Original Article

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A preliminary study on fit accuracy of removable partial denture frameworks fabricated digitally and conventionally using the micro-CT

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Objectives: To compare the fit accuracy of the retentive clasps as parts of removable partial denture frameworks fabricated by digitally assisted technique and that fabricated by a conventional procedure using the micro-computed tomography (micro-CT) analysis.

Materials and Methods: A cobalt-chromium (Co-Cr) model with partial edentulous area at the upper right second premolar was constructed and used as a master model. Three groups of removable partial denture frameworks with direct retainers on the upper right first premolar and the upper right first molar were fabricated (n=5). The first group was digitally scanned by an intraoral scanner. In the second group, a conventional impression was taken with alginate, poured with type IV gypsum and digitally scanned by a laboratory scanner. Both groups were virtually surveyed, designed and 3D-printed as resin frameworks prior to lost-wax casting. The third group was conventionally fabricated. The frameworks from each group were then positioned on the Co-Cr master model. The gap widths were analyzed at the terminal end of the retentive clasp using the micro-CT. A two-way ANOVA with a multiple comparison Bonferroni test was used to compare the mean differences of gap width among the groups and the mean differences of gap width between teeth in the same group at 0.05 significance level.

Results: The mean gap width of the second group that received a laboratory scanning was significantly greater than those of the other groups. There was no statistically significant difference between the mean gap width of the frameworks received an intraoral scanning and a conventionally fabricated ($p>0.05$). Furthermore, the statistically significant difference of the mean gap width between tooth 14 (151.19±1.12μm) and 16 (181.71±8.03μm) was observed only in the second group that received a laboratory scanning ($p<0.05$).

Conclusion: Removable partial denture frameworks fabricated from digitally-assisted technique with the use of intraoral scanning and a conventional procedure exhibited better fit accuracy than those fabricated digitally with the use of laboratory scanning.

Keywords: CAD/CAM, fit accuracy, gap discrepancy, micro-CT, removable partial denture frameworks

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Introduction

For decades, removable partial dentures (RPDs) have been one of the treatment options among partially edentulous patients [1] and sufficient retention is the key success of any removable prostheses' fabrication [2]. The conventional procedure not only relies on the experience of a dental technician, but also incorporates multiple errors and inaccuracies in every step and often affects the prosthesis fit. A poor-fitting prosthesis may lead to pain and discomfort which further cause patient dissatisfaction. It also increases the laboratory and dentist's cost and chair time [3-5].

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In recent years, digital dentistry that incorporates computer-controlled components is playing an important role in dental prosthesis fabrication. The three-dimensional computer-aided design and computer-aided manufacturing (CAD/CAM) technology has been introduced in fixed dental prostheses (FDPs) since 1980s. Instead of using a conventional impression technique, the digital impression is taken by either intraoral or laboratory scanner ~~is used~~ to capture the marginal detail and tooth structure. Any kind of indirect restorations can be then virtually designed using a specialized software and fabricated by means of a subtractive manufacturing [6]. The major advantage of a digital scanning is the capability of direct data acquisition from a prepared tooth in real time. It eliminates discomfort that patients may experience from a conventional impression procedure. It also minimizes cost, time and storage space for impression materials, disinfectants and gypsum models. Besides, the digital images can be stored indefinitely with good quality and achievability. However, some factors such as experience of dental technicians, requirement of implant-specific scan body, digital alteration of the occlusion, difficulty of scanning path should be taken into consideration [7].

Not only applicable in fixed dental prostheses, CAD/CAM also has potential to fabricate customized removable dental prosthesis by means of additive manufacturing through rapid prototyping [8]. One of the current techniques that is applied in dentistry is called “polyjet 3D printing” [9]. After scanning and designing each framework component, a photosensitive resin will be printed out layer by layer and solidified under ultraviolet light. Without the need of refractory model fabrication, the resin pattern can be further processed by lost-wax casting and manually polished similar to the conventional technique [8, 9]. It is expected that by decreasing human involvement and manufacturing steps, the fit accuracy of CAD/CAM-fabricated removable partial dentures should be equal or better than the conventional one with less time-consuming. However, unlike the fixed dental prostheses, there has been very few studies conducted on or ever compared the quality of the frameworks fabricated by conventional and CAD/CAM technique [10-15].

Currently, a methodology involving micro-computed tomography (micro-CT) has been proposed as a reliable and non-destructive method to evaluate the internal and marginal adaptation of dental restorations [16, 17]. It works in the same way as hospital CT scan, but on a smaller scale with greatly increased resolution. The benefit of using micro-computed tomography for scanning is the possibility of seeing both external and internal surfaces without damaging the model [16]. Moreover, it works with any surface, shape, color or material, up to a certain density and/or thickness penetrable with X-rays. Generally, generating time can be as fast as a few seconds or longer than an hour, depending on the resolution requirements, size and density of the object [18].

The purpose of this preliminary study was to compare the fit accuracy at the terminal end of the retentive clasps of removable partial denture frameworks fabricated by digitally assisted technique that received either intraoral or laboratory scanning and fabricated by conventional procedure using micro-computed tomography (micro-CT) analysis. The null hypothesis (H0) was that there were no differences in the gap width between three groups.

Materials and Methods

Master models preparation and framework design for removable partial denture

A type IV gypsum model with an edentulous area at 15 and tooth 14 and 16 *(standard AG-3 restorative typodont tooth, Practicon Inc., NC, USA)* was constructed as shown in Figure 1. The proposed framework design of a removable partial denture is shown in Figure 2. Akers clasps were designed as direct retainers on the abutment teeth with retentive arm engaged in 0.01 inch-undercut in relation to the path of insertion and survey lines, and reciprocal arms placed above the height of contour. Two occlusal rest seats were located adjacent to the edentulous space on both abutment teeth with 1.5 millimeters in depth and one-third of the buccolingual distance in width. The minor connector was round-mesh. After tooth preparation was done on the gypsum model, this model was then duplicated with polyvinyl siloxane (PVS) impression material *(Wacker Dental ADS611, Wacker Chemie AG, Munich, Germany)* and casted using cobalt-chromium (Co-Cr) alloys as a master model *(Vitallium® Alloy, Dentsply Sirona, PA, USA)*. The outer surface was air-abraded with aluminum oxide (particle size 50 *μm*) using a laboratory sandblaster *(Hi-Blaster III, Shofu Co., Kyoto, Japan)*. The indentations were made by a small carbide bur at three different areas of each abutment tooth to represent the terminal end, middle third and occlusal third of the retentive clasp as shown in Figure 3.

Figure 1 A type IV gypsum model with standard AG-3 restorative typodont tooth 14, 16 *(Practicon Inc., NC, USA)* and edentulous space at 15.

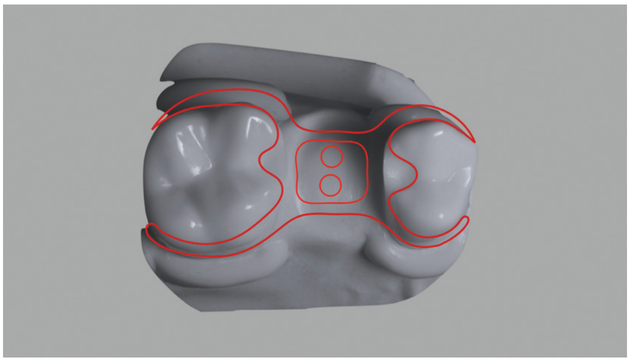

Figure 2 The design of removable partial denture framework consisted of direct retainers, i.e. Akers clasps engaged at 0.01-inch, reciprocal clasp arms, mesial and distal occlusal rest on tooth 14 and 16, and a retentive round-mesh minor connector.

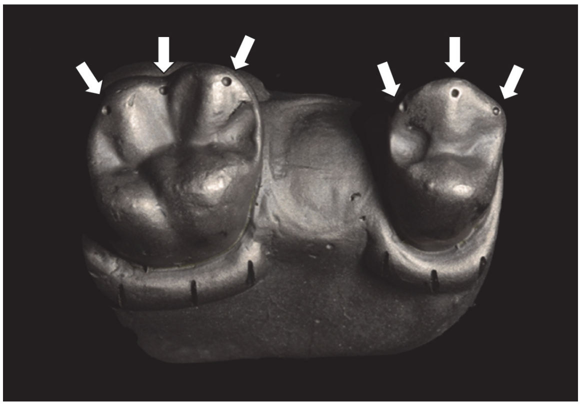

Figure 3 The indentation was made at three different areas on each abutment tooth to represent the terminal end, middle and occlusal third of the retentive clasps.

Experimental groups

The materials used in this experiment are shown in Table 1. Three experimental groups were involved; two groups were digitally assisted with digital scanning and the last group was conventionally made. In the first group (n=5), the Co-Cr master model was scanned with 3Shape TRIOS®3 intraoral scanner *(3Shape A/S, Copenhegen, Denmark)* whereas in the second group (n=5), the conventional impression with alginate (Kromopan USA Inc., Illinois, USA) was taken, poured with type IV gypsum and scanned with 3Shape D900L laboratory scanner *(3Shape A/S, Copenhegen, Denmark)*. The removable partial denture frameworks were designed with a CAD software *(3Shape Dental System™)*. A clasp's stabilizer was added in both digitally-assisted groups to prevent both retentive and reciprocal clasps from being mispositioned as shown in Figure 4. The Objet30 Prime *(Stratasys, MN, USA)* was used for 3D printing of the resin pattern. The lost-wax casting was then processed and finished by a single operator without grinding the intaglio surfaces of the clasps. In the third group (n=5), the removable partial denture frameworks were fabricated by a conventional procedure.

Gap assessment and measurement

The removable partial denture frameworks from each group were positioned on the Co-Cr master model. The gap widths between abutment teeth and retentive clasps were analyzed using micro-CT *(SKYSCAN 1173, Bruker Corp., Aartselaar, Belgium)* with data viewer software version 1.5.4.6 and CT analyzer software version 1.16.10. The scanning parameters are shown in Table 2. In this preliminary study, the gap widths were analyzed only at the indented area representing the terminal ends of the retentive clasps as shown in Figure 5 and 6.

Statistical analysis

For each group, the gap widths at the terminal end of the retentive clasps were recorded. Shapiro-Wilk test and Levene's test were performed to validate the normality of the data and equality of variances between groups of data, respectively. A two-way ANOVA with multiple comparison (Bonferroni test) was used to compare the mean differences of gap width among the groups and the mean differences of gap width between teeth in the same group at 0.05 significance level.

Table 1 Materials used in this experiment

Materials	Manufacturer
Kromopan® 100 Chromatic Alginate Type 1	Kromopan USA Inc., Illinois, USA
M-Dent® Dental Gypsum Product Anti-microbial Dental stone type IV	Noritake SCG Plaster, Bangkok, Thailand
Casting Wax	BEGO GmbH & Co. KG, Bremen, Germany
Polyjet Photopolymer MED610™	*Stratasys*, Minnesota USA
Objet Support SUP705	*Stratasys,* Minnesota, USA
VR investment	Dentsply Sirona, Pennsylvania, USA
CADVEST	Nobilium, New York, USA
Vitallium® Alloy	Dentsply Sirona, Pennsylvania, USA

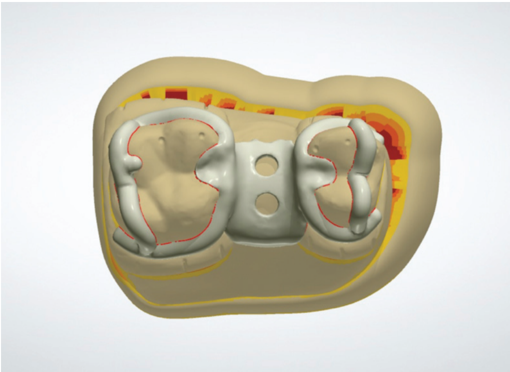

Figure 4 The clasp's stabilizers in digitally-assisted group connected retentive and reciprocal clasp arms.

Table 2 Micro-CT scanning parameters used in gap analysis

Accelerating voltage	130 kV
Current	61 μA
Exposure time	2950 ms per frame
Filter	Brass
Rotation step	0.1°

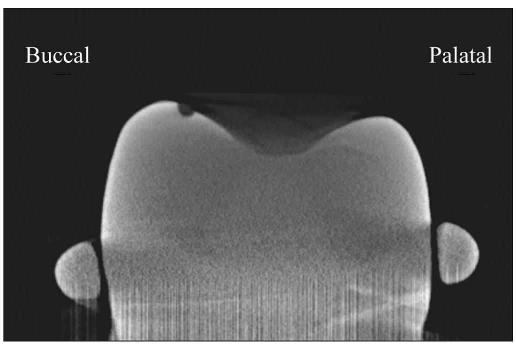

Figure 5 The micro-CT image for gap analysis on tooth 16 at the indented area representing terminal end of the retentive clasp.

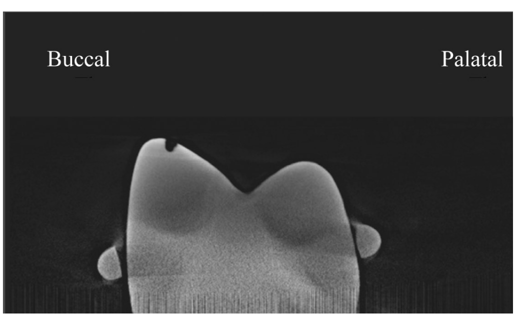

Figure 6 The micro-CT image for gap analysis on tooth 14 at the indented area representing terminal end of the retentive clasp.

Results

The results from a micro-CT analysis revealed the gap between teeth and the terminal end of retentive clasps in all groups. The mean gap widths with standard deviation (μm) are shown in Table 3. The mean gap width of the second group that used a laboratory scanner was statistically significantly greater than those of the other groups. There was no statistically significant difference between the mean gap width of the frameworks fabricated via an intraoral scanning and a conventional procedure ($p>0.05$). Furthermore, the statistically significant difference of the mean gap width between tooth 14 (151.19±1.12 μm) and 16 (181.71±8.03 μm) was observed only in the second group ($p<0.05$).

Discussion

Micro-computed tomography or micro-CT is a three-dimensional x-ray imaging system [16]. It is a non-destructive testing method which in recent years has changed from a qualitative imaging to a quantitative measurement in various applications, especially in the materials sciences [17-20]. It has great advantages in studying and detecting any objects that have complexity in size and shape without the need of sample preparation, staining or thin slicing [16-19]. In this study, rather than a conventional light microscopy and internal replication with elastomeric impression materials such as light-body silicone, the micro-computed tomography scanning was used as an alternative technique to investigate the fit of cobalt-chromium framework on the abutment teeth [21-22].

Table 3 Mean and standard deviation (μm) of gap widths at the terminal end of the retentive clasp

Group	Gap width at terminal end of the retentive clasp	
	Tooth 14	Tooth 16
1. *3Shape TRIOS3 intraoral scanning* (n=5)	123.9±4.9 [A,a]	117.0±2.3 [C,a]
2. *3Shape D900L laboratory scanning* (n=5)	151.2±1.1 [B,b]	181.7±8.0 [D,c]
3. *Conventional procedure* (n=5)	108.4±7.9 [A,d]	114.0±2.8 [C,d]

* *Mean pairs with different superscripts represent statistical difference (P<0.05).*

* *Capital letters indicate statistical differences among groups in a column.*

* *Lower case letters indicate statistical differences between tooth 14 and 16 of the same group in a row.*

Many studies reported the possibility and success of CAD/CAM application on the removable partial dental prosthesis [10-15]. Theoretically, in order to achieve the optimal retention and stability for removable partial dentures, the abutment teeth should be engaged at least three areas which are the occlusal rest, retentive terminal clasp area, and reciprocal clasp area [23]. It has been expected that any digitally-assisted techniques should have better fit accuracy than the conventional procedure due to superior scanning accuracy and lesser human intervention. However, in this experiment, the digitally-assisted group using laboratory scanning presented the greatest gap widths. Therefore, the null hypothesis was rejected.

From the present study, the mean gap widths of digitally-assisted groups were in the range of 117 μm to 181 μm whereas the mean gap widths of conventionally-made group were in the range of 108 μm to 114 μm. The results were consistent with that reported by Lee JW et al., 2017 with mean gap width of digitally-assisted group of 162.33±131.2 μm [21]. Arnold C et al., 2018 reported the mean horizontal and vertical gap width of the retentive clasps fabricated by indirect rapid prototyping (wax inject printing combined with lost-wax technique) were 323±188 μm and 112±60 μm, respectively whereas the mean horizontal and vertical discrepancy of the conventional technique were 133±59 μm and 74±25 μm, respectively [22].

An inaccuracy of alginate impression material varies between 44 and 188 μm [24]. It is crucial that the digital scanners used in dental prosthesis fabrication should have equal or higher accuracy than a conventional impression. The trueness and precision of 3Shape TRIOS3® intraoral scanner used in this study were reported to be 6.9±0.9 μm and 4.5±0.9 μm, respectively [23]. For 3Shape D900L, on the other hand, is a laboratory scanner with high accuracy up to 7 μm [24]. Both digital scanners were clinically satisfied and acceptable in case of single-tooth restorations [26, 27]. However, in case of long-span restorations such as fixed prostheses with more than five elements, full-arch prostheses on natural teeth or dental implants, they could introduce more systematic errors and result in failure of prosthesis fabrication [27-30]. Unlike the intraoral scanning, the group using laboratory scanning accumulated the errors introduced by a conventional impression procedure including the handling properties of both impression materials and a gypsum model resulting in a greater discrepancy in this study. Moreover, the mean gap width of tooth 16 was only statistically significantly larger than tooth 14 in the digitally-assisted group using laboratory scanning. This could be associated with the limitation of a laboratory scanner in detecting the anatomical complexity of a molar tooth in comparison with a premolar.

For the digitally-assisted groups, the accuracy of a 3D-printing machine, thickness of liquid photopolymers' layers and post-printing process all together play crucial roles in the final fit of the removable partial denture frameworks. It greatly varies depending on shape, geometry, size and orientation of the original models. Lee Ky et al. reported that the printed resin patterns made by polyjet 3D printing tended to be 0.71% slightly larger than the original models in both linear and volumetric measurement [31]. However, within the limitation of this preliminary study, the fit accuracy of the printed resin pattern and clasps has not yet been investigated.

The fabrication of removable partial denture frameworks of both digitally-assisted groups and a conventionally-made group in this study were still relied on the traditional lost-wax casting. The accurate casting is difficult to achieve in terms of size and shape due to the dimensional changes of investment materials, metal alloy solidification shrinkage and distortion of the wax pattern [32, 33]. In addition, CADVEST *(Nobilium, NY, USA)* is a phosphate-bonded investment specially developed for using with printed resin patterns. The studies of this material in regard to quality and accuracy of the removable partial denture frameworks have not yet been fully explored in the literature.

Conclusion

Removable partial denture frameworks fabricated from digitally-assisted technique with the use of intraoral scanning and a conventional procedure exhibited better fit accuracy than those fabricated digitally with the use of laboratory scanning.

References

1. Frank RP, Brudvik JS, Leroux B, Milgrom P, Hawkins N. Relationship between the standards of removable partial denture construction, clinical acceptability, and patient satisfaction. ***J Prosthet Dent*** 2000; 83: 521-7.
2. Shams A, Tavanafar S, Dastjerdi MR, Chaijan KA. Patient satisfaction and complication rates after delivery of removable partial dentures: A 4-year retrospective study. ***SRM J Res Dent Sci*** 2015; 6: 225-9.
3. Rudd RW, Rudd KD. A review of 243 errors possible during the fabrication of a removable partial denture: part I. ***J Prosthet Dent*** 2001; 86: 251-61.
4. Rudd RW, Rudd KD. A review of 243 errors possible during the fabrication of a removable partial denture: part II. ***J Prosthet Dent*** 2001; 86: 262-76.
5. Rudd RW, Rudd KD. A review of 243 errors possible during the fabrication of a removable partial denture: part III. ***J Prosthet Dent*** 2001; 86: 277-88.
6. Miyazaki T, Hotta Y, Kunii J, Kuriyama S, Tamaki Y. A review of dental CAD/CAM: current status and future perspectives from 20 years of experience. ***Dent Mater J*** 2009; 28: 44-56.
7. Alghazzawi T. Advancements in CAD/CAM technology: Options for practical implementation. ***J Prosthodont Res*** 2016; 60: 72-84.
8. Abduo J, Lyons K, Bennamoun M. Trends in Computer-Aided Manufacturing in Prosthodontics: A Review of the Available Streams. ***Int J Dent*** 2014; 1-15.
9. Nayar S, Bhuminathan S, Bhat WM. Rapid prototyping and stereolithography in dentistry. ***J Pharm Bioallied Sci*** 2015; 7: S216-9.
10. 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.
11. Williams RJ., Bibb R, Rafik T. A technique for fabricating patterns for removable partial denture frameworks using digitized casts and electronic surveying. ***J Prosthet Dent*** 2004; 91: 85-8.
12. Hussein OM, Hussein LA. Novel 3D Modeling Technique of Removable Partial Denture Framework Manufactured by 3D Printing Technology. ***Int J Adv Res*** 2014; 2: 686-94.

13. Bibb RJ., Eggbeer D., Williams RJ., Woodward A. Trial fitting of a removable partial denture framework made using computer-aided design and rapid prototyping techniques. *Proc Inst Mech Eng H* 2006; 220: 793-7.
14. Williams R. J., Bibb R., Eggbeer D., Collis J. Use of CAD/CAM technology to fabricate a removable partial denture framework. *J Prosthet Dent* 2006; 96: 96-9.
15. Lang L. A., Tulunoglu I. A critically appraised topic review of computer-aided design/computer-aided machining of removable partial denture frameworks. *Dent Clin North Am* 2014; 58: 247-55.
16. Wakabayashi K, Sohmura T, Nakamura T, Kojima T, Kinuta S, Takahashi J, Yatani H. New evaluation method by microfocus radiograph CT for 3D assessment of internal adaptation of all-ceramic crowns. *Dent Mater J* 2005; 24: 362-7.
17. Borba, M., Cesar, P. F., Griggs, J. A., & Della Bona, Á. Adaptation of all-ceramic fixed partial dentures. *Dent Mater* 2011; 27: 1119–26.
18. Swain M. V., Xue J. State of the art of Micro-CT application in dental research. *Int J oral Sci* 2009; 1:177-88
19. Shahmoradi M, Swain M.V. Quantitative characterization and micro-CT mineral mapping of natural fissural enamel lesions. *J Dent* 2016; 46:23-9
20. Du Plessis A, le Roux S, Els J, Booysen G, Blaine D. Application of microCT to the non-destructive testing of an additive manufactured titanium component. *Case Studies in Nondestructive Testing and Evaluation* 2015; 4:1-7.
21. 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 Prosthet Dent* 2017; 118; 468-474.
22. Arnold C, Hey J, Schweyen R, Setz JM. Accuracy of CAD-CAM-fabricated removable partial dentures. *J Prosthet Dent* 2018; 119: 586-92
23. Carr, Alan B, David T. Brown, and William L. McCracken's Removable Partial Prosthodontics. 13th ed. St. Louis, Mo: Mosby, 2015.
24. Peutzfeldt A, Asmussen E. Accuracy of alginate and elastomeric impression materials. *Scand J Dent Res* 1989; 97: 375-9.
25. Hack GD., Patzelt S. Evaluation of the Accuracy of Six Intraoral Scanning Devices: An in-vitro Investigation. *J Am Dent Assoc* 2015; 10: 1-5.
26. Luthardt RG, Loos R, Quaas S. Accuracy of intraoral data acquisition in comparison to the conventional impression. *Int J Comput Dent* 2005; 8: 283-94.
27. Mangano F, Gandolfi A, Luongo G, Logozzo S. Intraoral scanners in dentistry: a review of the current literature. *BMC Oral Health* 2017; 17: 149.
28. Ryakhovskiy A, Kostyukova V. Comparative analysis of 3D data accuracy of single tooth and full dental arch captured by different intraoral and laboratory digital impression systems. *Stomatologiia* 2016; 95 : 65.
29. Ender A., Attin T., Mehl A. In vivo precision of conventional and digital methods of obtaining complete arch dental impressions. *J Prosthet Dent* 2016; 115: 313-20.
30. Rudolph H., Salmen H., Moldan M., et al. Accuracy of intraoral and extraoral digital data acquisition for dental restorations. *J Appl Oral Sci* 2016; 24 : 85-94
31. Lee KY, Cho JW, Chang NY, Chae JM, Kang KH, Kim SC, Cho JH. Accuracy of three-dimensional printing for manufacturing replica teeth. *Korean J Orthod* 2015; 45 : 217-25.
32. Fenlon MR., Juszczyk AS., Hughes RJ., Walter JD., Sherriff M. Accuracy of fit of cobalt–chromium removable partial denture frameworks on master casts. *Eur J Prosthodont Restor Dent* 1993; 1: 127–30.
33. Anan MT, Al-Saadi MH. Fit accuracy of metal partial removable dental prosthesis frameworks fabricated by traditional or light curing modeling material technique: An in vitro study. *Saudi Dent J* 2015; 27: 149-54.