overall differences and interquartile ranges in the SLS frameworks than the AM-Cast frameworks, suggesting that SLS frameworks are superior in fabrication accuracy and reproducibility, and our results were in accordance with those reported in a previous study [19]. The setting conditions of the reinforcement bar had no effect on the amount of displacement of the rests in the AM-Cast framework. Meanwhile, we confirmed that the setting conditions of the reinforcement bar affected the amount of displacement in the rests of the SLS framework. Stern et al. measured the space between the rests of a metal plate fabricated by the conventional casting technique and their corresponding rest seats, and observed that the mean value was 173 to 215 µm [21]. Dunham et al. measured the same space and reported values in the range of 0 to 828 µm, with a mean value of 193±203 µm [24]. The absolute differences in the AM and SLS rests in this study were expected to be within a clinically acceptable range.

The median and mean values of each rest in the AM-Cast frameworks indicated a tendency of the direction of displacement to be affected by the presence of a reinforcement bar (AM-Cast-0: #34: +, #37: &, #45: +, AM-Cast-1: #34: +, #37: +, #45: +, AM-Cast-2: #34: +, #37: +, #45: +). However, in the SLS frameworks, the median and mean values for each rest indicated that the direction of displacement was not affected by the presence of the reinforcement bar (SLS-0: #34: +, #37: +, #45: +, SLS-1: #34: +, #37: +, #45: +, SLS-2: #34: +, #37: +, #45: +). Both inward and outward displacements with respect to the design data were observed in the AM-Cast frameworks, with the exception of AM-Cast-1. Therefore, it is important to carefully inspect at the try-in of the metal framework on the working cast.

Large differences were observed in the central area of the lingual bar in AM-Cast-0. It is likely that major deformation of the framework occurred due to contraction of the casting pattern at this site, which coincides with the center of the framework [26]. The main reasons for uneven contraction of the casting pattern are thought to be residual stresses occurring during the 3D printing process [27] and degradation after fabrication due to sunlight [28]. Setting a reinforcement bar was found to control displacement in the central area of the lingual bar. However, when the AM-Cast frameworks were set with two reinforcement bars, a large difference was observed in the left-side joining area of the lingual bar. In addition, the displacement at this site was in agreement with the site where the reinforcement bar was attached. This was possibly because the reinforcement bar acted as a sprue that led to local casting shrinkage at the site of attachment. The reinforcement bar used in this study had a diameter of 2.5 mm and...
sufficient length. The number, dimension, and attachment site of the sprue influence the accuracy of casting [29]. Local casting shrinkage has been reported to occur with a characteristic distribution at abrupt changes in cross-sectional thickness at the sprue junction [30]. The central area of the lingual bar showed a large difference in the SLS frameworks regardless of the reinforcement bar conditions. This was probably due to the buckling deformation that occurs during metal additive manufacturing [31]. These residual stresses are likely to affect not only the fit of the RPD but also its strength [18], and further study is needed on the sintering conditions, such as the build angle and positioning of the support material.

A limitation of the present study is that only a single pattern was designed, specifically, the typical mandibular Kennedy Class II Modification 1 of edentulous spaces. Different designs are possible, depending on the site and extent of the partially edentulous region. Further investigation is needed in the future in the maxilla, considering the difference in shape and significant variations.

When a metal framework with a lingual bar is fabricated using the CAD/CAM technique for a typical mandibular Kennedy Class II Modification 1 pattern of edentulous spaces, the following aspects must be considered:

1. A reinforcement bar is effective to improve the accuracy of the major connector of the framework when using a 3D-printed pattern. However, as the accuracy of the site of attachment of the reinforcement bar declines considerably, it is desirable to position this at a site, such as the retentive latticework, which is not involved in the fit of the framework.

2. Setting with a reinforcement bar is largely ineffective to improve the accuracy of the central area of the lingual bar when fabricating by SLS.

5. Conclusion

The setting of a single reinforcement bar on the retentive latticework contributed to improving the accuracy of the lingual bar in frameworks cast using a 3D-printed pattern. Reinforcement bars were not found to have an effect on displacement of the central area of the lingual bar in the frameworks fabricated by SLS.

Conflict of interest

There are no conflicts of interest regarding this study.

References

[1] Zitzmann NU, Hagmann E, Weiger R. What is the prevalence of various types of prosthetic dental restorations in Europe? Clin Oral Implants Res 2007;18 Suppl 1:20-33
[2] Table 16 of the Survey of Dental Diseases (2016). https://www.mhlw.go.jp/toukei/list/dl/62-28-02.pdf. [Accessed on November 13, 2019]
[3] Kim JJ. Revisiting the Removable Partial Denture. Dent Clin North Am 2017;71:1351-5.
[4] Douglass CW, Watson AJ. Future needs for fixed and removable partial dentures in Europe? Clin Oral Implants Res 2013;71:1351-5.
[5] Arafa KAO. Assessment of the fit of removable partial denture fabricated by computer-aided designing/computer aided manufacturing technology. Saudi Med J. 2018;39:17-22.
[6] Williams RJ, Bibb R, Rafik T. A technique for fabricating patterns for removable partial denture frameworks using digitized casts and electronic surveying. J Prosthodont 2004;9:81-8.
[7] Eggbeer D, Bibb R, Williams R. The computer-aided design and rapid prototyping fabrication of removable partial denture frameworks. Proc Inst Mech Eng H 2005;219:195-202.
[8] Wang Y, Zhao YJ, Wu L, Lu PJ. Preliminary Study on CAD of Removable Partial Denture Framework. Appl Mech Mater 2012; 220-3: 2777-82.
[9] Hussein MO, Hussein LA. Novel 3D modeling technique of removable partial denture framework manufactured by 3D printing technology. Int J Adv Res 2014;9: 686-94.
[10] Lima JM, Anami I.C, Araujo RM, Pavanelli CA. Removable partial dentures: use of rapid prototyping. J Prosthodont 2014;23:588-91.
[11] Alfüi-Segbaya F, Williams RJ, George R. Additive Manufacturing: A Novel Method for Fabricating Cobalt-Chromium Removable Partial Denture Frameworks. Eur J Prosthodont Restor Dent 2017;25:73-8.
[12] Lee JW, Park JM, Park EJ, Heo SJ, Koak JY, Kim SK. Accuracy of a digital removable partial denture fabricated by casting a rapid prototyped pattern: A clinical study. J Prosthodont 2017;218:468-74.
[13] Bibb R, Eggbeer D, Williams R. Rapid manufacture of removable partial denture frameworks. Rapid Prototyping J 2006;12:95-9.
[14] Williams RJ, Bibb R, Eggbeer D, Collis J. Use of CAD/CAM technology to fabricate a removable partial denture framework. J Prosthodont 2006;16:96-9.
[15] Ye H, Ning J, Li M, Niu L, Yang J, Sun Y et al. Preliminary Clinical Application of Removable Partial Denture Frameworks Fabricated Using Computer-Aided Design and Rapid Prototyping Techniques. Int J Prosthodont 2017;30:348-53.
[16] Kruth JP, Merceïs P. Residual stresses in selective laser sintering and selective laser melting. Rapid Prototyp J. 2006;5:254-65.
[17] Tasaka A, Shimizu T, Kato Y, Okano H, Ida Y, Higuchi S, et al. Accuracy of removable partial denture framework fabricated by casting with a 3D printed pattern and selective laser sintering. J Prosthodont Res 2019 doi: 10.1016/j.jpor.2019.07.009.
[18] Chen HH, Li H, Zhao Y, Zhang X, Wang Y, Liu P. Adaptation of removable partial denture frameworks fabricated by selective laser melting. J Prosthodont 2019;12:316-24.
[19] Stem MA, Brudvik JS, Frank RP. Clinical evaluation of removable partial denture rest seat adaptation. J Prosthodont 1985;53:658-62.
[20] Diwan R, Talic Y, Omar N, Sadiq W. The effect of storage time of removable partial denture wax pattern on the accuracy of fit of the cast framework. J Prosthodont 1997;77:375-81.
[21] Ali M, Naim R, Sherriff M, Water NE. The distortion of cast cobalt-chromium alloy partial denture frameworks fitted to a working cast. J Prosthodont 1997;78:419-24.
[22] Dunham D, Brudvik JS, Morris WJ, Plummer KD, Cameron SM. A clinical investigation of the fit of removable partial dental prosthesis clasp assemblies. J Prosthodont 2006;95:323-6.
[23] Gowri V, Patil NP, Nadiger RK, Gutta SS. Effect of anchorage on the accuracy of fit in removable partial denture framework. J Prosthodont 2010;19:387-90.
[24] Gebelein M, Richter G, Range U, Reitermeier B. Dimensional changes of one-piece frameworks cast from titanium, base metal, or noble metal alloys and supported on telescopic crowns. J Prosthodont 2003;89:193-200.
[25] Schmutzler C, Zimmermann A, Zaeh MF. Compensating Warpage of 3D Printed Parts Using Free-Form Deformation. Procedia CIRP 2016;41:1017-22.
[26] Revilla-León M, Özcan M. Additive Manufacturing Technologies Used for Processing Polymers: Current Status and Potential Application in Prosthetic Dentistry. J Prosthodont 2019;28:1466-158.
[27] Burnett CA, Brudvik MJ, Morris WJ, Plummer KD. The effect of storage time of removable partial denture frameworks fabricated by selective laser melting. J Prosthodont 2017;26:278-281.
[28] Lewis AJ. Radiographic Evaluation of Porosities in Removable Partial Denture Castings. J Prosthodont 1978;39:278-281.
[29] Malekjafarian A, OBrien EJ, Micu LA. Investigation of Buckling Capacity of Metal Materials Manufactured by Laser 3D Printing. Procedia Manuf 2017;7:696-700.

Copyright: This is an open-access article distributed under the terms of Creative Commons Attribution License 4.0 (CCBY 4.0), which allows users to distribute and copy the material in any format so long as attribution is given to the author(s).