

CLINICAL RESEARCH

Evaluation of removable partial denture frameworks fabricated using 3 different techniques



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ABSTRACT

Statement of problem. Rapid advancements in computer-aided design and computer-aided manufacturing (CAD-CAM) have opened new pathways in the fabrication of removable partial dentures (RPDs) through additive and subtractive processes. Questions remain whether the digital pathway is an acceptable one compared with conventional analog or combined analog and digital pathways.

Purpose. The purpose of this clinical study was to determine the quality of RPD frameworks fabricated using 3 different fabrication methods: analog, combined analog-digital, and digital.

Material and methods. Three RPD frameworks were fabricated for each of the 9 participants using each of the 3 techniques. Of the 9 participants enrolled, 4 were of Kennedy class I, 3 were of Kennedy class II, and 2 were of Kennedy class III. The first technique was completely analog: a physical impression was made using polyvinyl siloxane, stone casts were made, a survey was performed, and a laboratory technician waxed and cast the RPD framework. The combined analog-digital workflow had the analog steps, but the stone cast was scanned with a laboratory scanner to generate a digital cast. The 3Shape CAD software was then used to design a digital RPD, which was fabricated from a cobalt-chromium alloy by selective laser melting. The third technique was completely digital: an intraoral digital scanner was used to make a definitive scan, which was sent to the 3Shape software for digitally designing the RPD framework and subsequent selective laser melting for fabrication. For all frameworks in the same participant, the same design was used for consistency. The evaluation consisted of a yes/no survey with 7 framework-related parameters and was completed by 5 clinicians. For statistics, an overall *P* value was calculated using a chi-squared test to determine any difference among the groups ($\alpha=.05$).

Results. Seven of the 9 participants received the framework fabricated using the digital pathway as their definitive prosthesis. The completely digital method was significantly better than the traditional method of analog fabrication ($P<.001$). Intraoral scanning was also significantly better than the combined method of fabrication ($P<.001$). The completely analog method was better than the combined method of framework fabrication ($P=.008$).

Conclusions. Within the limitations of this clinical study, it was concluded that the combined analog-digital pathway of RPD fabrication was the least clinically acceptable one as determined by 5 calibrated clinicians using a yes/no questionnaire, whereas the completely digital method of fabrication was found to be the best. (*J Prosthet Dent* 2019;122:390-5)

Rapid advancements in computer-aided design and computer-aided manufacturing (CAD-CAM) have opened new pathways in the fabrication of removable partial denture (RPD) frameworks through additive and subtractive processes.¹ To produce a digital file that can be milled or 3D printed, sophisticated 3D dental modeling software programs have been used. Several commercial CAD software systems, including 3Shape Dental System and

Exocad, have recently become available for 3D designing of RPD frameworks.²

Once digitally designed, different pathways exist for the fabrication of the RPD framework. The typical digital workflow includes obtaining a digital model of the oral hard and soft tissues. This can be accomplished directly from an intraoral digital scan or from a laboratory digital scan of a stone cast. Second, the path of insertion is defined, and undercuts are color coded based on the

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Clinical Implications

The digital pathway for removable partial denture framework fabrication is a viable alternative to analog techniques.

depth. Subsequently, the virtual block-outs are automatically calculated and displayed on the virtual cast. The retention grid and major connector are designed, followed by the rests and clasps.²

After the design is completed, the software will digitally export the designed RPD framework in the form of a stereolithography (SLA) file. The SLA file can be used for the additive or subtractive manufacturing of the RPD framework.² Depending on the manufacturing process, a definitive prosthesis can be made directly from the digital design or from an intermediate product in the form of a resin-elimination pattern which will subsequently be invested and cast.³⁻⁶ These new digital workflows may be beneficial compared with the traditional process of waxing and investing, where wax pattern distortion and refractory cast distortion may lead to poorly fitting castings.^{7,8}

Although dentistry has had a long association with subtractive manufacturing such as milling, 3D printing has opened new possibilities of manufacturing which are impossible with subtractive manufacturing.⁴ Additive manufacturing 3D printing techniques include SLA, digital light projection (DLP), jet printing, fused deposition modeling (FDM), and selective laser melting (SLM).⁹ The SLA technique uses ultraviolet (UV) lasers for polymerization of photosensitive resin materials in small layer thicknesses ranging from 10 μm to 100 μm depending on the accuracy desired. This technique is used to manufacture a wide variety of objects, including dental casts, resin wax patterns, resin RPD frameworks, interim restorations, removable denture-base material, denture teeth, and surgical guides.⁴⁻⁶ DLP has a similar accuracy and range of uses but is a much faster technology and can polymerize an entire layer in 1 pulse. Postprint polymerization is used for both DLP and SLA with a light-emitting diode UV light source to ensure complete polymerization and biocompatibility.^{4,5}

Jet printing uses a series of resin-jet print heads from which thin streams of resin material are jetted onto the build platform to create each incremental layer. Each jetted layer is then polymerized using a UV light source. Finally, SLM is a technique that melts metal powders using high-power lasers which results in fusion of the powder particles into a solid layer. This technique can be used to print titanium and cobalt-chromium alloy (Co-Cr) for RPD frameworks.^{4,5} Laboratories can use these additive techniques to fabricate removable dental

prostheses. Recently, SLM has been shown to produce clinically acceptable RPD frameworks.² Furthermore, these SLM Co-Cr alloy frameworks are considered to have better microstructure and mechanical properties than cast or milled RPD frameworks.¹⁰

These digital design and manufacturing workflows on the laboratory side can be combined with digital definitive scans on the clinical side for an all-digital workflow. The literature is mixed regarding the accuracy of complete-arch and edentulous digital scans.¹¹⁻¹⁹ Recently, digital scans have been shown to have significantly better trueness than physical impressions for edentulous arches.¹¹ Trueness is a measure of how close the scan is to reality and is defined as the measurement bias or systematic error between the reference object and the target object.²⁰ In general, the literature suggests that digital scans have the same accuracy as conventional impressions when they are used for hard tissues.¹²⁻¹⁵

In contrast, some studies have concluded that edentulous tissue scanning is difficult and lacks the accuracy of hard-tissue scanning.^{16,18} However, high accuracy may not be as critical in edentulous areas as the soft tissues have been reported to depress up to 300 μm beneath the distal extension of an RPD.¹⁶ A recent study reported that the median value of trueness for edentulous areas was 54 to 180 μm and the precision was 109 to 215 μm .¹¹ This trueness is consistent with that of other studies reporting on complete-arch scan accuracy.¹⁹

The scan pattern affects the accuracy of intraoral digital scans and can lead to a wide discrepancy in precision.²¹ In addition, the scanner type used can also lead to varying levels of trueness and precision, with some scanners performing better than others.¹⁷ For this reason, many clinicians are more comfortable with analog impression techniques. The laboratory may choose to convert the physical stone cast or analog impression into a digital cast using a laboratory scanner. These scanners are remarkably accurate.^{17,21}

The purpose of this study was to evaluate the clinical fit of RPD frameworks produced by 3 manufacturing pathways: analog, combined analog-digital, and digital. The null hypothesis was that no difference would be found in clinical acceptability as determined by 5 calibrated clinicians using a yes/no questionnaire.

MATERIAL AND METHODS

The appropriate institutional review board approval was obtained, and 9 participants were randomly selected to participate in this clinical study. Simple random sampling was used to select individuals from a list of potential participants using a table of random numbers. Three RPD frameworks were fabricated for each of the 9 participants using each of the 3 techniques, labeled 1 to 3 (Fig. 1). Of the 9 participants selected, 4 were of Kennedy class I (all

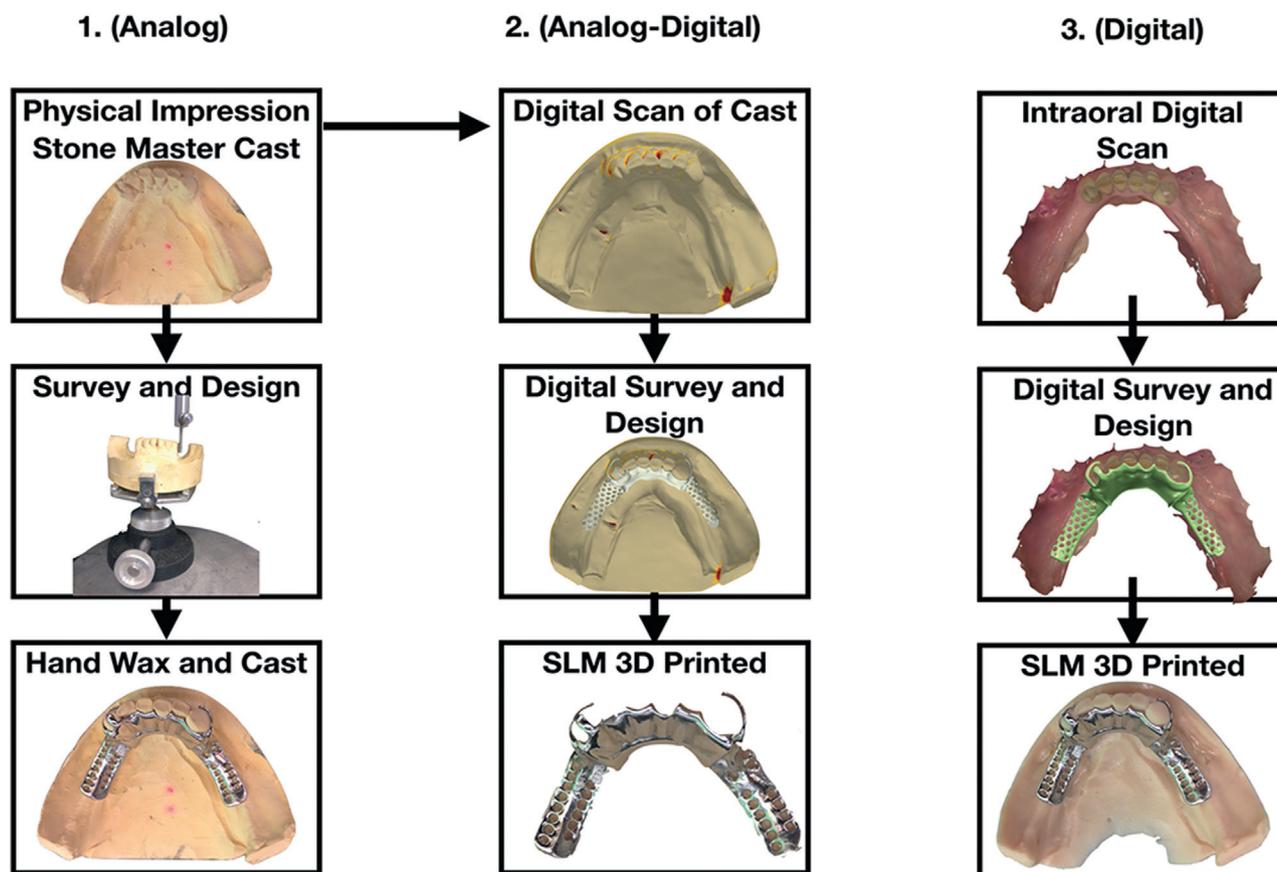


Figure 1. Experimental design with 3 workflows compared in graphical form. SLM, selective laser melting.

mandibular), 3 were of Kennedy class II (2 mandibular and 1 maxillary), and 2 were of Kennedy class III (all maxillary). The first technique was completely analog: a physical impression was made using polyvinyl siloxane (Extrude; Kerr Corp), and a stone cast was poured using Type IV stone (Silky-Rock; Whip Mix Corp). In an edentulous area, border molding was first accomplished using a green modeling plastic impression compound (Green Stick Compound; Kerr Corp). The impression and stone cast were evaluated critically to ensure quality. The stone cast was surveyed (Ney Surveyor; Dentsply Sirona), and the framework pattern, identical to the pattern design for the other pathways, was hand drawn using a red pencil (#65045 Red/Blue; Charles Leonard, Inc). A laboratory technician waxed an RPD framework using the design, invested it, and cast it in Co-Cr alloy (Vitallium 2000; Dentsply Sirona).

The second technique was a combined analog-digital technique, in which a physical definitive impression was made and a stone cast was fabricated as before. The stone cast was then scanned using a laboratory scanner (D800; 3Shape) to generate a digital model. The 3Shape CAD software was used to design a digital RPD (Dental System 2016 Premium; 3Shape). The digital RPD design was then sent to the Sherer Dental Laboratory, Rock Hill,

Table 1. Criteria used to clinically evaluate removable dental prosthesis frameworks

All rests are fully seated as prepared and designed. No discernible difference between tooth and metal rests.	Yes/no
All guide plates contact proximal tooth surfaces.	Yes/no
No detectable rock on major connector except on Kennedy class I and Kennedy class II due to tissue stop.	Yes/no
Circumferential clasp has continuous contact around the abutment tooth.	Yes/no
I-Bar has contact from depth of undercut to height of contour.	Yes/no
Lingual plating has no discernible space between teeth and framework.	Yes/no
No detectable opening from periphery of the major connector to soft tissue.	Yes/no

SC, to be selective laser melted in Co-Cr alloy (EOS CobaltChrome SP2; EOS GmbH).

The third technique was the completely digital pathway, in which an intraoral digital scan was used (3Shape TRIOS III; 3Shape) to make a definitive scan, which was then uploaded to the CAD software (Dental System 2016 Premium; 3Shape) for digitally designing the RPD framework. For all RPD frameworks in the same participant, the same design was used for consistency. Furthermore, the same laboratory technician fabricated all the RPD frameworks. The digital RPD framework was

Table 2. Results from clinical evaluation forms

Participant No.	Arch Treated	RPD Class	Results			Delivered
			Digital	Analog-Digital	Analog	
1	Mandibular	I Modification 1	35 yes	35 no	35 no	Intraoral
2	Mandibular	II Modification 1	35 yes	33 no, 2 yes	33 no, 2 yes	Intraoral
3	Mandibular	I	35 yes	35 no	35 no	Intraoral
4	Mandibular	II Modification 1	35 yes	33 yes, 32 no	33 yes, 32 no	Intraoral
5	Maxillary	III	32 yes, 3 no	35 no	33 yes, 2 no	Traditional
6	Maxillary	III Modification 1	35 yes	28 yes, 7 no	28 yes, 7 no	Intraoral
7	Mandibular	I	35 yes	33 yes, 2 no	33 yes, 2 no	Intraoral
8	Mandibular	I	35 yes	35 yes	30 yes, 5 no	Intraoral
9	Maxillary	II Modification 2	35 yes	35 yes	30 yes, 5 no	Combined

RPD, removable partial denture.

then exported and sent to be SLM-formed in Co-Cr alloy (EOS CobaltChrome SP2; EOS GmbH). Only the arches that were to have RPD frameworks fabricated were scanned.

Five clinicians, 3 prosthodontists and 2 general dentists, were calibrated for participation. The examining clinicians were calibrated in several sessions that reviewed ideal RPD framework fit, with several examples seated on partially edentulous casts that had areas of fit and misfit corresponding to the survey.

The Cohen Kappa was computed to compare all raters with each other individually. The Cohen Kappa metric was equal to 1 for almost all rater comparisons, a near-perfect agreement, showing that the raters were correctly calibrated to find the same results. During the RPD framework evaluation appointment, each calibrated clinician evaluated the framework using the criteria shown in Table 1. Only the initial fit was evaluated with no adjustments. To decrease the selection bias, 3 casts for each patient were placed in a numbered cup so that the evaluators could not determine the method of fabrication. All frameworks were polished, and the examining clinicians were instructed to place the RPD frameworks in the mouth without looking at the intaglio surfaces to avoid bias from the visible 3D-printed layers. The overall best fit was then determined by each evaluator, and that RPD framework was ultimately used for the definitive processing and delivery of the prosthesis to the patient.

For statistical analysis, an overall *P* value was calculated using a statistical software program (IBM SPSS Statistics, v25; IBM Corp) using a chi-square test to determine any difference between the groups ($\alpha=.05$).

RESULTS

Raw data are shown in Tables 2 and 3. The completely digital method produced RPD frameworks with a significantly better clinical fit than the analog method of fabrication ($P<.001$). The digital method was also significantly better than the analog-digital method of framework fabrication ($P<.001$). The completely analog method

was better than the analog-digital method of framework fabrication ($P<.001$). No differences existed among the Kennedy classifications ($P>.05$). Seven of the 9 participants received the framework fabricated using the digital pathway as their definitive prosthesis.

DISCUSSION

The null hypothesis was rejected as differences existed in the survey results regarding the fit of the RPD frameworks fabricated with the 3 different pathways. RPD frameworks can be considered the ultimate test of accuracy for a pathway because they involve both hard and soft tissues. A rigid prosthesis is fabricated which contacts considerable surface area where small errors can lead to significant discrepancies in fit. It is not surprising that the completely digital pathway of framework fabrication using intraoral digital scans was considered to produce a better fitting RPD framework, with 7 of the 9 patients receiving the framework fabricated by this method. Recent studies have reported that intraoral digital scans have similar or better trueness, precision, and prosthetic quality than conventional techniques.¹¹⁻¹⁵

Intraoral scans have better clinical success and accuracy than traditional impressions.²¹⁻²³ The 3Shape TRIOS III scanner was used in this study and has been shown to have a complete-arch scan accuracy of approximately 52 μm .²⁴

Surprisingly, in this study, the analog technique was found to be better than the analog-digital pathway of fabrication. One potential reason is the compounding of errors in making a physical impression, pouring it into the stone, and then scanning that into a digital cast. These 3 steps have intrinsic errors that can compound into a clinically detectable error in a rigid RPD framework. The error of the 3Shape D800 laboratory scanner is approximately 50 μm , which compounds with the inaccuracy of a physical impression and stone cast.¹⁷

As with any recently introduced technique, there is a learning curve when transitioning from making physical impressions to digital scanning. Trying to obtain accurate

Table 3. Results presented with rater information

Clinical Evaluation of Metal Framework for RPDs				
Question	Rater	Digital	Analog-Digital	Analog
1	1	8 yes, 1 no	4 yes, 5 no	4 yes, 5 no
1	2	9 yes	3 yes, 6 no	4 yes, 5 no
1	3	9 yes	3 yes, 6 no	3 yes, 6 no
1	4	9 yes	4 yes, 5 no	4 yes, 5 no
1	5	9 yes	4 yes, 5 no	5 yes, 4 no
2	1	9 yes	5 yes, 4 no	6 yes, 3 no
2	2	9 yes	5 yes, 4 no	6 yes, 3 no
2	3	9 yes	5 yes, 4 no	6 yes, 3 no
2	4	9 yes	5 yes, 4 no	6 yes, 3 no
2	5	9 yes	5 yes, 4 no	6 yes, 3 no
3	1	8 yes, 1 no	4 yes, 5 no	4 yes, 5 no
3	2	9 yes	4 yes, 5 no	5 yes, 4 no
3	3	9 yes	4 yes, 5 no	5 yes, 4 no
3	4	9 yes	5 yes, 4 no	6 yes, 3 no
3	5	9 yes	5 yes, 4 no	6 yes, 3 no
4	1	9 yes	5 yes, 4 no	6 yes, 3 no
4	2	9 yes	5 yes, 4 no	6 yes, 3 no
4	3	9 yes	5 yes, 4 no	6 yes, 3 no
4	4	9 yes	5 yes, 4 no	6 yes, 3 no
4	5	9 yes	5 yes, 4 no	6 yes, 3 no
5	1	9 yes	5 yes, 4 no	6 yes, 3 no
5	2	9 yes	5 yes, 4 no	6 yes, 3 no
5	3	9 yes	5 yes, 4 no	6 yes, 3 no
5	4	9 yes	5 yes, 4 no	6 yes, 3 no
5	5	9 yes	5 yes, 4 no	6 yes, 3 no
6	1	8 yes, 1 no	5 yes, 4 no	6 yes, 3 no
6	2	9 yes	4 yes, 5 no	5 yes, 4 no
6	3	9 yes	6 yes, 3 no	7 yes, 2 no
6	4	9 yes	6 yes, 3 no	7 yes, 2 no
6	5	9 yes	5 yes, 4 no	5 yes, 4 no
7	1	9 yes	5 yes, 4 no	6 yes, 3 no
7	2	9 yes	5 yes, 4 no	6 yes, 3 no
7	3	9 yes	5 yes, 4 no	6 yes, 3 no
7	4	9 yes	5 yes, 4 no	6 yes, 3 no
7	5	9 yes	5 yes, 4 no	6 yes, 3 no

RPD, removable partial denture.

scans of hamular notches and retromolar pads is difficult. Furthermore, digital scans can result in errors in comparison with analog impressions, including large deviations of soft-tissue reproduction in areas that are moveable and problems with wide arches.²⁵ Therefore, particular attention needs to be paid to the edentulous areas of patients requiring class I and class II RPDs.

Once the operator becomes proficient at scanning complete arches, this technique is quick and accurate. Because the problems with complete-arch impressions are avoided, patient compliance is enhanced. This technique is also better for those patients with a sensitive gag reflex. The ability to see the scanned arches on the computer screen allows immediate feedback, and any errors can be relatively easily corrected. Furthermore, because the accuracy of fit of the RPD frameworks was good, minimal chairside time was needed to assess the fit

of the RPD frameworks fabricated from the digital pathway.

The study has limitations. The critical areas of RPD framework fit were around the hard tissues with limited soft-tissue contacts. Therefore, with only the tissue-stops on the framework to evaluate soft tissue accuracy, it is difficult to tell whether all areas of the tissue are accurately captured from just a framework evaluation. The authors used a yes/no questionnaire rather than a Likert scale because of the difficulty in calibrating 5 different clinicians on a Likert-type scale. However, a Likert scale would have provided more information.

CONCLUSIONS

Within the limitations of this clinical study, the following conclusions were drawn:

1. The digital method of RPD framework fabrication was significantly better than the analog method of fabrication.
2. The digital method was also significantly better than the analog-digital method of framework fabrication.
3. The analog method was better than the analog-digital method of framework fabrication.

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Noteworthy Abstracts of the Current Literature

Microstructural development during heat treatment of a commercially available dental-grade lithium disilicate glass-ceramic

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Objective. To elucidate the microstructural evolution of a commercial dental-grade lithium disilicate glass-ceramic using a wide battery of in-situ and ex-situ characterization techniques.

Methods. In-situ X-ray thermo-diffractometry experiments were conducted on a commercially available dental-grade lithium disilicate glass-ceramic under both non-isothermal and isothermal heat treatments in air. These analyses were complemented by experiments of ex-situ X-ray diffractometry, field-emission scanning electron microscopy, energy-dispersive X-ray spectroscopy, differential scanning calorimetry, and field-emission scanning electron thermo-microscopy.

Results. It was found that the non-fired blue block consists of ~40 vol % crystals embedded in a glass matrix. The crystals are mainly lithium metasilicate (Li_2SiO_3) along with small amounts of lithium orthophosphate (Li_3PO_4) and lithium disilicate ($\text{Li}_2\text{Si}_2\text{O}_5$). Upon heating, the glassy matrix in the as-received block first crystallizes partially as SiO_2 (i.e., cristobalite) at ~660 °C. Then, the SiO_2 crystals react with the original Li_2SiO_3 crystals at ~735 °C, forming the desired $\text{Li}_2\text{Si}_2\text{O}_5$ crystals by a solid-state reaction in equimolar concentration ($\text{SiO}_2 + \text{Li}_2\text{SiO}_3 \rightarrow \text{Li}_2\text{Si}_2\text{O}_5$). Precipitation of added colourant Ce ions in the form of CeO_2 appears at ~775 °C. These events result in a glass-ceramic material with the aesthetic quality and mechanical integrity required for dental restorations. It also has a microstructure consisting essentially of elongated $\text{Li}_2\text{Si}_2\text{O}_5$ grains in a glassy matrix plus small cubic CeO_2 grains at the outermost part of the surface.

Significance. It was found that by judiciously controlling the heat treatment parameters, it is possible to tailor the microstructure of the resulting glass-ceramics and thus optimizing their performance and lifespan as dental restorations.

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