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RESEARCH AND EDUCATION

Seating-related adaptation and deformation of components of removable partial denture frameworks fabricated by different workflows

Jaafar Abduo, BDS, DClinDent, PhD, MRACDS (Pros),[a] Hadeel Ibrahim, BDS, DClinDent,[b] and Abdullah Barazanchi, BDS, DClinDent[c]

ABSTRACT

Statement of problem. Removable partial denture (RPD) frameworks have traditionally been produced by conventional impression making and casting. Due to the popularity of intraoral scanning (IOS) and digital manufacturing, RPD frameworks can be produced by alternative workflows.

Purpose. The purpose of this in vitro study was to assess the seating-related adaptation and deformation of components of RPD frameworks fabricated by different workflows.

Materials and methods. A partially edentulous mandibular arch was used as the master model. Three RPD framework manufacturing workflows were evaluated: the conventional impression making and casting (Imp-Cast) group, conventional impression making and digital fabrication by selective laser melting (Imp-SLM) group, and IOS and digital fabrication (IOS-SLM) group. According to each workflow, 10 frameworks were produced. The virtual superimposition of seated and unseated frameworks was executed to determine component adaptation (retentive arm, reciprocating arm, and occlusal rest) and component deformation (retentive arm and framework body). The 1-way analysis of variance (ANOVA) test was used to determine the differences among the groups (α=.05).

Results. No difference in component adaptation was observed for Imp-Cast and Imp-SLM (P>.05), and both were better than IOS-SLM (P<.001). The least retentive arm deformation was observed for Imp-SLM. Imp-Cast and Imp-SLM showed no difference in framework body deformation (P=.92), and both were better than IOS-SLM (P<.05). The IOS-SLM frameworks appeared narrower than the master model.

Conclusions. Frameworks fabricated from conventional casts exhibited comparable adaptation of components. In some comparisons, SLM fabrication was associated with less deformation than casting. Frameworks fabricated from IOS had the greatest adaptation error and deformation. As all the frameworks were seated on the master model without adjustment, the clinical relevance of this study's finding is yet to be determined. (J Prosthet Dent 2025;133:1080.e1-e9)

Removable partial dentures (RPDs) continue to be an acceptable treatment to replace missing teeth.[1–4] The traditional approach to fabricating RPD frameworks involves making an impression, producing a physical cast, fabricating a wax pattern, and casting the wax pattern with cobalt chromium (Co-Cr) alloy. Despite the reliability of this approach, it is technique sensitive and time-consuming, and requires a high level of technical skill.[1–7] In uncontrolled situations, the RPD framework may exhibit unacceptable intraoral fit that may create a gap between the framework and abutment teeth, increasing the risk of biological complications, pressure on the abutment, and eventually patient discomfort.[5,8–11] As a result, there is an ongoing interest in more reliable, less technique-sensitive, and more cost-efficient fabrication methods.

The recent advancement in digital technologies simplified RPD framework manufacturing by enabling more

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[a]Associate Professor in Prosthodontics, Convenor of Doctor of Clinical Dentistry (Prosthodontics) and Postgraduate Diploma in Clinical Dentistry (Implants), Melbourne Dental School, Melbourne University, Melbourne, Victoria, Australia.
[b]Clinical Lecturer in Prosthodontics and Convenor of Removable Prosthodontics, Melbourne Dental School, Melbourne University, Melbourne, Victoria, Australia.
[c]Senior Lecturer in Prosthodontics, Adelaide Dental School, The University of Adelaide, Adelaide, South Australia, Australia.

Clinical Implications

Frameworks fabricated from physical casts, whether digitally or conventionally, had comparable fit and deformation. While frameworks fabricated from IOS had greater error and deformation, the clinical significance of this observation is yet to be determined.

rapid and economical fabrication, requiring less laboratory manual work.[1,12–16] RPD frameworks can be additively produced by selective laser melting (SLM),[2,17] which involves the incremental building of the framework through melting metal powders with a high-energy laser beam.[17,18] SLM manufacturing has the advantage of producing large and complex specimens while still being highly accurate, making it ideal for RPD framework manufacturing.[19] Several laboratory and clinical reports have confirmed the usability of the SLM manufacturing of RPD frameworks and its acceptable outcomes in terms of fit and clinician and patient satisfaction.[1,5,11,20–28]

SLM frameworks can be produced using a physical definitive cast that is scanned with a laboratory scanner.[1–3] Alternatively, the workflow of RPD manufacturing can be further simplified by making a digital scan with an intraoral scanner (IOS), which simplifies the recording process for patients with a restricted mouth opening or a strong gag reflex.[16,29–31] The use of an IOS means the framework accuracy depends largely on the accuracy of the IOS, which is reduced with an increased scanning span and the involvement of edentulous areas and soft tissue.[21,29,32] Producing RPD frameworks without a physical definitive cast means framework fabrication errors are transferred directly to the intraoral tissue.[21,27,29,32]

The RPD framework should ideally seat on the abutment teeth with minimal gap and deformation of components, which translates to a more comfortable and reliable RPD.[5,8–11] It is anticipated that variations in framework fabrication techniques and workflows will influence the accuracy of fit and deformation pattern. Several RPD fit evaluation techniques have been implemented, including marginal gap evaluation, replica assessment, and 3-dimensional (3D) evaluation.[23,25,33,34] The present study used a 3D superimposition tool to measure the component adaptation and postseating deformation and aimed to evaluate the effect of RPD framework fabrication workflows on component adaptation and deformation. Two digital workflows were evaluated in the study: a conventional impression combined with digital fabrication workflow (Imp-SLM) and an IOS combined with digital fabrication workflow (IOS-SLM). The conventional workflow with conventional impression making and casting (Imp-Cast) served as the control. The null hypothesis was that the RPD framework fabrication workflow would have no effect on the adaptation or deformation of the components.

MATERIAL AND METHODS

A teaching model (Nissin Dental Model; Nissin Dental Products Inc) was modified by removing the second premolars and first molars. The modified model was replicated onto a master model with acrylic resin teeth and pink acrylic resin (Vertex Self-Curing Resin; Henry Schein). The master model represented a Kennedy class III modification 1 partially edentulous mandibular arch. All the abutment teeth had at least 0.25-mm buccal undercuts, and occlusal rest seats were prepared on the surfaces next to the edentulous areas (Fig. 1A). The dimensions of the occlusal rest seats were 3 mm mesiodistally, 3 mm buccolingually, and 1.5 mm occlusally.

The sample size was calculated with a software program (G*Power, v3.1.9.2; Heinrich-Heine-Universität Düsseldorf). With an effect size of 0.7,[5,24,25] α=.05, and a statistical power of 80%, a minimum of 9 frameworks per group were needed. Three framework groups were included (n=10): conventional impression making and casting (Imp-Cast), conventional impression making and digital fabrication (Imp-SLM), and IOS and digital fabrication (IOS-SLM). Ten trays were fabricated using light-polymerized acrylic resin material (LC Vertex; Henry Schein). Spacing of 3 mm was incorporated with 4

Figure 1. A, Occlusal view of master model. B, Representative Imp-Cast framework. C, Representative Imp-SLM framework. D, Representative IOS-SLM framework.

distributed stops. The fitting surface of the tray was coated with tray adhesive (VPS Tray Adhesive; Kerr Corp), and the impression was obtained at room temperature with light- and heavy-body polyvinyl siloxane impression material (Kerr Extrude; Kerr Corp). Ten dental casts were produced using type IV dental stone (GC Fujirock EP; GC Corp) and were used for the Imp-Cast group. The casts were converted to virtual casts after scanning with a laboratory scanner (Identica T300; Medit Corp) and were used for the Imp-SLM group.

The Imp-Cast group frameworks were fabricated by a commercial dental laboratory using conventional technique that involved producing refractory die, waxing, investing, and Co-Cr casting (Fig. 1B). The Imp-SLM group frameworks were designed on the virtual casts to simulate a combination of analog clinical workflow and digital laboratory workflow (Fig. 1C). For the IOS-SLM group frameworks, the master model was scanned 10 times using an IOS device (TRIOS 4; 3Shape A/S) in a mannequin head (Nissin Dental Simulator; Nissin Dental Products Inc). The virtual images were used for Co-Cr frameworks fabrication by SLM (Fig. 1D). The Imp-SLM and IOS-SLM frameworks were designed by a computer-aided design software program (exocad DentalCAD; exocad GmbH) and produced by an SLM-dedicated commercial dental laboratory with an SLM unit (AM 400; Renishaw). The SLM frameworks were oriented parallel to the occlusal plane with a build increment of 30 μm. All frameworks were designed according to the same laboratory work authorization that included an occlusal rest, buccal retentive arm, and lingual reciprocating arm on each abutment tooth. The selected major connector was a lingual bar to ensure the contact between the framework and the master model was only on the abutment teeth. The refinement and polishing of all the frameworks were completed by the dental laboratories.

All the frameworks were seated on the master model, and none of them required adjustment to improve the seating. Prior to the accuracy evaluation, each framework was scanned by the laboratory scanner in its passive and seated forms. For the passive form, the cameo and intaglio surfaces were scanned separately. The 2 surfaces were merged to generate a single virtual framework that captured the passive framework (passive image) prior to any potential seating-related deformation (Fig. 2A). In addition, the frameworks were scanned after seating on the master model to generate the virtual image of the seated framework (seating image) with possible deformation of the components (Fig. 2B). The master model was scanned with the laboratory scanner (Identica T300; Medit Corp) to serve as a reference image (Fig. 2C). Subsequently, 2 framework accuracy variables were evaluated: component adaptation and component deformation. For component adaptation, the passive image, seating image, and virtual master model were combined by using the seated image as reference for superimposition to relate the passive image to the virtual master model. The reference points for the passive image superimposition on the seated image were the occlusal rests, while the reference points for the superimposition of the virtual master model on the seated image were the cusp tips of the abutment teeth. Subsequently, the seating image was removed and the adaptation of each component (occlusal rest, retentive arm, and reciprocating arm) of the framework was measured on the master model (Fig. 2D). The adaptation referred to the distance between the intaglio surface of the component and the tooth surface. The measurements were completed manually at 1-mm intervals (Fig. 3A). If a space were detected between the component intaglio surface and the tooth surface, a positive direction was used to indicate a gap. For an overlap between the component intaglio surface and the tooth surface, negative direction was used to represent a binding region and subsequent deformation (Fig. 3B).

Deformation was evaluated at the retentive arm level and the framework body level. For the deformation of retentive arms, the passive image was superimposed against the seating image, and the deviations of the retentive arm on the seating image were quantified in comparison with those on the passive image (Fig. 3C, D). Each retentive arm was divided into 3 segments: base, middle, and tip. The framework body deformation was

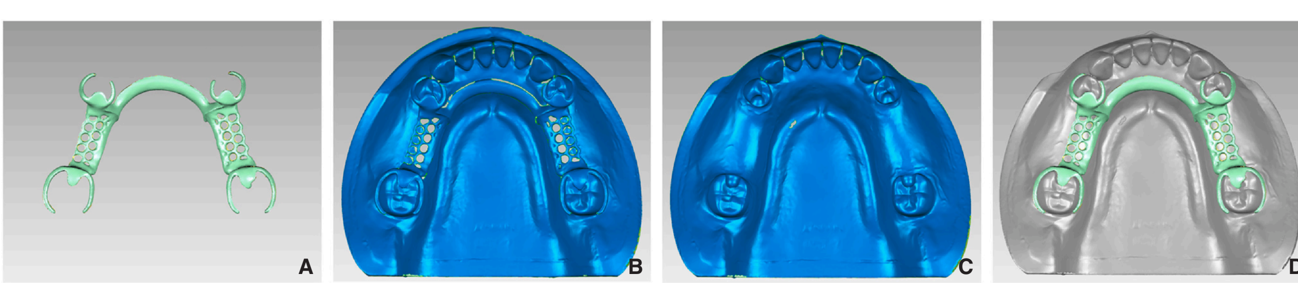

Figure 2. A, Passive image representing virtual framework without any seating-related deformation. B, Seating image comprised of scanned seated framework on master model. C, Virtual master model used as reference model. D, Following superimposition and removal of seating image, passive framework clearly visible on master model.

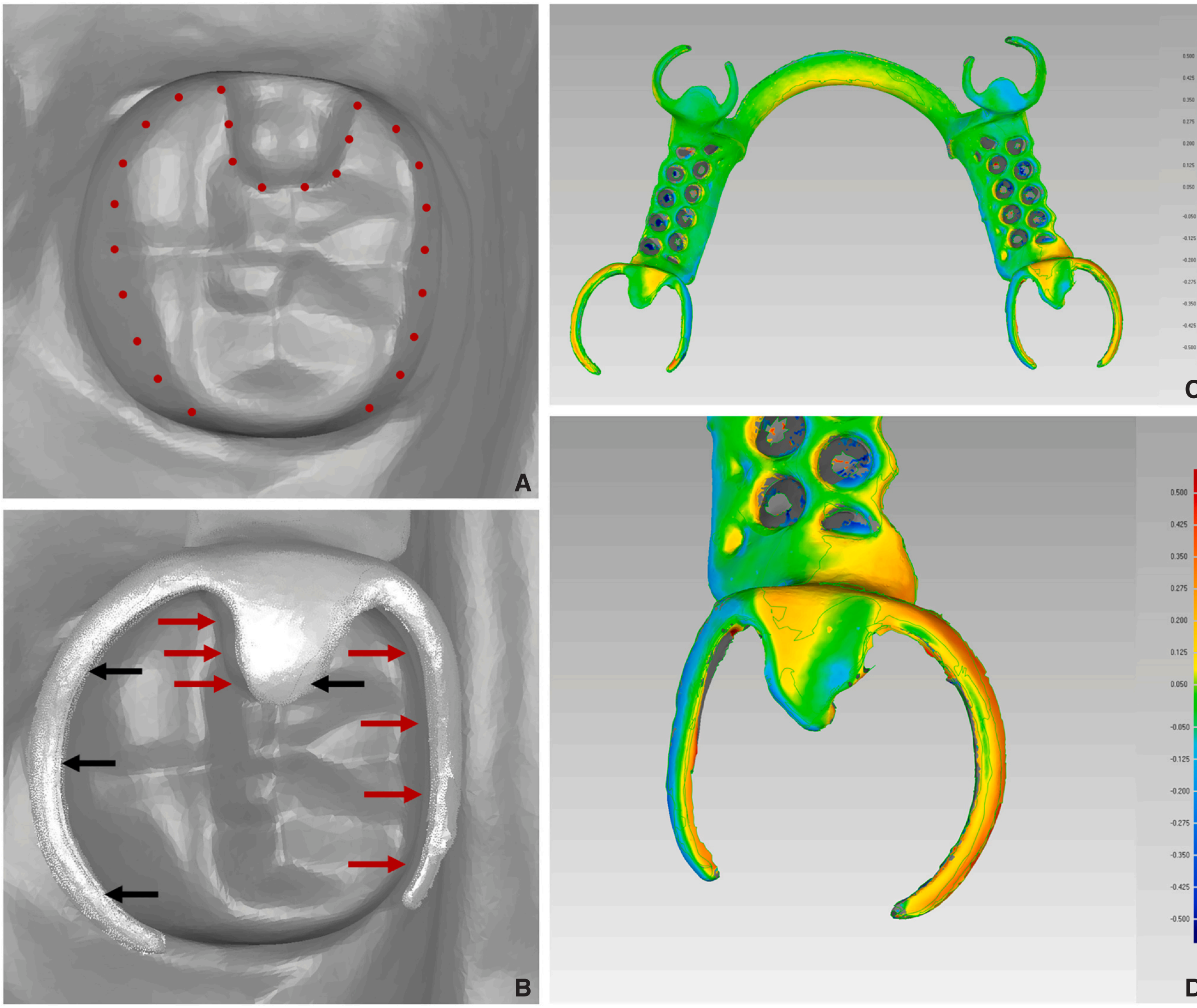

Figure 3. A, Illustration of 1-mm measuring intervals on abutment tooth around retentive arm, reciprocating arm, and occlusal rest. B, After virtual framework adaptation, detected gap recorded as +ve (*red arrows*), and overlapping region recorded as -ve (*black arrows*). C, Color coded map of virtual framework illustrating deformation pattern. D, Warmer colors on retentive arm indicate narrower retentive arm and buccal deformation following seating.

quantified by measuring the distance between the center of the occlusal rests on both sides at the premolar and molar levels. The difference between the distances on the frameworks on the passive image and seated image was determined. All the measurements were completed by a single operator (J.A.) using a metrology software program (Geomagic Control; 3D Systems).

The mean and standard deviation (SD) of the adaptation of components and deformation of components of every group were calculated. The Shapiro-Wilk test was applied to determine the normality of the data. Subsequently, the 2-way analysis of variance (ANOVA) test combined with Tukey post hoc tests were used to determine the differences among the groups. To evaluate the interaction between the fabrication workflow and retentive arm location, a 2-way ANOVA test was conducted. All statistical tests were completed with a statistical software package (IBM SPSS Statistics for Windows, v23; IBM Corp) (α=.05).

RESULTS

The 1-way ANOVA showed the significant effect of fabrication workflow on retentive arm adaptation (P<.001), reciprocating arm adaptation (P<.001), and occlusal rest adaptation (P<.001) (Table 1). For retentive arm adaptation, the post hoc test indicated no difference between the Imp-Cast and Imp SLM groups (P=.15), and both had better adaptation than the IOS-SLM

Table 1. Summary of adaptation magnitudes of retentive arm, reciprocating arm, and occlusal rest

	Imp-Cast	Imp-SLM	IOS-SLM	
	Retentive Arm			***P***
Mean (mm)	0.09	0.08	0.14	All<.001
SD (mm)	0.07	0.06	0.10	Imp-Cast vs Imp-SLM=.15
Maximum (mm)	0.34	0.29	0.50	Imp-Cast vs IOS-SLM<.001
Minimum (mm)	0.00	0.00	0.01	Imp-SLM vs IOS-SLM<.001
	Reciprocating arm			*P*
Mean (mm)	0.09	0.09	0.14	All<.001
SD (mm)	0.05	0.05	0.12	Imp-Cast vs Imp-SLM=.96
Maximum (mm)	0.32	0.24	0.51	Imp-Cast vs IOS-SLM<.001
Minimum (mm)	0.01	0.01	0.01	Imp-SLM vs IOS-SLM<.001
	Occlusal rest			*P*
Mean (mm)	0.13	0.13	0.17	All<.001
SD (mm)	0.08	0.07	0.12	Imp-Cast vs Imp-SLM=.99
Maximum (mm)	0.44	0.32	0.97	Imp-Cast vs IOS-SLM<.001
Minimum (mm)	0.02	0.02	0.02	Imp-SLM vs IOS-SLM<.001

Imp-Cast, conventional impression making and casting; Imp-SLM, conventional impression making and digital fabrication by selective laser melting; IOS-SLM, intraoral scanning and digital fabrication by selective laser melting; SD, standard deviation.

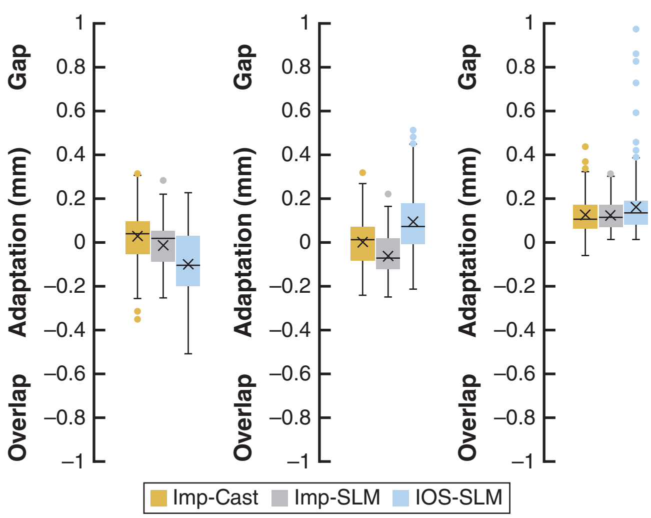

Figure 4. Box and whisker plots illustrating adaptation of different components. A, Retentive arm. B, Reciprocating arm. C, Occlusal rest.

group (*P*<.001). The Imp-Cast and Imp-SLM retentive arm adaptation was closer to 0, while the IOS-SLM group clearly had narrower retentive arms (Fig. 4A). No difference was found in the reciprocating arm adaptation for the Imp-Cast and Imp-SLM groups (*P*=.96). The IOS-SLM group had significantly worse reciprocating arm adaptation than the 2 groups (*P*<.001). In addition, the IOS-SLM reciprocating arm showed a tendency for spacing after seating (Fig. 4B). For the occlusal rest adaptation, the Imp-Cast and Imp-SLM showed no difference (*P*=.99), and both were better than the IOS-SLM group (*P*<.001). Most of the errors were positive (a gap between the framework rest and abutment rest seat), and the IOS-SLM group had noticeably larger gaps (Fig. 4C).

After the complete seating of the frameworks, all the groups showed deformation of the retentive arms, and none of the frameworks had completely passive retentive arms (Table 2). All the groups showed a greater tendency for the retentive arm to deform at the tip, followed by the middle and base (Fig. 5). The 2-way ANOVA revealed that the fabrication workflow had a significant effect on retentive arm deformation (*P*<.001), whereas the Imp-SLM had significantly less retentive arm deformation than Imp-Cast (*P*=.01) and IOS-SLM (*P*<.001) and the Imp-Cast and IOS-SLM were statistically similar (*P*=.09). The location on the retentive arm had a significant effect on the adaptation (*P*<.001). No difference was found between the base and the middle of the arm (*P*=.11), while the tip of the arm had significantly more deformation than the base (*P*<.001) and the middle (*P*<.002) of the arm. A significant interaction effect was found between the fabrication workflow and the retentive arm location (*P*<.001), indicating that the IOS-SLM was more prone to deformation at the tip of the arm.

The 1-way ANOVA showed a significant effect of the fabrication technique on total framework body deformation (*P*=.002). The IOS-SLM exhibited greater total framework body deformation, which was statistically significantly greater than that of Imp-Cast (*P*=.01) and Imp-SLM (*P*=.02), while the Imp-Cast and Imp-SLM were statistically similar (*P*=.92) (Table 3). All the IOS-SLM frameworks exhibited widening after seating on the master model, which indicated that the produced IOS-SLM frameworks tended to be narrower than the planned frameworks (Fig. 6).

DISCUSSION

The present study found that the different framework fabrication workflows influenced framework component adaptation and deformation. Frameworks fabricated from physical casts, whether digitally or conventionally, exhibited comparable fit and deformation. The digitally

Table 2. Summary of retentive arm deformation

	Imp-Cast	Imp-SLM	IOS-SLM	
	Retentive Arm Total Deformation			***P***
Mean (mm)	0.10	0.06	0.12	All<.001
SD (mm)	0.06	0.05	0.08	Imp-Cast vs Imp-SLM=.01
Maximum (mm)	0.28	0.28	0.28	Imp-Cast vs IOS-SLM=.09
Minimum (mm)	0.01	0.01	0.00	Imp-SLM vs IOS-SLM<.001
	Retentive arm base			*P*
Mean (mm)	0.08	0.03	0.08	All=.002
SD (mm)	0.04	0.02	0.07	Imp-Cast vs Imp-SLM=.01
Maximum (mm)	0.20	0.08	0.23	Imp-Cast vs IOS-SLM=.90
Minimum (mm)	0.01	0.01	0.00	Imp-SLM vs IOS-SLM=.004
	Retentive arm middle portion			*P*
Mean (mm)	0.09	0.06	0.11	All=.007
SD (mm)	0.049	0.03	0.08	Imp-Cast vs Imp-SLM=.11
Maximum (mm)	0.23	0.15	0.26	Imp-Cast vs IOS-SLM=.46
Minimum (mm)	0.03	0.02	0.00	Imp-SLM vs IOS-SLM=.003
	Retentive arm tip			*P*
Mean (mm)	0.12	0.10	0.16	All=.03
SD (mm)	0.08	0.06	0.09	Imp-Cast vs Imp-SLM=.75
Maximum (mm)	0.28	0.28	0.28	Imp-Cast vs IOS-SLM=.15
Minimum (mm)	0.01	0.05	0.01	Imp-SLM vs IOS-SLM=.03

Imp-Cast, conventional impression making and casting; Imp-SLM, conventional impression making and digital fabrication by selective laser melting; IOS-SLM, intraoral scanning and digital fabrication by selective laser melting; SD, standard deviation.

fabricated framework from IOS had greater error and deformation. Therefore, the null hypothesis that the RPD framework fabrication workflow would have no effect on component adaptation and deformation was rejected. The observed differences among the groups can be attributed to the IOS rather than the framework fabrication technique.

Ideal seating of RPD frameworks should allow close adaptation of framework components to natural teeth with minimal deformation.[5,8–11] Such adaptation will reduce patient discomfort, reduce the need for framework adjustments, minimize the risk of abutment teeth displacement, and ultimately reduce the risk of framework deformation after years of service. Framework fit can be evaluated by measuring the gaps between the seated framework components and the teeth. However, this technique measures the fit after complete seating and the deformation of the elastic components.[33] Additionally, the technique does not evaluate the internal adaptation of the frameworks and the degree of binding at the intaglio surfaces.[5,24,25] Thus, even if the framework appears accurately seated, it may still induce load on the abutment teeth. Other studies used the replica technique, placing light- body silicone on the fitting surface of the framework prior to seating.[23,25,34] While this technique can map the fit of the framework,

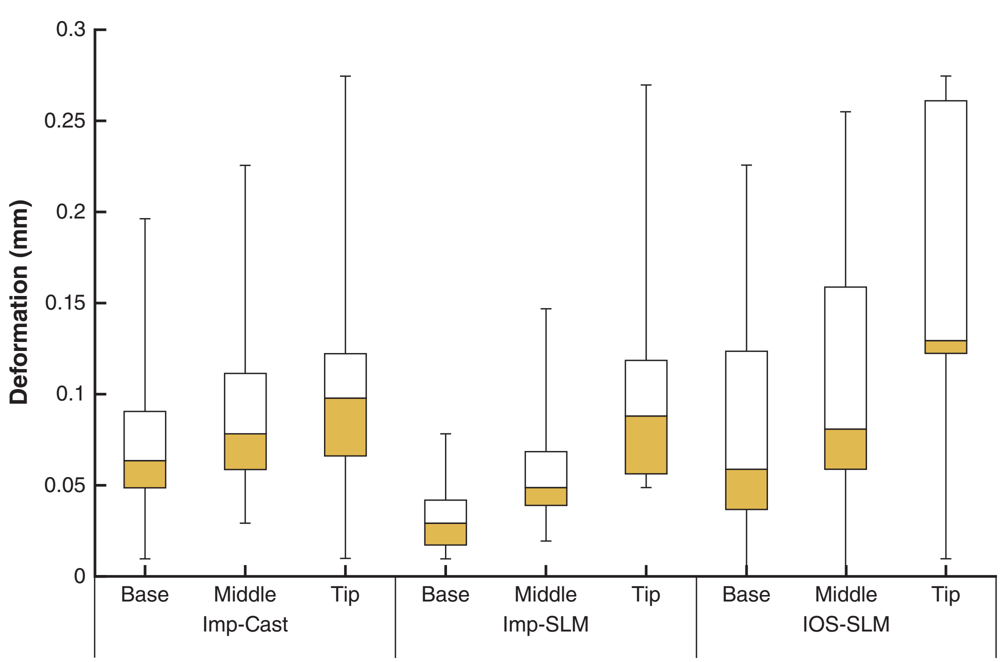

Figure 5. Box and whisker plot illustrating retentive arm deformation at different locations.

Table 3. Summary of framework body deformation

	Imp-Cast	Imp-SLM	IOS-SLM	
	Total Framework Deformation			*P*
Mean (mm)	0.15	0.19	0.44	All=.002
SD (mm)	0.12	0.15	0.42	Imp-Cast vs Imp-SLM=.92
Maximum (mm)	0.37	0.50	1.62	Imp-Cast vs IOS-SLM=.005
Minimum (mm)	0.01	0.00	0.03	Imp-SLM vs IOS-SLM=.015

Imp-Cast, conventional impression making and casting; Imp-SLM, conventional impression making and digital fabrication by selective laser melting; IOS-SLM, intraoral scanning and digital fabrication by selective laser melting; SD, standard deviation.

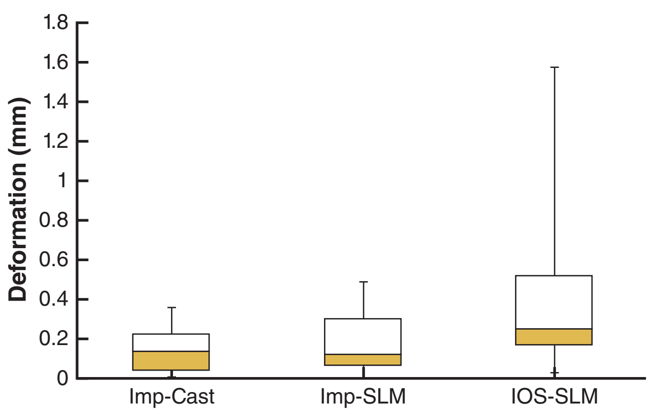

Figure 6. Box and whisker plot illustrating framework body deformation.

the silicone replica may distort or and tear when the framework is removed.[23,25] Recently, the virtual evaluation of framework accuracy has been used in laboratory studies[5,19,24] by superimposing scanned framework intaglio surface on the virtual framework design[5,19] or the virtual master model.[24] This approach is advantageous in mapping errors at the fitting surface of completely passive framework but does not quantify any seating-related error. To overcome these limitations, the present study implemented a method enabling framework assessment before and after seating on the master model. The key step involved using the seated framework virtual image as a reference for superimposition of the scanned framework onto the master model.

In the present study, the similar outcomes of Imp-SLM and Imp-Cast, which were fabricated on the same casts, confirm the reliability of the SLM fabrication of RPD frameworks. The accuracy of SLM has been attributed to a reduced number of fabrication steps and materials, reduced human intervention, and SLM versatility in producing large complex patterns with fine details.[2,5,12,14,15] The passive incremental fabrication of the SLM framework pattern further minimizes processing-related strains.[18] These fabrication features have been reported in several studies to explain the better fit of the SLM frameworks over conventional frameworks that involve waxing, casting, finishing, and polishing.[12,22,23] However, other studies[24,25,28,33,34] have indicated that frameworks produced by conventional workflows fit better than those produced by SLM. Such observations were attributed to SLM framework fitting surface roughness,[25,33] implications of the RPD design, design complexity, and partial edentulism presentation in the SLM manufacturing process.[24,34] Nevertheless, clinical studies[21,27] have confirmed the similarity between SLM and conventional cast frameworks in terms of clinical fitting time, accuracy of fit, and patient satisfaction.

In contrast with the SLM frameworks of the Imp-SLM group, the SLM frameworks of the IOS-SLM group had greater adaptation errors and deformation at every comparison. As the same manufacturing process was followed for the IOS-SLM and Imp-SLM groups, the greater errors and deformations can be related to the IOS process. IOS of the whole arch consists of numerous images of a confined field from one end of the arch to the other. The final virtual model of the arch is generated by stitching the various recorded images. It has been consistently shown that the longer the span and the greater the area of scanning, the greater the amount of stitching and, consequently, the greater the chance of error development.[31] This is further exaggerated by the necessity to scan all the tooth surfaces and soft tissue areas required for RPD fabrication, which further enlarges the total scanned area. Normally, the greatest error is found at extremities of the arch, where the scanned image appears narrower than the original model.[31] This finding was consistent with the observed IOS-SLM framework error and deformation where the frameworks were widened after seating on the master model, with these deformations being evident at the retentive arm and the body of the framework. Since all the IOS-SLM frameworks were seated on the master model without prior adjustments, it is likely that the whole framework deformed during seating, including the IOS-SLM framework major connector. This deformation can be attributed to the thinner SLM framework major connector and possibly the quality of the SLM metal. This observation appears contrary to those of previous laboratory and clinical reports that frameworks fabricated by SLM from IOS or conventional impressions did not differ.[24,29]

The observed Co-Cr framework adaptation and retentive arm deformation of the present study was up to 300 µm, similar to that reported by earlier studies (range of 50 to 400 µm).[1,12,15,20,25,27] Therefore, the differences observed among the different framework groups in the present study may not be clinically significant, and all of them were clinically acceptable as they were inserted with gentle pressure and without adjustment of the intaglio surface. Since the present study demonstrated that the SLM frameworks produced from conventional casts exhibited a consistently better fit than the frameworks produced from IOS, future studies are needed to evaluate the features that may influence the accuracy of IOS for RPD manufacturing, such as tooth alignment, edentulism pattern, and level of mouth opening. Further, the effect of microstructure, porosity, surface roughness, and material properties of SLM frameworks require further validation.[1,12,14,15,25]

The results from the present study should be interpreted with caution and cannot be generalized to different RPD designs. The outcome is generalizable to tooth-supported RPD design with short-span posterior edentulous areas. The presence of unbound or large-span edentulous areas requires further validation as it poses additional challenges when obtaining an IOS.[21,29,32] Further, the present study design did not simulate clinically relevant aspects that can influence the reliability of scanning, such as presence of saliva, variable soft tissue presentation, patient movement, body temperature, restricted mouth opening, and variations in abutment tooth condition.[21]

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. Frameworks fabricated from conventional casts exhibited comparable adaptation of components.
2. In some comparisons, the SLM fabrication had less deformation than casting.
3. Frameworks fabricated from IOS had the greatest adaptation error and deformation.
4. As all the frameworks were seated on the master model without adjustment, the clinical relevance of this study's findings is yet to be determined.

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Corresponding author:
Assoc Prof Jaafar Abduo
Melbourne Dental School
Melbourne University
720 Swanston Street
Melbourne, Victoria 3010
AUSTRALIA
Email: jaafar.abduo@unimelb.edu.au

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