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A Preliminary Study on the Accuracy of Cast Metal Removable Partial Denture Frameworks Produced from Wax, Printed, and Milled Patterns

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Purpose: To compare the accuracy of two digital workflows for producing resin patterns to be cast into metal frameworks compared to an identical framework manufactured conventionally from a wax pattern. ***Materials and Methods:*** Nine casts were duplicated from a maxillary master cast of a partially edentulous arch. Their accuracy was determined by measuring the same points in two and three dimensions using a reflex microscope, which was also used to measure all frameworks to an accuracy of 4 µm. The same design was used throughout. Three casts were used to make a framework conventionally from an invested wax pattern. Six casts were scanned, and a digital pattern created. Three patterns were milled from a resin block, and three were 3D printed with resin. Then each pattern was cast. ***Results:*** The sample size precluded direct statistical conclusions, but no significant differences were found. Duplicate models showed minimal differences compared to the master cast. All patterns and all frameworks showed some level of difference compared to the master cast, but no differences were greater than those reported in the literature as being clinically acceptable. The maximum overall discrepancy between the cast frameworks was 0.64 mm, and at the rest seats was 0.262 mm. ***Conclusion:*** Within the limitations of this study, given the very small actual differences both within and between the groups of the three different workflows, the use of digitally produced resin patterns prior to their being cast as metal frameworks is both feasible and well within the accepted limits for clinical acceptability. *Int J Prosthodont 2023;36:730–737. doi: 10.11607/ijp.7663*

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Epidemiologic studies indicate a decline in complete tooth loss and an increase in partial tooth loss.[1] This trend remains prevalent globally, leading to compromised esthetics and a decrease in masticatory ability such that food choices are affected as well as cognitive abilities related to mastication and occlusion.[2–5]

The most cost-effective treatment for the replacement of missing teeth is a removable partial denture (RPD), which can be based entirely in acrylic resin or be reinforced by a rigid framework, usually metal.[6–8] A conventional RPD serves as the first, and often the only, prosthodontic option for partially dentate patients because of its relatively low cost and noninvasive nature. However, long-term use of RPDs has been associated with an increased risk of caries, periodontitis, and alveolar bone resorption.[9–12] A well-designed and constructed RPD and continual maintenance of oral hygiene are crucial factors in maintaining the health of the remaining dentition.[13] An evaluation

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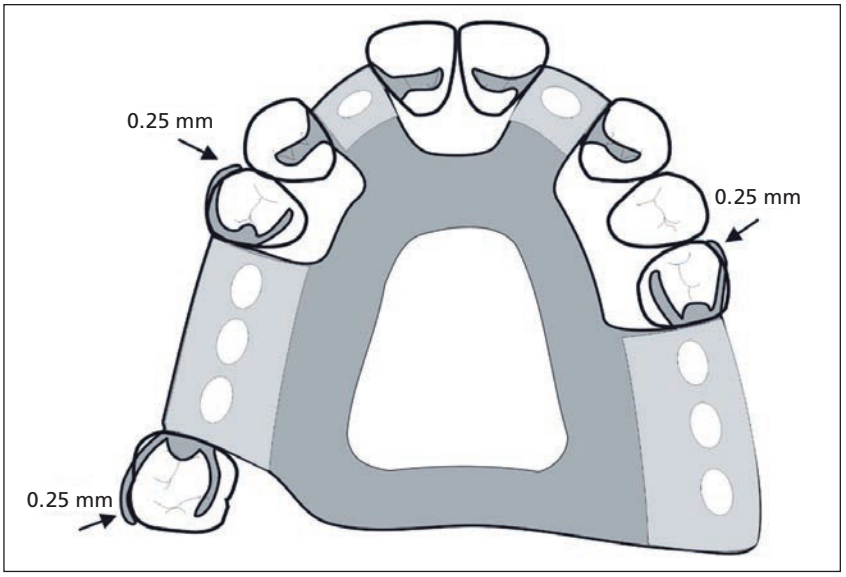


Fig 1 Design for the maxillary Kennedy Class II partial denture.

of the long-term outcomes of metal-framework RPDs[14] reported a mean survival time of 8 years, with a positive outcome probability of 90% after 5 years. This was similar to other studies concluding that RPDs with simple, hygienic designs are clinically successful.[1,6,13,15,16]

The accuracy of the framework fit is important.[17–19] When fit was assessed using a mirror and explorer,[19] it was found that almost a third of the examined frameworks had a poor fit. Similar findings have been reported by others.[20,21] Many subjective methods for analyzing the accuracy and fit of metal frameworks have been reported,[19,22] but a more objective method is to measure the internal fit using a silicone registration material.[21–23] The early work by Stern et al[20] provided insight into the levels of tolerance of a clinically acceptable fit. They evaluated the gap between the cast occlusal rest and the corresponding rest seat and reported a range of 0.069 to 0.387 mm. Dunham et al[21] reported a discrepancy of 0.193 ± 0.203 mm with a range of 0 to 0.828 mm. Even though results were described quantitatively, the frameworks were judged as clinically acceptable. Lee et al[23] found a mean discrepancy of 0.248 mm between the fit at the periphery and the center in cingulum rests.

To date, the studies measuring discrepancy of fit have been for RPDs that have been worn successfully by patients, so it is reasonable to assume that a tolerance of misfit of possibly up to 0.9 mm would be within a clinically acceptable range. It would be preferable, though, that this range be as small as possible.

It has been suggested that a digitally constructed prosthesis may reduce the errors inherent in the conventional technique.[24,25] Although a selective laser melting technique showed comparable accuracy of trial fittings compared to cast frameworks, the disadvantages outweighed the advantages due to the high cost of the sintering machinery and materials.[26,27] Rapid prototyping, an additive technique, has been introduced to overcome the problems encountered during subtractive material manufacturing[22,24] but has yet to be evaluated fully in terms of accuracy.

A digital workflow that produces a resin framework to be cast conventionally could reduce the time and cost compared to milling or sintering; therefore, this study set out to compare the accuracy of digital workflows that produce a resin framework pattern to be cast conventionally to an identical framework manufactured from a wax pattern. The viability of such a digital workflow would form a platform for future prospective and comparative studies. The null hypothesis was that there would be no differences in the accuracy of the frameworks produced by such digital workflows compared to a conventional workflow.

MATERIALS AND METHODS

Master Cast and Working Casts

A maxillary master cast of a Kennedy Class II modification 3 partially edentulous arch was used. The framework design is described in Fig 1. Seven rest seats were prepared on the abutment teeth of 17, 14, 13, 11, 21, 23, and 25 (FDI). After rest seat preparations, the model was duplicated (Mold Star 30, Smooth-On), and nine working casts were poured with type IV gypsum dental stone (Silky-Rock, WhipMix) and mixed according to the manufacturer's instructions. All casts were poured using the same silicone-base mold by one technician on the same day. Each model was numbered in numerical order.

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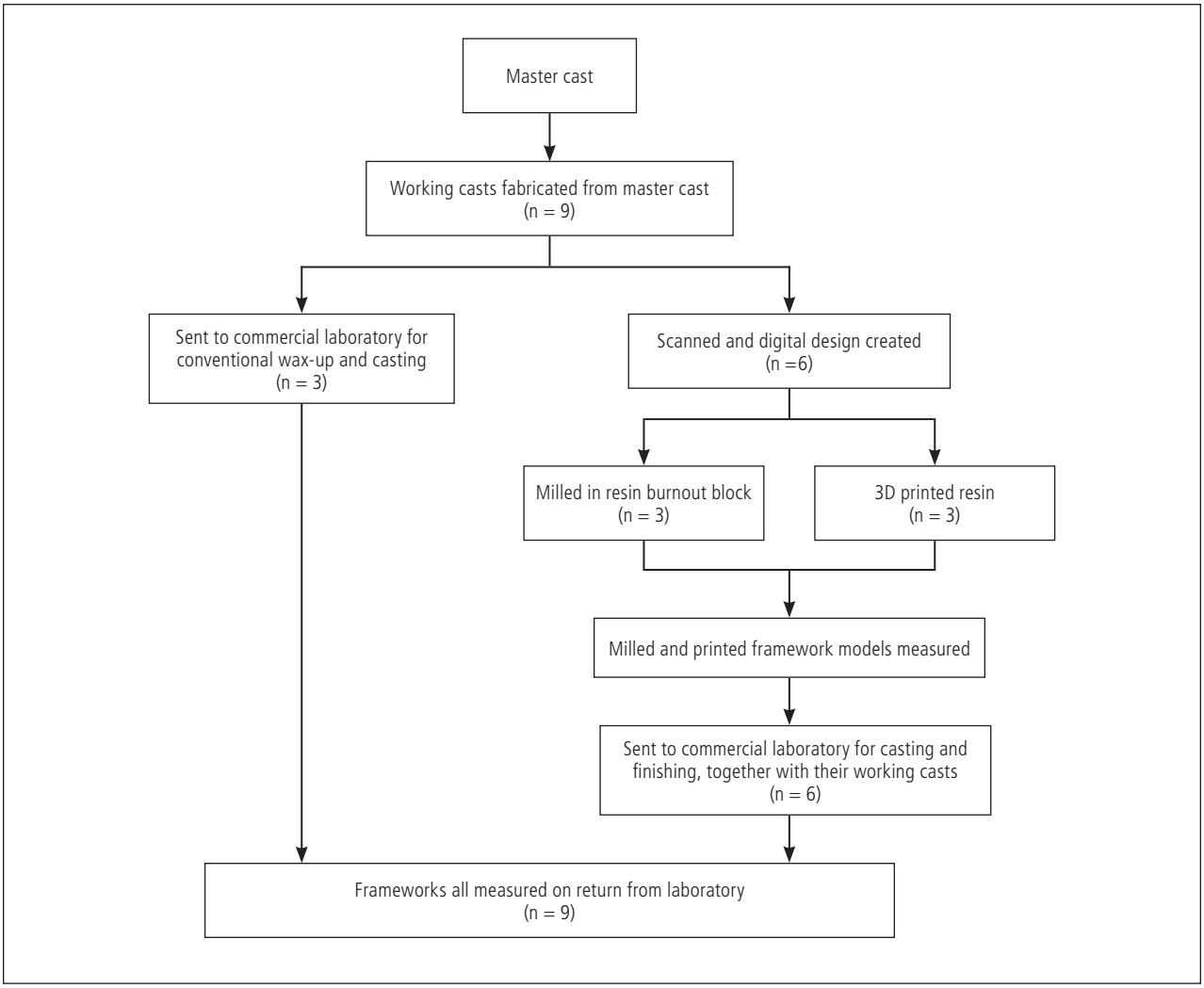


Fig 2 Flowchart of study protocol.

Surveying

Surveying was undertaken prior to the design and rest preparations. The path of insertion for all casts was standardized as perpendicular to the occlusal plane, with the cast tilted slightly in an anterior direction.

Framework Fabrication

The full workflow of frameworks and measurements is shown in Fig 2. For the conventional technique, three working casts were sent to a commercial laboratory with instructions to produce three finished metal frameworks per the design to be returned on each cast. For the milled frameworks, six casts were scanned (D2000 extraoral scanner, 3Shape), the framework was digitally created (using 3Shape designing software version 2.19.2.0; Fig 3), and the completed design was exported into a standard tessellation language (.stl) file. Three digital patterns were milled from a resin burnout block (acrylic resin, Yamahachi; imes-icore CORiTEC 350 Pro Plus, imes-icore milling unit), and three were printed in resin (NextDent, 3D Systems) using a 3D printer (MoonRay, SprintRay) (Fig 4). Each printed framework was washed with isopropyl alcohol for 15 minutes to ensure all uncured resin was removed. Each milled and printed framework was measured and then sent to the same laboratory as for the conventional technique together with the corresponding cast with instructions to cast and finish the frameworks. One laboratory technician fabricated all of the frameworks.

Measurements

For determining the accuracy of the models, three predetermined reference points were chosen: the cusp tips of the buccal cusps of teeth 14 and 25, and the distobuccal cusp tip of tooth 17. For the overall comparison of distortion of the frameworks, three predetermined points were identified: the tips of the buccal clasp arms on teeth 17, 14, and 25. For accuracy of the rest seats

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of the cast frameworks compared to their corresponding casts, five predetermined points were identified: the maximum curvature on the tangent of curvature for the framework rests, and the lowest curvature of the rests on the cast (Fig 5). All measurements were made using a reflex microscope (Consultantnet), which measures in three dimensions to an accuracy of 4 mm.

For the overall comparison of distortion of the frameworks, linear measurements were assessed by measuring the distances between the three buccal cusp tips as between points 1 and 2, 2 and 3, and 1 and 3 (Fig 5), and 3D measurements were assessed using the angles created between these points, as angles 1–2–3, 1–3–2, and 2–1–3.

Data Analysis

The sample size estimation was selected from previous studies that inspected internal discrepancy of two or three types of framework components.[26–31] However, it is acknowledged that this was a small sample size, necessitated by resource constraints.

To determine whether the mean of the observations could be used for further analysis, an intrarater reliability test between all measurement occasions was used with intraclass correlation coefficient (ICC). Measurements using the reflex microscope rely on the perceptual ability of the observer to move a point of light in three dimensions. Although the reported accuracy is up to 4 mm, the positioning of the light point, particularly in the *z*-axis, is difficult. Therefore, measurements were made on three separate occasions for the resin patterns and on six separate occasions for the casts and cast frameworks. Then, the mean of the measurements made on more than one occasion that gave either good or excellent ICC values were used for further analysis. Each metric was compared between workflows using one-way analysis of variance (ANOVA) or *t* test for two workflows. Where the data did not meet the assumptions for one-way ANOVA, nonparametric alternatives (Kruskal-Wallis test and Wilcoxon rank-sum test) were used. The intrarater reliability for the measurement occasions was assessed using the ICC on the following scale[32]: < 0.5 = poor; ≥ 0.5 to 0.74 = moderate; ≥ 0.75–0.89 = good; ≥ 0.90 = excellent.

RESULTS

The selected measurements for each metric showed ICC values with good or excellent correlations, and so these were used for further analysis.

In terms of the accuracy of all the casts, one-way ANOVA was not significant at $P = .13$, .13, and .98 for the three standard cast points (14, 25, and 17, respectively) between the cusp tips. The comparison of accuracy of the printed and milled frameworks revealed no significant differences in either the linear or 3D measurements. Similarly, when comparing the models to their corresponding cast frameworks, one-sample *t* test and

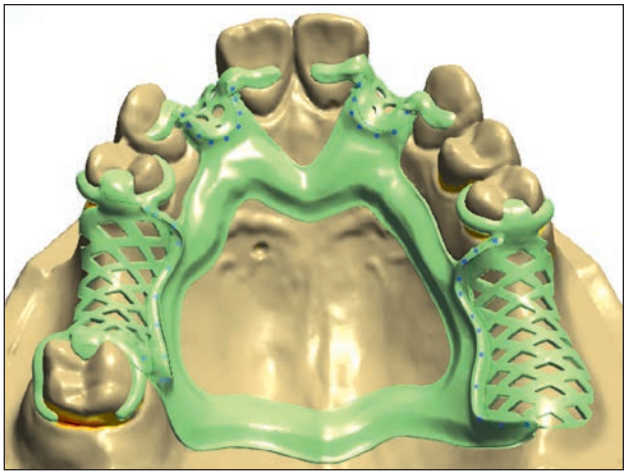


Fig 3 Digital design of cobalt-chromium RPD milled framework.

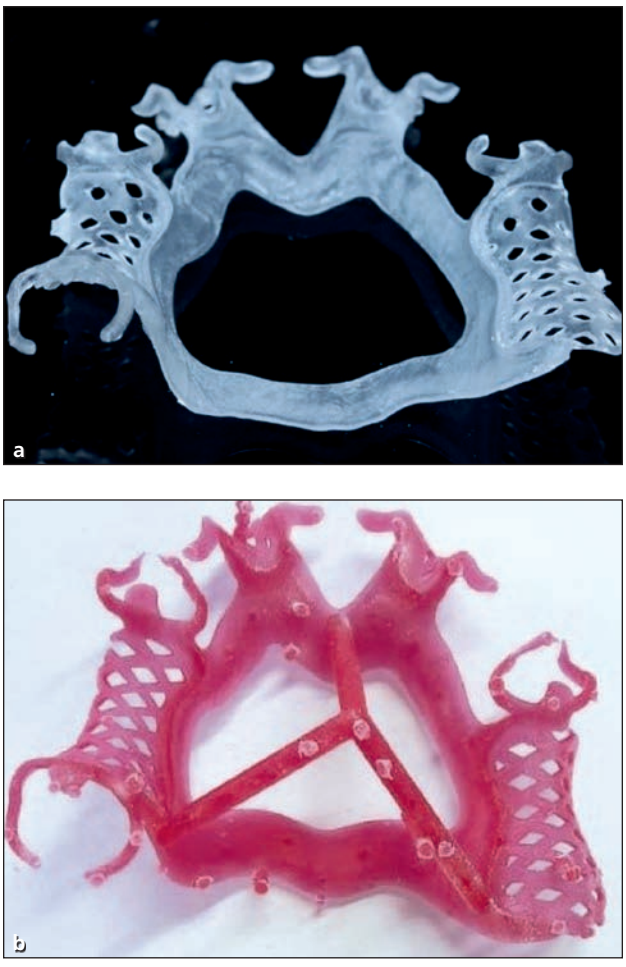


Fig 4 *(a)* Milled and *(b)* printed resin frameworks.

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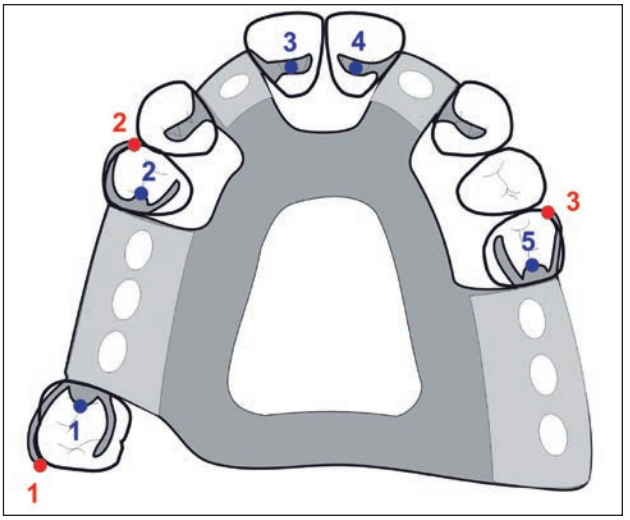


Fig 5 The three points corresponding to the cusp tips (red) and the five points corresponding to the rest seats (blue).

Table 1 Mean Differences (mm) Between the Cast Frameworks Compared to Their Wax, Printed, and Milled Patterns

Points measured with good/excellent ICC	Wax	Printed	Milled
Linear measurements			
Points 1–2	0.890	0.461	0.883
Points 2–3	0.577	0.279	0.005
Points 1–3	0.281	0.324	0.838
Angular measurements			
Angle 1–2–3	0.591	0.062	1.448
Angle 1–3–2	0.394	0.765	1.066
Angle 2–1–3	1.297	0.377	0.627
Overall mean	0.672	0.378	0.811

Table 2 Mean Differences (mm) Between the Patterns and Cast Frameworks Compared to Their Corresponding Models

Points measured with good/excellent ICC	Printed pattern	Milled pattern	Frameworks cast from wax patterns	Frameworks cast from printed patterns	Frameworks cast from milled patterns
Linear measurements					
Points 1–2	0.047	0.090	0.322	0.288	0.672
Points 2–3	0.380	0.616	0.633	0.217	0.244
Points 1–3	0.533	0.207	0.368	0.022	0.944
Angular measurements					
Angle 1–2–3	0.439	0.583	0.813	0.008	0.547
Angle 1–3–2	0.885	0.222	0.348	0.726	0.909
Angle 2–1–3	0.219	0.901	1.354	0.789	0.171

Wilcoxon rank-sum test found no statistical difference at any of the points measured.

The actual mean difference of the cast frameworks compared to their respective wax, printed, and milled frameworks were calculated (Table 1). The first casting from one of the milled frameworks was miscast, hence, there were only two cast frameworks. There were no statistically significant differences between any of the cast frameworks.

The accuracy of the patterns and cast frameworks to their corresponding models is shown in Table 2. The differences were again not statistically significant, nor was the accuracy of the rest seats of the cast frameworks compared to the models (Table 3).

Although the number of patterns and frameworks was few, a preliminary time analysis was carried out to compare the workflows. It was found that, on average, the conventional technique took 9 hours and 45 minutes, the milled workflow 8 hours and 15 minutes, and the printed pattern workflow 7 hours and 45 minutes. However, these times will vary from laboratory to laboratory, as will the material costs.

DISCUSSION

Clinical experience with cast cobalt-chromium (Co-Cr) alloy RPDs showed that a framework seldom fits the mouth accurately without the need for some adjustments. This may be due to frameworks being fabricated from high-shrinkage alloys, as well as the complexity of the work stages used in the RPD. Recent studies have reported acceptable clinical outcomes with digitally produced RPD frameworks.[28,30] However, these studies have subjectively described the clinical outcomes, with insufficient information regarding any acceptable clinical measurement.

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Table 3 Mean Differences (mm) in Rest Seat Positions Compared to Their Wax, Printed, and Milled Patterns for Frameworks

Points measured with good/excellent ICC	Cast framework from printed patterns	Cast framework from milled patterns	Conventional cast framework from wax patterns	Overall mean
Points 1–2	0.470	0.248	0.293	0.337
Points 1–3	0.319	0.156	0.004	0.160
Points 1–4	0.373	0.301	0.326	0.333
Points 1–5	0.301	0.055	0.208	0.188
Points 2–3	0.137	0.084	0.123	0.115
Points 2–4	0.127	0.070	0.027	0.075
Points 2–5	0.040	0.187	0.200	0.142
Points 3–4	0.152	0.129	0.305	0.195
Points 3–5	0.255	0.236	0.125	0.205
Points 4–5	0.450	0.321	0.338	0.370
Overall mean	0.262	0.179	0.195	0.212

Eggbeer et al[31] are documented as the first to build a resin RPD framework using stereolithography. These frameworks were then cast using conventional methods. Further reports[27,30] have shown that the theoretical possibility of applying digital technologies to denture framework production has become a functional reality, but once again the clinical acceptability was determined subjectively.

Complex shapes are difficult to fabricate with traditional milling devices due to the size and applied angle of the milling tool.[33] Rapid prototyping (RP) does not have this limitation, as 3D printers are able to fabricate more complex shapes. An inherent problem with 3D printing, however, is the unavoidable shrinkage that occurs during the printing process, and so the accuracy may be a limitation.[33] An evaluation of the overall accuracy and fit of conventional vs CAD/CAM RPDs, as well as the accuracy and fit of each component, found that both the conventional and 3D-printing methods of fabrication revealed clinically acceptable adaptation.[34] The largest discrepancy was in the anterior strap of the major connectors in printed frameworks. An earlier study concluded that RPDs produced by RP, while clinically acceptable, exhibited the highest discrepancies, but attributed this to inaccuracies during scanning or software errors.[28]

Digital scans may result in errors when compared to analog impressions, such as reproducibility in moveable soft tissue areas, as well as the surfaces being covered by saliva.[35] Selective laser melting (SLM) is an additive manufacturing technique that has been used to print titanium and chrome-cobalt RPD frameworks and has been considered to result in better microstructure and mechanical properties, as well as clinically acceptable frameworks.[22,36] However, there are large cost considerations in not only the equipment but also the materials for SLM. It is now possible for clinicians to fabricate RPD frameworks using a combination of analog and digital or a completely digital workflow. In the present study, cost and resource considerations prompted the use of a combined analog and digital workflow.

The accuracy of casts is dependent on a multitude of clinical and laboratory variables including impression techniques, pouring methods, and material properties.[37,38] The accuracy of casts duplicated from a master cast does not appear to have been tested or reported in the literature. This study attempted to first establish the accuracy of duplicated standard casts compared to a master cast and then to determine the accuracy of digitally designed resin frameworks produced by two different methods, as well as the accuracy of their cast equivalents to frameworks produced by the conventional method.

Measurements were made using the reflex microscope, which is able to measure in three dimensions. This requires manipulation of a light point in three dimensions and can therefore be subject to operator error. Speculand et al[39] showed that it was possible to generate reproducible results with an operator measurement error of less than 0.15 mm for linear distances and also found the microscope undermeasured by 0.28% or by up to 0.14 mm per 50 mm. Therefore, in the present study, all measurements were made on at least three different occasions, and an ICC was calculated to determine the correlation between the different measurements. It was found that only certain pairs of measurements correlated for some measurements, and in others, there was correlation over more than 2 days. Therefore, only those multiple measurements that showed good or excellent correlation were used for analysis.

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Evaluation of the accuracy of the duplicate casts to the master cast showed differences ranging from –0.33 mm to 0.271 mm. Negative values may be associated with gypsum expansion, which is similar to findings from a study reporting expansion that may reach approximately 0.2%.[36] In this study, there were no statistically significant differences between the duplicated models. Using the digital workflow as in the present study still requires a duplicate model, and the accuracy and consistency of duplication used here was shown to be acceptable.

Different methods have been described in generating a digital RPD.[27,31,40] In this study, two different techniques were used for the production of resin patterns, both using the same digital data from a digitally designed RPD framework. The results showed no difference between the printed and milled frameworks. The mean of the differences of all measurement points between the printed frameworks was 0.423 mm, and between the milled frameworks was 0.561 mm. When comparing the resin pattern frameworks to their corresponding models, the mean of the differences of all measurement points between the printed frameworks and their models was 0.417 mm, and between the milled frameworks and their models was 0.436 mm. These differences within the patterns, and between patterns and their models, although small, could be accounted for by either the accuracy of the printing and milling processes themselves or the inherent (in)accuracy in the measurement points on the models. In addition, it is possible that there may be some release of stresses in the resins as a result of the printing and milling processes. What is important, though, is the relationships between the patterns and their castings, and then of their finished castings to the original models.

The overall mean difference of all measurement points between the cast frameworks and their printed patterns was 0.377 mm, and between the cast frameworks and their milled patterns was 0.627 mm. The overall mean difference of all measurement points between the cast frameworks from printed patterns and the models was 0.342 mm; between the cast frameworks from milled patterns and the models was 0.581 mm; and between the conventionally cast frameworks from wax patterns and the models was 0.640 mm.

These differences may well be due to the inherent differences and accumulated inaccuracies of the materials, but would also seem to indicate differences in the casting processes. This could first be linked to the need to burn out the resin or wax, as there may be differences in the burnout between the printed and milled materials; and second, the investment procedures may differ. The conventional technique requires the creation of a refractory model onto which the wax pattern is sealed, and then this is invested. The resin patterns are invested completely in investment material, and it is possible that this is more accurate.

Discrepancies of fit have been reported in the literature, with no consensus other than the fact that it is accepted that there will be a degree of misfit that is clinically acceptable. Some studies have attempted to quantify this, and Dunham et al[21] summarized these by reporting a range of misfit up to 0.828 mm. As these were all from RPDs that had been successfully worn, it would seem reasonable to conclude that this provides a range for clinical acceptability, although there is no current consensus and so this remains debatable. The results from the present study are therefore all within this range, with the discrepancy of 0.342 mm for the frameworks cast from the printed patterns providing the best result.

This study also attempted to quantitatively highlight the discrepancy between rests and rest seats. Most of the occlusal rests (76%) by Dunham et al[21] did not contact the intended surface, and Eggbeer et al[31] referred to a clinically acceptable gap as being 0.311 mm. The results in this study revealed that the difference in the rest seats between the frameworks made from the printed patterns and the models was 0.262 mm; between the frameworks from the milled patterns and the models was 0.179 mm; and between the frameworks from the wax patterns and the models was 0.195 mm. The overall mean for all frameworks was 0.212 mm. All of these are well within the clinically accepted differences. The null hypothesis was therefore accepted.

The preliminary time analysis carried out revealed that the total time taken on average was greater for the conventional technique, at 9 hours and 45 minutes. The milled workflow took on average 8 hours and 15 minutes, and the printed pattern workflow took 7 hours and 45 minutes. In addition, there will be material cost differences between the resins used for milling and printing, with the latter being 20% of the cost of the former.

Apart from the time factor, it has been pointed out that the advantages offered with digitally constructed frameworks include the ability to clinically try in and modify a framework prior to casting.[34]

Limitations

The results should be interpreted with caution, as the small sample size, necessitated by resource constraints, meant that statistical comparisons may not be anything other than chance at the 5% level. However, what is considered important is that there was very little variation in the actual measurements obtained, and all variations were within what have become clinically acceptable limits. The viability of these digital workflows is therefore validated.

CONCLUSIONS

Within the limitations of this study, it can be concluded that, given the very small variations in the measurements

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both within and between the groups of the three different workflows, the use of digitally produced resin patterns prior to their being cast as metal frameworks is feasible within the accepted limits for clinical acceptability.

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