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In-vitro Evaluation of Accuracy of Conventional and CAD/CAM Removable Partial Denture Frameworks

Pooya Soltanzadeh

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LOMA LINDA UNIVERSITY
School of Dentistry
in conjunction with the
Faculty of Graduate Studies

In-vitro Evaluation of Accuracy of Conventional and CAD/CAM Removable Partial
Denture Frameworks

by

Pooya Soltanzadeh

A Thesis submitted in partial satisfaction of
the requirements for the degree
Master of Science in Prosthodontics

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Each person whose signature appears below certifies that this thesis in his/her opinion is adequate, in scope and quality, as a thesis for the degree Master of Science.

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ABBREVIATIONS

CAD/CAM	Computer-Aided Design/Computer-Aided Manufacturing
RPD	Removable Partial Denture
STL	Standard Tessellation Language
LWT	Lost-Wax Technique
CAD/RP	Computer-aided design/Rapid Prototyping
CAD/RPS	Computer-aided design/Rapid Prototyping from Stone
LWTR	Lost-Wax Technique from Resin
RP	Rapid Prototyping
Co-Cr	Cobalt-Chromium
3D	3-Dimensional
PVS	Polyvinylsiloxane
SLM	Selective Laser Melting
ABS	Acrylonitrile Butadiene Styrene
µm	Micron
mm	Millimeter
SD	Standard Deviation

ABSTRACT OF THE THESIS

In-vitro Evaluation of Accuracy of Conventional and CAD/CAM Removable Partial Denture Frameworks

by

Pooya Soltanzadeh

Master of Science, Graduate Program in Prosthodontics
Loma Linda University, August 2018
Dr. Mathew Kattadiyil, Chairperson

Purpose: Computer-aided design/computer-aided manufacturing (CAD/CAM) technology is gaining popularity in dentistry, and more recently, to fabricate removable partial dentures (RPD). The purpose of this study was 1) to evaluate the overall accuracy and fit of conventional versus CAD/CAM fabricated printed RPD frameworks based on STL data analysis, and 2) to evaluate the accuracy and fit of each component of the RPD framework.

Materials and Methods: A maxillary metal framework was designed for a Kennedy class III modification I situation. The master model was scanned and used to compare the fit and accuracy of the RPD frameworks. A total of 40 impressions (conventional and digital) of the master cast were made and divided into 4 groups based on fabrication method: Group I, conventional method (Lost-wax technique); group II, CAD-rapid prototyping (CAD-RP); group III, CAD-rapid prototyping from stone model (CAD-RPS); and group IV, Lost-wax technique from resin model (LWTR). RPD frameworks were fabricated in cobalt-chromium alloy. All frameworks were scanned and the gap distance to the original master model in 8 different locations were measured, as well as color mapping with a comprehensive metrology software. Data were statistically analyzed using the Kruskal-Wallis analysis of variance and post hoc comparisons, followed by the Bonferroni method

for pairwise comparisons ($\alpha = 0.05$).

Results: Color mapping revealed distinct discrepancies in major connectors amongst the groups. When compared to 3D printed frameworks, conventional cast frameworks fabricated either from dental stone or 3D printed resin models revealed significantly better fit ($P < 0.05$) with the major connectors and guide plates. The biggest gap ($> 0.3\text{mm}$) was observed with the anterior strap of the major connector with the printed frameworks (groups II and III). The method of fabrication did not affect the adaptation of the rests or reciprocation plates.

Conclusions: Within the limitations of this study, although both methods revealed clinically acceptable adaptation, the conventional processed RPD groups revealed better overall fit and accuracy.

CHAPTER ONE

INTRODUCTION AND REVIEW OF THE LITERATURE

Accurate treatment planning, design, and fabrication of removable partial denture (RPD) frameworks is critical for success. Variables such as hard/soft tissue anatomy, occlusal relationships, tooth position, and patient desires for esthetics and comfort should dictate the RPD framework design that can best meet the individual patient's needs. Intimate contacts between the metal framework and the teeth, the fit between the base and supporting tissues, and well adapted, fully extended mucosal bases, provides the support, stability and retention of an RPD.¹

Traditionally, RPD design involved the fabrication of stone casts, evaluation and geometric characterization of the tooth and soft tissues related to the path of insertion, and careful fabrication of RPD framework using a direct waxing method.² However, in recent years, computer-aided design/computer-aided manufacturing (CAD/CAM) technology has been gaining popularity for the fabrication of various dental restorations.³ The CAD/CAM technique for the fabrication of RPD frameworks began with the aid of rapid prototyping (RP). In 2004, Williams et al. designed and printed a resin RPD framework using CAD/CAM technology.¹ The resin framework was then cast into a metal framework using the conventional lost-wax technique.¹ Later, the authors reported a technique where an RPD framework was designed and fabricated using the CAD/RP technique.⁴ Using this technique, RPD frameworks, made from cobalt-chromium (Co-Cr) alloy, could be directly printed.⁵

With regards to accuracy, studies have shown that digital impressions, using intra oral scanners, are comparable to polyvinylsiloxane (PVS) impression materials.⁶⁻¹⁰ The

advantage of virtually planning and designing of fixed and removable prostheses is that specific geometric analysis tools enables the dentist or laboratory technician to create designs, with a micrometer-level of accuracy that can be visualized in cross sections.^{4,11} For RPD framework design, the virtual model can be surveyed, designed and printed directly in resin or metal. If a resin framework is printed, it has the advantage of being able to be tried in clinically and modified, prior to conventional casting of the metal framework.^{4,11-13}

Clinical experience with cast cobalt-chromium (Co-Cr) alloy partial dentures reveals a framework seldom fits the mouth optimally without adjustments. In fact, seventy-five percent of removable partial dentures do not fit the mouth on the day of insertion. Improper fit may contribute to movement of the associated teeth and discomfort. Improper fit may also be the primary reason that many removable partial dentures are not worn. The need for both laboratory and clinical framework adjustments reflects the dimensional inaccuracies that inevitably occur at various stages of framework fabrication. Hypothetically, compared to the conventional method of RPD framework fabrication, direct printing using CAD and RP, more specifically selective laser melting (SLM) technology, is more accurate because less steps are needed, which reduces errors in fabrication. Furthermore, time and labor costs are reduced.^{4,14-17} Previous studies have shown SLM-fabricated Co-Cr alloys have superior microstructural homogeneity over conventionally cast Co-Cr alloys.¹⁸⁻²⁰ This method of fabrication would make the alloy more resistant to distortion, which may lead to favorable occlusal force distribution among the remaining teeth or supporting tissues.²¹ Clinically acceptable results have been reported for RPD frameworks fabricated with RP using SLM technology.^{3,5,22} Despite the lack of clinical trials and long term clinical outcomes,²³⁻²⁵ limited studies have reported

the following advantages: Improved mechanical properties, increased patient satisfaction, reduced laboratory time, and availability of saved data for future prosthesis reproduction if required.^{23,26-30}

Various methods to analyze the accuracy and fit of an RPD framework have been reported.^{9,22,31-36} Some of these methods include the application of different disclosing materials,^{22,32,34} sectioning the RPD and direct measurements of the gaps in between the prosthesis and the master casts,³⁵ and digital superimposition of models.^{7,9,36} Recently, STL data analysis with digital superimposition have been utilized to evaluate various dental restoration (e.g. Dentures, crowns, and fixed partial dentures).^{7,9,36} Furthermore, color mapping has provided valuable general information regarding the adaptation and accuracy of these restorations.^{7,9,36}

To date, no study has evaluated and compared the accuracy and fit of 3D printed RPD frameworks to conventional methods of fabrication using quantitative based STL data analysis and digital superimposition.

Aim

The purpose of this study was to evaluate the overall accuracy and fit of conventional versus CAD/CAM fabricated RPD frameworks based on STL data analysis, and to evaluate the accuracy and fit of each component of the RPD, and the framework. The null hypothesis was that there would be no significant differences in the accuracy and fit of RPD frameworks, using various techniques for data acquisition and methods of fabrication.

CHAPTER TWO

MATERIALS AND METHODS

Fabrication of the Master Cast

A 3D printed model of a maxillary arch with a Kennedy class III modification I situation was fabricated in Acrylonitrile Butadiene Styrene (ABS) (Stratasys Inc., Eden Prairie).³⁷ Four rest seats were prepared on the abutment teeth of #'s 3, 6, 12, and 14 respectively. The printed model was surveyed using a Ney Surveyor and modified to ensure parallel guiding planes. For each of the abutment teeth, the positions of the terminal end of the retentive clasps were identified and marked using a 0.010" undercut gauge instrument. Four pyramid-shaped structures (2mm×2mm with 2mm height) as well as 3 notches (2mm width) at the rest areas, were created and served as landmarks for software measurements and analyses. These landmarks were made to facilitate the process of digital superimposition between the master model and frameworks with higher accuracy. Outlines measuring 0.5mm×0.5mm of the clasps for all abutment teeth were created using a high speed rotary instrument (Midwest Quiet-Air; Midwest Dental Products Corp). After modifications were made, the model was duplicated using a silicone-based duplication material (Vivid Image; Pearson Dental). The impression was poured with Type IV scannable dental stone (FujiRock OptiXscan; GC America Inc), and was used as the reference model throughout the study (Figure 1).

After 24 hours of setting time, the reference model was scanned using the 3Shape D900 model scanner (3SD900) (3Shape North America) and the STL file was used as the reference data set. The same reference stone model was used to create the samples for all groups.



Figure 1. Maxillary reference model with modifications for Kennedy Class III, modification I framework design.

This study consisted of 4 groups of 10 samples in each group, for a total of 40 samples (n=40). All RPD frameworks were fabricated using cobalt-chromium (Co-Cr) alloy. Details regarding the fabrication of RPD frameworks for each group are presented below (Figure 2).

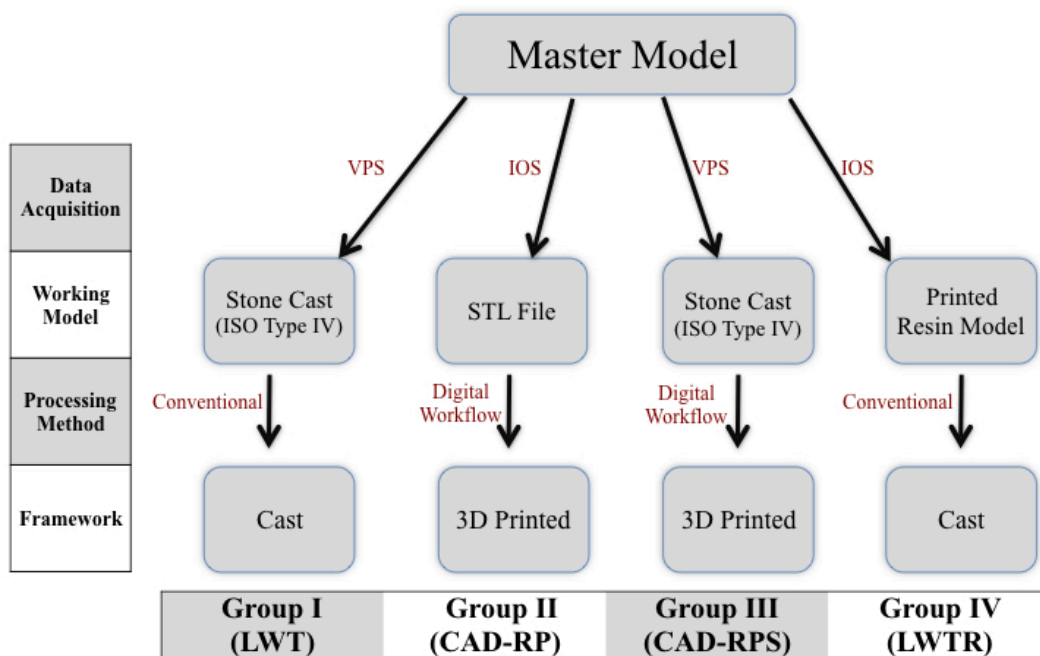


Figure 2. Flowchart depicting the fabrication of RPD frameworks of each group.

Group I: Conventional Method: Lost-wax Technique (LWT)

The reference model was duplicated using a silicone-based duplication material (Vivid Image; Pearson Dental), and 10 casts were made using a Type IV scannable dental stone (FujiRock OptiXscan; GC America Inc). For better consistency and standardization among the casts, the amount of powder and liquid (distilled water) were measured by liquid dispenser (AquaSpense, 115 V; Whip Mix Corp.) and mixed by programmable vacuum mixing unit (VPM2; Whip Mix Corp.). All samples were poured in one day and stored in a dark non-humid environment for 24 hours. The models were numbered and mailed to a commercial lab for the fabrication of 10 conventionally fabricated cast Co-Cr frameworks. The RPD frameworks were cast using Co-Cr alloy, finished and air particle abraded with 50 μ m aluminum oxide (Al_2O_3) under 2 bar pressure. All frameworks were

fabricated by one lab technician (figure 3).

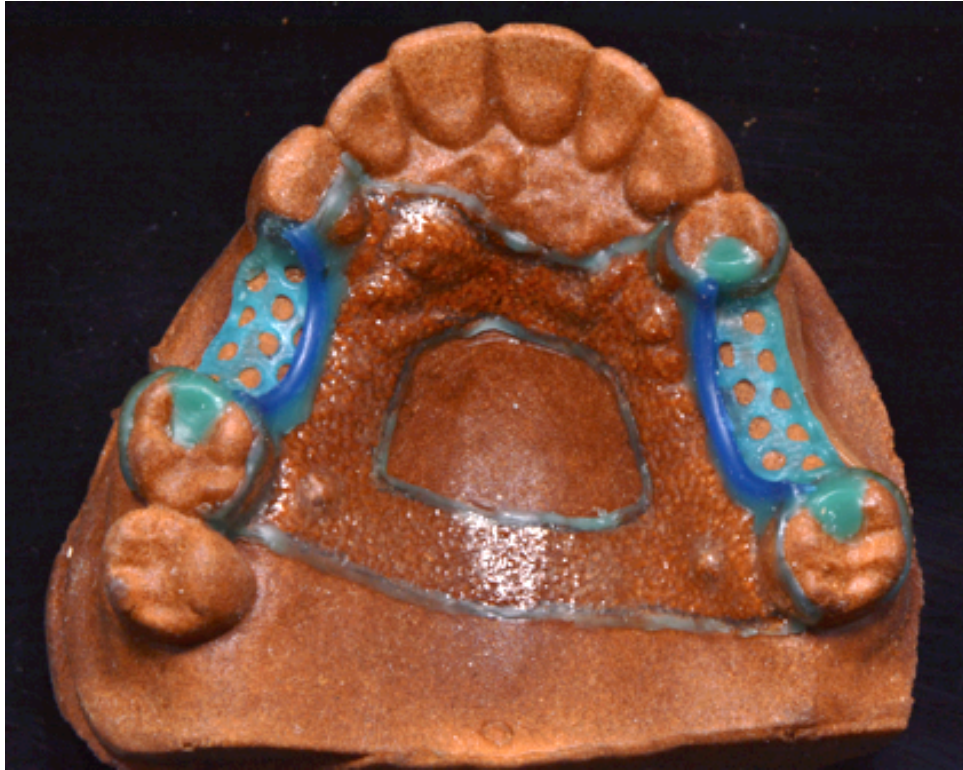


Figure 3. Wax pattern on the refractory cast for conventional cast RPD.

Group II: CAD-rapid Prototyping (CAD-RP)

Ten scans were made of the reference model using the 3Shape TRIOS 3 (3ST) (3Shape North America) intraoral scanner. Between each scan, the scanner was switched off and restarted to simulate different individual digital data acquisitions. Each individual scan was digitally designed using and RPD designing software (3Shape Removable Partial Design; Core3dcentres). After the designs were complete, the digital files were sent directly to 3DRPD[®] Company (Montreal, QC H1V 2C8) for fabrication of the RPD frameworks (Figure 4).

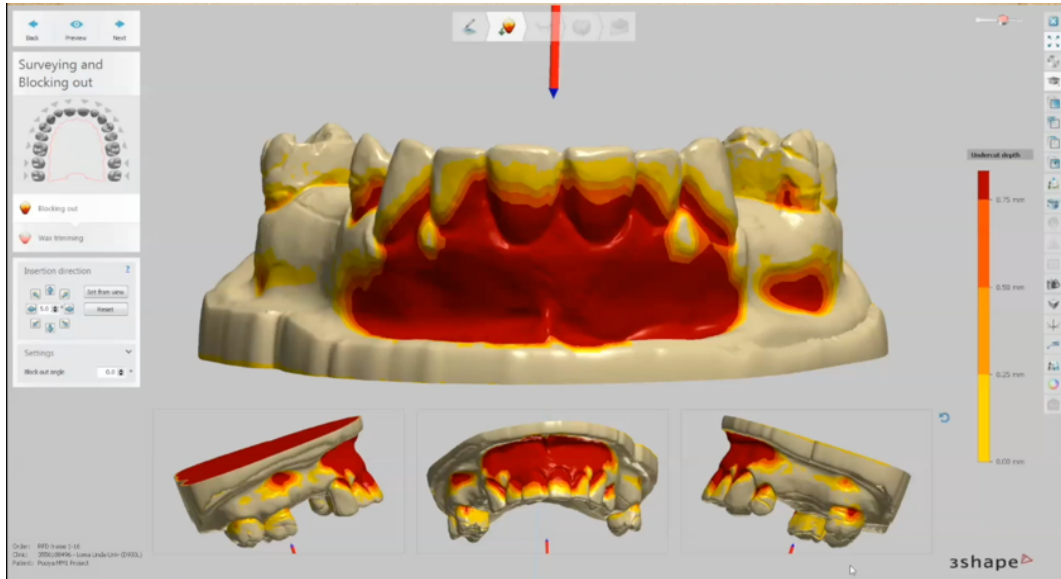


Figure 4. Digital surveying of the maxillary model.

Group III: CAD-rapid Prototyping from Stone Model (CAD-RPS)

The reference model was duplicated using a silicone-based duplication material (Vivid Image; Pearson Dental), and 10 stone casts were made using a Type IV scannable dental stone (FujiRock OptiXscan; GC America Inc). The casts were scanned using the 3ST. Between each scan, the scanner was switched off and restarted to simulate different individual digital data acquisitions. Each digital cast was designed on the computer and emailed as STL files to 3DRPD[®] company for fabrication of the RPD frameworks.

Group IV: Lost-wax Technique from Resin Model (LWTR)

The reference model was scanned using the 3ST 10 times. Between each scan, the scanner unit was switched off and restarted to simulate different individual digital data acquisitions. Each individual scanned data was exported as STL file format from the database, and imported into a 3D printing software (Preform Software; Formlabs Inc).

Each scan data was printed with a desktop, stereolithographic printer (Form 2; Formlabs Inc) coupled with synergistic biocompatible resin (Dental SG; Formlabs Inc) (figure 5).³⁸



Figure 5. 3D resin printed models used for Group IV (LWTR).

Each printed model was numbered and sent to a commercial lab for fabrication of the frameworks. The RPD frameworks were cast using Co-Cr alloy, finished and air particle abraded with Al₂O₃ under 2 bar pressure. All frameworks were fabricated by 1 laboratory technician.

Evaluating the Fit by Digital Superimposition

After receiving all finished RPD frameworks (figure 6A, 6B), the intaglio surfaces were scanned with a lab scanner (Dental Wings iSeries, Montreal, QC, Canada).³⁹ The STL file of each RPD framework was superimposed onto the STL file of the master model using a surface matching software program (Geomagic Control 2014; 3D Systems).³⁶

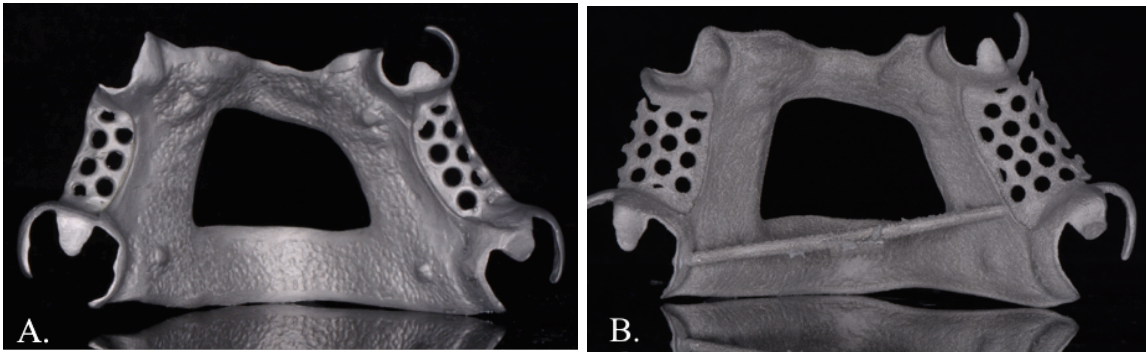


Figure 6.A. Conventional cast RPD framework; **B.** 3D printed RPD framework

The following measurements (diameter) were made of the following areas of the RPD framework: 1) rest seats (2mm), 2) major connectors (4mm), 3) proximal plates (3mm), 4) reciprocation plates or clasps (3mm), and 5) the origin of the retentive arms (2mm). Depending on the size of each area, an average of 20 to 40 points were selected. Color surface mapping was created to visually display the adaption of the framework with the model. A total of 25 areas were measured (Figure 7).

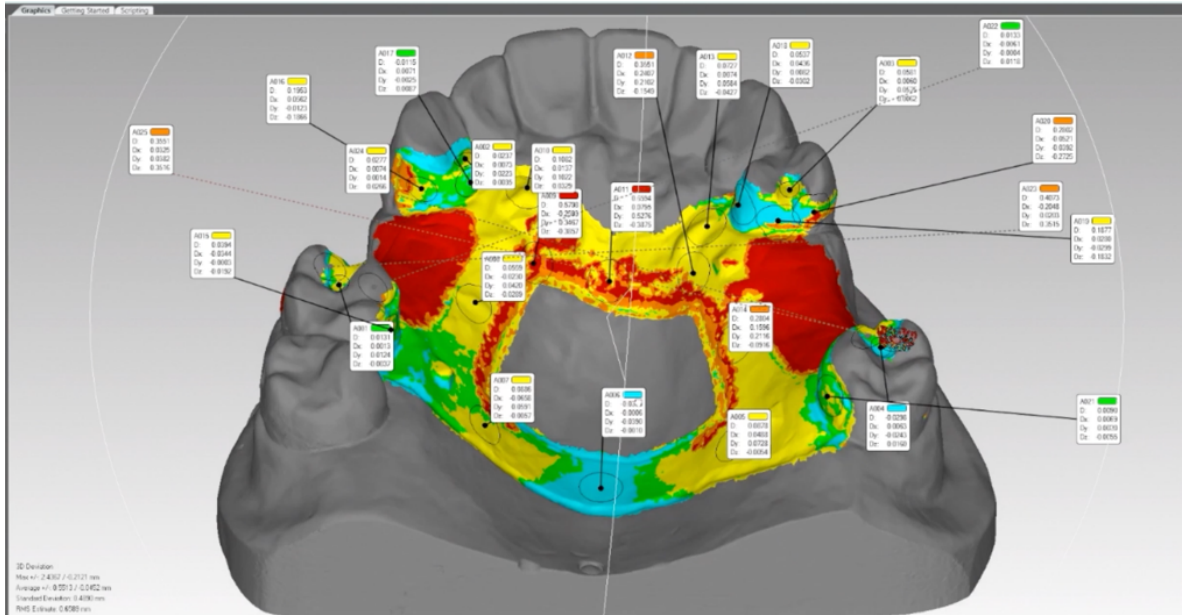


Figure 7. Digital superimposition and measurements of specific areas of an RPD framework.

Three different methods of superimposition were completed for analyzing the best fit: 1) overall adaptation of the framework to the master model, 2) adaptation of the major connector without the clasp assemblies, and 3) adaptation of the clasp assemblies without the major connectors. After each of these superimpositions, the rest of the framework was virtually oriented to the reference points and gap distances were measured. Measurements obtained from superimposition of the clasp assemblies without the major connectors revealed the best fit over the other methods and provided the basis for the evaluation of fit and accuracy.

Statistical Analysis

The Kruskal-Wallis analysis of variance was performed to determine the difference between each processing technique. This analysis compared each of the processing

technique measurements by location, and determined whether the differences were significant. Post hoc comparisons for multiple testing and the Levene test were used to determine the homogeneity of variance among the processing techniques. All tests of hypotheses were considered two-sided ($\alpha = 0.05$).

CHAPTER THREE

RESULTS

All areas (25) of each specimen, in each group, were analyzed. Between group comparisons were made of the RPD components. Three additional comparisons were made for the major connector, specifically the anterior strap, the posterior strap, and the combined anterior-posterior strap of each group.

A gap from 0 to 50 μm was considered close contact (no gap),³⁵ and a gap from 50 to 311 μm was defined as clinically acceptable fit.¹¹ The lowest value (best fit) for overall framework adaptation was obtained from the LWT group I, and the highest value (worst fit) was found with the CAD-RPS group (Table 1).

Table 1. Overall fit accuracy of frameworks.

Group	Mean (mm) \pm S.D.
Group I (LWT)	0.027 \pm 0.04
Group II (CAD-RP)	0.15 \pm 0.013
Group III (CAD-RPS)	0.16 \pm 0.02
Group IV (LWTR)	0.005 \pm 0.030

The overall gaps were statistically significantly less with the LWT and LWTR groups, when compared to the 3D printed framework groups ($P < 0.05$) (figure 8). There was no statistically significant difference between the conventionally cast frameworks (LWT versus LWTR), as well as between the 3D printed frameworks (CAD-RP versus CAD-RPS) ($P > 0.05$).

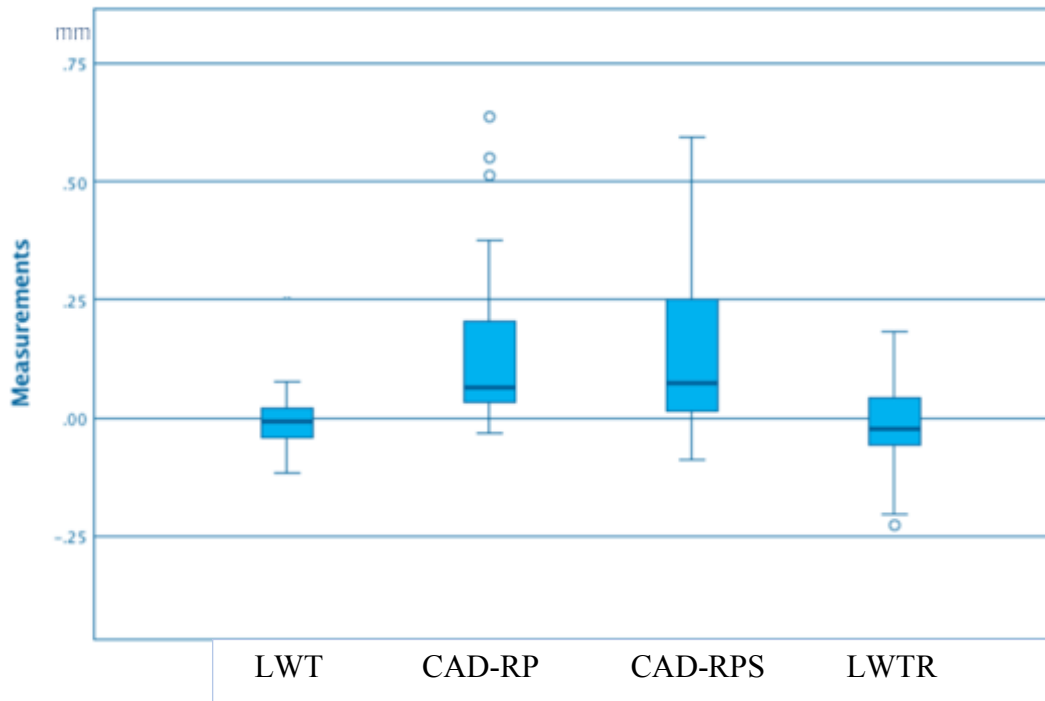


Figure 8. Overall adaptation of frameworks to the model.

The mean values measured for rests, guiding plates, and reciprocal plates or clasps from all groups were less than 50 μm , and were considered as close contacts (Table 2).

Table 2. Mean accuracy fit of specific framework components for each group.

Components	Specific Components	<u>Group I (LWT)</u> Mean (mm)±S.D.		<u>Group II (CAD-RP)</u> Mean (mm)±S.D.		<u>Group III (CAD-RPS)</u> Mean (mm)±S.D.		<u>Group III (LWTR)</u> Mean (mm)±S.D.	
		<u>Mean</u>	<u>Overall</u>	<u>Mean</u>	<u>Overall</u>	<u>Mean</u>	<u>Overall</u>	<u>Mean</u>	<u>Overall</u>
Major connector	Anterior strap	-0.015±0.08 ^a		0.33±0.05		0.32±0.08		- 0.09±0.06	
	Posterior strap	-0.06±0.10	-0.04±0.08	0.018±0.04	0.19±0.03	0.009±0.04	0.20±0.05	- 0.2±0.12	- 0.15±0.08
	A-P strap	-0.095±0.08		0.11±0.1		0.17±0.07		- 0.21±0.1	
Rest		-0.02±0.02		0.03±0.03		0.003±0.02		- 0.032±0.01	
Guiding plates		-0.03±0.03		0.12±0.03		0.13±0.05		0.053±0.06	
Reciprocal plates		0.0002±0.05		0.013±0.04		0.02±0.08		0.016±0.04	
Approaching arms		0.35±0.2		0.41±0.06		0.5±0.05		0.4±0.04	

^aSignificant differences found for major connector (p<.05)

For the major connectors, the lowest values obtained were from conventionally cast frameworks (LWT and LWTR), and were statistically significantly different when compared to the 3D printed frameworks (CAD-RP and CAD-RPS) ($P < 0.05$). The largest misfits (highest values) were found with the anterior straps, of the major connectors, with the CAD-RP and CAD-RPS groups (Figure 9).

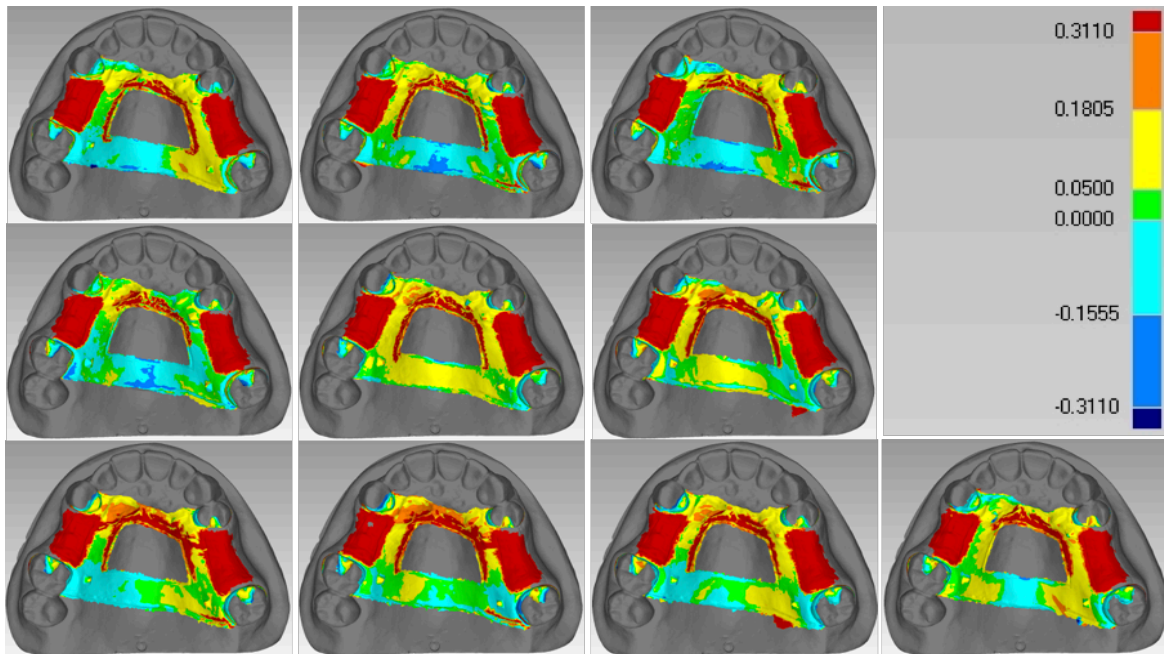


Figure 9. Color mapping after superimposition (CAD-RPS).

The mean gaps for each 3D printed framework were greater than the clinically acceptable range ($> 311 \mu\text{m}$), and were significantly different from the LWT and LWTR groups ($p < 0.05$) (Table 2). For the posterior straps of the major connectors, all groups had close contacts to the master model ($< 50 \mu\text{m}$), with the exception of the LWTR group, although the mean value for that group was within the clinically acceptable range ($< 311 \mu\text{m}$). For the approaching arms, the mean value for all groups was $> 311 \mu\text{m}$ (not

clinically acceptable). Specifically, group III (CAD-RPS) had the highest values when compared to the other groups.

CHAPTER FOUR

DISCUSSION

Several studies have reported the acceptable clinical outcomes with CAD/CAM fabricated RPD frameworks.^{3,5,22} However, there is lack of strong evidence that CAD-RP technique for fabricating RPD frameworks provides the best fit and results for the patients.²³ In this study, conventionally cast RPD frameworks using two different fabrication techniques revealed distinct differences with fit accuracy. Therefore, the null hypothesis was rejected.

The frameworks that were made using the lost-wax technique from stone models (LWT) revealed the best fit among all tested groups. However, all other groups (LWTR, CAD-RP and CAD-RPS) revealed clinically acceptable fit ($< 311 \mu\text{m}$). These results were similar to the study by Arnold et al.³ and Ye et al.²² which found that CAD-RP frameworks exhibited the highest discrepancies, but were within clinically acceptable limits. The biggest discrepancy was found with the anterior strap of the major connectors in groups II and III (CAD-RP and CAD-RPS). This could be attributed to inaccuracies during scanning of complete arch cases using digital scanners,^{8,9} or induced software errors while processing the STL files.¹¹ Also, the authors speculate some structural flaws may happen during printing or heat treatment of 3D printed frameworks during manufacturing process.

It was noted that between cast frameworks, those that were made from 3D printed resins had inferior fit when compared to the LWT group made from stone models.

Although no statistical differences were found between cast RPD groups ($P>0.05$) but as

it was shown in studies by Al-Imam et al and Cho et al, the printed resin models would produce less accurate working models.^{7,38}

Regarding the overall fit of RPD frameworks, Dunham et al.³⁴ reported 230 ± 222 μm of discrepancy for tooth-supported frameworks, while Ye et al.²² reported the average gap for CAD-RP frameworks and conventional RPD frameworks was 174 ± 117 μm and 108 ± 84 μm , respectively.¹⁷ In studies that rated the fit of the frameworks subjectively, the accuracy was rated as good or satisfactory.^{4,5,11,29} However, due to the subjective nature of their evaluation methods, our results cannot be directly compared with the results obtained in those studies. Moreover, some of the studies chose a less complex RPD framework design.^{4,5}

Although the mean fit accuracy of rests, guiding plates and reciprocal plates or clasps between groups revealed statistical differences, all measurements were clinically acceptable and were considered as closed contacts (<50 μm).³⁵ The approaching arm for the retentive clasp in all groups revealed a high amount of misfit (gap), which was similar to the study by Keltjens et al⁴⁰ where they reported about 60% of the RPD cases had misfits between the clasps and abutment teeth. In the present study, 95% of the samples (38 out of 40) had more than 311 μm gap between the approaching arms and the abutment teeth.

In contrast to these studies, in order to increase the validity of the study and minimize the induced human error during manufacturing, the intaglio surface of the frameworks were not finished or polished. We decided to not alter the intaglio surface based on a study by Brudvik et al., who reported an average of 127 μm of metal loss from the surface after finishing and polishing Co-Cr frameworks.¹⁷ Therefore, the average

misfit values that were reported in this study were lower compared to other similar studies.^{3,5,11,22,34}

To date, due to the complexity of regular RPD structures, and a wide range of designs, few studies have evaluated the fit and accuracy of RPDs quantitatively; specifically, by digital superimposition of the STL format of the scanned models. To evaluate the fit and accuracy of RPD frameworks, visual inspection, pressing test, as well as indirect measurements of the gap filled with an impression material, have been reported in the literature.³²⁻³⁵ However, a limitation regarding past methods is that these measurements were made in specific locations, and thus, do not reflect the actual overall fit of the RPD framework. Our methodology is novel; by using superimposition, we were able to obtain many data points and calculate the best possible fit between the master model and the RPD frameworks. Furthermore, the implementation of color mapping helped to identify the over-pressed or misfit areas of the frameworks. Color mapping revealed the largest misfit happened in the major connectors. Overall, more gaps were found with the CAD-RP frameworks while more tissue contacts and compressibility were found with cast frameworks.

Finishing and polishing of the intaglio surfaces may improve the fit the prosthesis. The authors recommend additional studies to evaluating fit accuracy of frameworks after final finished and polishing process. Furthermore, because of the limitations with using one commercial for the fabrication of conventional frameworks, and another lab for 3D frameworks, the authors suggest future studies to evaluate framework fit accuracies that are fabricated from different manufacturers.

CHAPTER FIVE

CONCLUSION

Within the limitations of the present study, the conventional processed RPD frameworks (LWT) revealed better fit and accuracy when compared to 3D printed frameworks. However, all methods revealed clinically acceptable fit. No significant differences with the fit of 3D printed frameworks were observed with regards to scanning methods (direct and indirect). High fit accuracy ($<50\ \mu\text{m}$) in the areas of the rest seats, guiding plates and reciprocal plates or clasps for all fabrication methods were observed. The least fit accuracy was observed with the major connectors; particularly the anterior straps that were fabricated using the CAD rapid prototyping technique.

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