A PRELIMINARY STUDY ON THE ACCURACY AND COST OF A DIGITAL WORKFLOW FOR METAL-BASED REMOVABLE PARTIAL DENTURE FRAMEWORKS

YASMIN OSMAN LATIB

A research report submitted to the Faculty of Health Sciences, University of the Witwatersrand, in partial fulfilment of the requirements for the degree of Master in Dentistry (Prosthodontics).

Supervisor:
Professor CP Owen
Co-Supervisor:
Dr MG Thokoane
School of Oral Health Sciences, Faculty of Health Sciences, University of the Witwatersrand, South Africa
Johannesburg, 2020

DECLARATION

I, Yasmin Osman Latib, declare that this research report is my own work. It has been submitted for the degree of Master in Dentistry in the Faculty of Health Sciences at the University of the Witwatersrand, Parktown, Johannesburg, South Africa. It has not been submitted before for any other degree or examination at this or any other University.

Latib

…………………………………………….
This 23rd day of March 2020

RESEARCH OUTPUT

Conference Proceedings

Poster Presentation

Osman Latib Y, Owen CP, Thokoane MG. A preliminary study on the accuracy and cost of a digital workflow for metal-based removable partial denture frameworks. Poster presentation at the 18th ICP Biennial Congress 2019 - 4 – 7 September 2019, Amsterdam.

ABSTRACT

Purpose: The most cost-effective treatment for the replacement of missing teeth is by removable partial dentures, which can either be based entirely in acrylic resin, or be reinforced by a metal framework. Metal frameworks have been traditionally made by the lost wax casting method, which is a lengthy and labour-intensive process. The introduction of computer-aided design and computer-aided manufacture (CAD/CAM) has revolutionised traditional dentistry, where it has been shown to be sufficiently accurate, less labour-intensive and cost-effective. The purpose of this study was to compare the accuracy and comparative costs of two digital workflows that produce resin framework patterns to be cast conventionally with an identical framework manufactured conventionally from a wax pattern.

Method and materials: A maxillary master cast was made of a Kennedy Class II modification 3 partially edentulous arch, with appropriate tooth preparations. The same design for the framework was used throughout. From the master cast, 9 casts were made, and their accuracy determined. All measurements of casts and frameworks were made in three dimensions using the Reflex Microscope (Consultantnet Ltd, Cambridge, UK) which measures to an accuracy of 4µm. Six casts were scanned using a D2000 extra-oral scanner (3shape, Denmark). The other three casts were used for the conventional casting technique, by sending normal instructions for the design to a commercial laboratory. The six scanned models were imported into design software (3shape, Denmark, version 2.19.2.0) and a pattern designed on each in accordance with the design. Three digital patterns were milled in a resin burnout block (Yamahachi, Japan) using the Imes-iCoreCoritec350 Pro plus milling unit (Germany) and three were printed with resin burnout (Nextdent, 3S systems, Netherlands) using a 3D printer (Moonray, Sprintray, North America). Each framework and its model was measured using the reflex microscope at pre-determined points on the framework. Thereafter, the milled and printed frameworks, together with their corresponding casts, were conventionally cast and all 9 frameworks were then measured at the pre-determined points. One milled resin framework was miscast. This was a processing error that occurred during the traditional casting method.

Results: All resin patterns and all cast frameworks showed intra- and inter-group consistency. The sample size precluded direct statistical conclusions, but no significant differences were found. Duplicate models were accurate and showed minimal differences compared with the master cast. All patterns and all frameworks showed some level of differences to the master cast, but no differences were greater than those reported in the literature as being clinically successful. The maximum overall discrepancy between the cast frameworks was 0.64 mm and at the rest seats, 0.262 mm. The preliminary cost analysis carried out revealed that the total time taken on average, was greater for the conventional technique.

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

It is recommended that further economic analyses be carried out, as well as further studies using these digital workflows, to determine the clinical acceptability of the methods.

ACKNOWLEDGEMENTS

In completion of this work, I would like to express my sincerest gratitude to:

Firstly, to The Supreme Being, The Almighty, for bringing me to where I am today, for granting me the willingness and strength to complete my studies.

I would like to express my gratitude and appreciation to Professor Peter Owen, for his encouragement, support, expertise, knowledge and invaluable advice throughout my research and studies. You have been an inspiration, and your dedication, willingness, motivation and encouragement have opened my eyes to the wonders of academics and research.

To my Supervisor, Dr Meriting Thokoane, for your invaluable assistance and guidance in completing this report.

To my father, my role model. No dream was too big and you had always encouraged me to reach for the stars and beyond! Your unconditional love has been my light in difficult times and even though you are no longer with me, I could not have reached where I am today without your encouragement, belief and support. For always believing in me, encouraging me, and always being there.

To my siblings, for your continued support in my endeavour to conquer anything and everything.

To my sister Sameeha. Words cannot describe how grateful I am for having you in my life. Thank you for all your encouragement and making me believe that everything is possible.

To my niece and nephews. Your everlasting love has been my beacon and guiding star the past four years.

Rahel Kader, my beloved best friend. Thank you for being you! Thank you for your strength, your continuous support and motivation, thank you for believing in me!

A special thank you to:

To Professor JL Shackleton, Head of Department of Oral Rehabilitation, University of the Witwatersrand, for aiding in the financial support for this research, and more importantly, your presence, encouragement and strength kept me going through the completion of this work.

Lastly, my sincerest gratitude to the FRC grant programme at the Health Science Research Office, University of the Witwatersrand, who made it possible for this research to continue.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION AND LITERATURE REVIEW

1.1. Introduction

Epidemiological studies have indicated a decline in complete tooth loss, and an increase in the prevalence of partial tooth loss (Campbell *et al*., 2017). Factors relating to the shift from complete to partial edentulism include increased life expectancy, a rise in the number of elderly individuals within the population and the suggested improvement of maintenance of oral health (Campbell *et al*., 2017). Tooth loss remains prevalent globally and leads to compromised aesthetics as well as a decrease in masticatory ability such that food choices may be affected as well as cognitive abilities related to mastication and occlusion (Sheiham *et al.,* 1999; Wöstmann *et al*., 2005; Klineberg *et al* 2014; Ali *et al*., 2019).

Prosthodontic options available for replacing missing teeth include tooth-supported fixed dental prostheses, implant-supported fixed and removable dental prostheses, removable partial dentures and no treatment (shortened dental arch). The most cost-effective treatment for the replacement of missing teeth is by removable partial dentures, which can either be based entirely in acrylic resin, or be reinforced by a rigid framework, usually metal (Vermeulen *et al*., 1996; Zlatarić *et al*., 2003; Almufleh *et al*., 2018).

1.2. Treatment outcomes of removable partial dentures

An improvement in the maintenance of oral hygiene has resulted in an increased need for treatment of partial edentulism (Campbell *et al*., 2017). A conventional removable partial denture serves as the first and often the only prosthodontic option for partially dentate patients because of its relatively low cost and non-invasive nature. The indications and advantages of a removable partial denture (RPD) have been stated as, *inter alia* to overcome financial limitations; to act as provisional prostheses; to become transitional prostheses for the failing dentition; when dental implants are not feasible; and to replace lost hard and soft tissues especially in long edentulous spans (Campbell *et al*., 2017).

The literature, however, is rife with reports of failure of RPDs. In a review, Campbell *et al.* (2017) reported that "failure rates of RPDs have led many to conclude that RPDs are harmful to periodontal tissue and may contribute to carious lesion formation". Previous studies have reported that the long-term use of RPDs was associated with an increased risk of caries, periodontitis and alveolar bone resorption (Chandler and Brudvik, 1984; Aquilino *et al*., 2001; Zlatarić *et al*., 2002; Koyama *et al*., 2010). However, Bergman *et al.* (1982) concluded that a well designed and constructed RPD which allowed continual maintenance of oral hygiene was a crucial factor in maintaining the health of the remaining dentition.

Rehmann *et al*. (2013) evaluated the long-term outcomes of metal framework RPDs and reported a mean survival time of 8 years, with a positive outcome probability of 90% after 5 years. The only parameter that significantly influenced this probability was the prosthesis location, where a lower denture had a lower survival time. This was similar to studies reported by Vanzeveren *et al*. (2003a, 2003b). These studies, as well as others, have concluded that RPDs with simple, hygienic designs are clinically successful (Vermeulen *et al*., 1996; Bergman *et al.* 1982; Campbell *et al*., 2017).

1.3. Stellite alloys

In the 1930s, stellite alloys were introduced as an alternative to gold alloys. The base metal alloys were cobalt-chromium (Co-Cr) and nickel chromium (Ni-Cr) as well as Ni-Cr alloys containing beryllium (Kim *et al*., 2016). The use of Co-Cr has increased over many decades, most probably because of their low cost, excellent biocompatibility, low density, high elastic modulus, superior strength, heat resistance, and rigidity (Phillips, 1982; Wataha and Messer, 2004; Al Jabbari, 2014). Studies comparing Co-Cr to Ni-Cr found that Co-Cr based alloys possessed better biocompatibility and higher resistance to corrosion and tarnish than Ni-Cr based alloys (Craig and Hanks, 1988). These factors, together with concerns regarding allergic reactions and potential carcinogenic effects of nickel and beryllium have resulted in the widespread use of Co-Cr (Al Jabbari, 2014; Kim *et al*., 2016).

The composition of Co-Cr alloys varies between manufacturers. Anusavice *et al*. (2013) reported the composition of common Co-Cr alloys to be 60% cobalt, 25% chromium, 10% nickel, 5% molybdenum and 0.3% carbon. McCabe and Walls (2013), on the other hand, reported the composition to be 35 – 65% cobalt, 25 – 35% chromium, 0 – 30% nickel, a small amount of molybdenum and a trace quantity of beryllium, carbon and silicon.

1.4. Accuracy of models

The conventional methods of impression making and pouring of impressions with gypsum products, to produce casts for the construction of prostheses, form the foundation of any prosthetic procedure in dentistry. The accuracy of casts is dependent on a multitude of clinical and laboratory variables including impression techniques and pouring methods, and material properties (Papaspyridakos *et al.,* 2014). In an *in vitro* study Hoods-Moonsammy and colleagues (2014) compared the accuracy of three impression materials: a polyether, a polyvinyl siloxane (PVS) monophase and PVS putty and wash for long-span implant supported prostheses. PVS monophase and polyether displayed the least discrepancy. However, even under strict conditions some distortion was found; although not statistically significant this can contribute to the cumulative distortion and ultimate misfit of a prosthesis (Hoods-Moonsammy *et al*., 2014).

The accuracy of models duplicated from a master cast does not appear to have been tested or reported in the literature, although accuracy of digital scans compared with material-based impressions has been compared for the construction of dies, and found to be sufficiently accurate for clinical application (Kim *et al*. 2013).

1.5. Accuracy of frameworks

The accuracy of the fit of the framework is an important contributing factor to the success of removable partial dentures (Fenlon *et al.*, 1993; Ali *et al*., 1997; Frank *et al*. 2000). Frank *et al*. (2000) found that in 76% of the patients surveyed a lack of fit was a common source of dissatisfaction with their RPD. The study assessed fit using visual and tactile examination using a mirror and explorer. Furthermore, fit was rated good if "*all rest seats appeared to be seated, all rigid elements touched the teeth and the major connector did not impinge on the underlying soft tissue or having a visible relief space greater than 1mm*". The researchers found that almost a third (32%) of the frameworks evaluated had a poor fit. Stern *et al.* (1985) and Dunham *et al*. (2006) reported similar findings.

Conventional casting has been reported to yield inconsistent results (Kim *et al*., 2017). Co-Cr alloys for partial denture framework restorations have shown a 2.33% shrinkage after casting (Anusavice *et al*., 2013). Attempts to compensate for this have included, *inter alia*, computer-generated oversized wax design, or controlling the mould expansion (Carr and Brown, 2011, Powers and Wataha, 2014). A digitally constructed prosthesis could allow for the elimination of waxing on a comparatively rough refractory cast, which may reduce the potential for errors and result in better quality control in the dental laboratory and lead to improved framework fit (Kim *et al*., 2017; Lima *et al*., 2014).

Various methods to analyse the accuracy and fit of Co-Cr frameworks have been reported (Ye *et al*., 2017). The most-used methodology for assessment includes visual and tactile examination on the cast or clinically in the patient's mouth, and the internal fit between the RPD and the oral tissues has been measured using a silicone registration material (Dunham *et al*., 2006; Ye *et al*., 2017). Other methods include sectioning the framework and direct measurements between the prosthesis and master cast, the use of disclosing materials and digital superimposition of models (Cho *et al*., 2015; Stern *et al*., 1985).

Saad *et al*. (2019) described the criteria used for evaluating of the guiding plane/plate relation as well as the accuracy of fit of occlusal rests and major connector of conventionally and digitally fabricated RPD frameworks. The guiding plane relation was evaluated with visual inspection intra-orally and with the use of a disclosing agent (occlusion spray). To test the major connector and the fit of the occlusal rest, they used two disclosing agents (auto polymerizing fast set acrylic resin material and vinyl polysiloxane material respectively). The method of using vinyl polysiloxane was similar to that described by Dunham *et al*. (2006).

Visual and tactile examination have been measured subjectively, with accuracy of the framework being described as good or satisfactory. Qualitative evaluation of clinical fitness has included a visual inspection and a pressing test. The visual inspection was proposed by Frank *et al*. (2000) and included the following observations: "whether all rests were seated; whether all rigid elements touched the teeth, and that the major connector did not impinge on the underlying soft tissue and had no visible relief space >1 mm". The pressing test involved a cement plugger that was held on the occlusal rest perpendicular to the occlusal plane and observing any detectable movements whilst applying pressure on the rest (Frank *et al*., 2000).

To date, few studies have evaluated the fit and accuracy of RPDs quantitatively. This has been attributed to the complexity of RPD structures, the variety of component materials and the wide variety of designs. Stern *et al*. (1985) and Dunham *et al*. (2006) proposed similar approaches to quantify the space between the rest and rest seat, where they evaluated the depth of discrepancy (vertical measurement). The early work by Stern *et al*. (1985) provided insight into the levels of tolerance of a clinically acceptable fit of an RPD. They evaluated the degree of adaptation between the cast occlusal rest and the corresponding rest seat intra-orally and reported an average gap thickness of 69 to 387 µm between the occlusal rest and the rest seat. Five of the 47 rests evaluated had an average overall fit of 50 to 100 µm, while seven had averages greater than 250 µm. The remainder 35 rests had an average distance between metal and rest seat of 100 to 250 µm. These results show the lack of intimate contact between the RPD framework and prepared rest seat.

Dunham *et al.* (2006) reported even greater discrepancies with an average thickness of 193 ± 203 µm (with a range of 0 to 828 µm) for cast frameworks. Even though results were described quantitatively, the frameworks were judged as acceptable by the examiners. Whilst no mention has been made of an acceptable clinical discrepancy, one can postulate from these studies that the tolerance level of a clinically acceptable fit to be 69 to 828 µm.

Lee *et al*., (2017) evaluated the discrepancy under both cingulum and occlusal rests using a silicone replica technique and measured the centre and periphery of the rests. The mean discrepancy was 248 µm and there were no differences in terms of whether the RPD was tooth or tooth and tissue supported. They did find a significant difference between the fit at the periphery and at the centre in the cingulum rest. 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 possibly of up to 900 μm would be within a clinically acceptable range. It would be preferable, though, that this range be as small as possible.

1.6. Digital dentistry/technology

The last century has shown significant advances in dental technologies. Manufacturing processing techniques and systems have been introduced into dentistry, where computer-aided design and computer-aided manufacture (CAD/CAM) has revolutionised traditional dentistry, with the introduction of CAD/CAM crowns, bridges and implant-supported prostheses and the increasing use of digital impressions. A digital impression may be captured/created either directly with intraoral scanning or indirectly with extra-oral scanning of working casts.

A direct intraoral scan may compensate for the inaccuracies inherent in any distortions with impression material and gypsum casts, but may not always be feasible for full-mouth reproduction of all teeth and soft tissues (Mangano *et al*., 2017). Ender *et al.* (2016) reported that from their study comparing full-arch digital with analogue impressions, the accuracy was dependent on the impression material. They reported that a digital full-arch impression could be more accurate than an irreversible hydrocolloid, but not as accurate as elastomeric materials.

The uptake of CAD/CAM in the manufacture of RPD frameworks has been slow, mainly because the CAM technique relies heavily on subtractive methods such as grinding, cutting and milling. These processes have been shown to be time consuming and expensive, with spatial restrictions limiting the production of complex shapes and the possibility of deformation or breaking in thin areas during manufacturing (Kim *et al*., 2017; Kruth *et al*., 2005; Lima *et al*., 2014). Rapid prototyping (RP), which is an additive manufacturing technique, has been introduced to overcome the problems encountered during subtractive material manufacturing (Kim *et al*., 2017; Ye *et al*., 2017) but has yet to be evaluated fully in terms of cost-effectiveness and accuracy.

Commonly used RP techniques include stereolithography, three-dimensional printing, fused deposition modelling, selective laser sintering and selective laser melting (Ye *et al*., 2017). The latter two are layer-wise material addition techniques that allow the generation of frameworks by selectively consolidating successive layers of powder material on top of each other, using thermal energy supplied by a focused and computer-controlled laser beam (Kruth *et al*., 2005; Santos *et al*., 2006).

Bibb *et al*. (2006a) and Williams *et al*. (2006) both used a selective laser melting technique. The advantages of this technique were reported to be high durability, and comparable accuracy of the quality of fit and function on trial fittings to cast Co-Cr frameworks. The disadvantages, however, outweighed the advantages, mainly due to the high cost of the sintering machinery and materials (Bibb *et al*., 2006a; Williams *et al*., 2006).

Bibb *et al*. (2006b) reported a clinical case in which a metal framework was produced using CAD/CAM and RP. The authors constructed an epoxy resin prototype that was cast manually through the lost wax technique. The framework was test-fitted clinically intra-orally. After minor adjustments were made to the framework, the clinical supervisor visually confirmed the framework as satisfactory. There was no quantitative evaluation, but it was reported that the accuracy of the framework was similar to traditional cast frameworks and required fewer adjustments. This study was a clinical application of a previous *in vitro* study describing the process (Eggbeer *et al.* 2005).

The cost/benefit ratio is an important factor when comparing CAD/CAM constructed RPDs to conventionally cast RPDs. Conventional cast RPDs are constructed in the dental laboratory and are not only labour-intensive (Wu *et al*., 2012; Lang and Tulunoglu, 2014), but experience-dependent too (Lang and Tulunoglu, 2014). Although the workflow of a CAD/CAM designed framework is perhaps more efficient, CAD/CAM constructed RPDs are less cost-effective because of the high costs of the scanning equipment, CAD software and rapid prototyping/manufacturing equipment and materials (Williams *et al*., 2004). Lima *et al.* (2014) highlighted that whilst CAD/CAM technology was able to eliminate errors inherent in the steps in conventional casting, many advances still needed to be made so that appropriate equipment and software can be developed and the high costs of production reduced.

1.7. Purpose

No studies have assessed quantitatively the accuracy of a digital workflow that produces a resin framework which is subsequently cast conventionally. This has the potential to reduce the cost compared with milling directly, or sintering a framework, therefore this study set out to establish the viability of such a digital workflow and form a platform for future prospective and comparative studies.

2. AIM AND OBJECTIVES

2.1. Aim

The aim of this *in vitro* study was to compare the accuracy and comparative costs of a digital workflow that produces a resin framework pattern to be cast conventionally with an identical framework manufactured conventionally from a wax pattern.

2.2. Objectives

1. To establish the accuracy of duplicated standard casts to a master cast.
2. To compare the accuracy of a milled and printed polymethylmethacrylate framework with its cast and finished equivalent and to compare that casting with one produced conventionally from a wax pattern.
3. To compare the costs of the digital workflow to that of the conventional workflow, in terms of the materials and laboratory procedures used.

2.3. Null Hypotheses

There are no differences in the accuracy of a metal RPD framework produced by a digital workflow compared with a conventional workflow.

3. MATERIALS AND METHOD

An ethical waiver was issued by the Human Research Ethics Committee of the University of the Witwatersrand for the laboratory-based study and the clearance certificate number is W-CJ-141205-1 (Appendix A).

3.1. Master Cast and Working Casts

A maxillary master cast of a Kennedy Class II modification 3 partially edentulous arch (Figure 3.1) was used. The framework design was as per Figure 3.2. Seven rest seats were prepared on the abutment teeth of 17, 14, 13, 11, 21, 23, and 25 respectively. After rest preparations, the model was duplicated using a silicone-based mould material (Mold Star 30, Smooth-On, Inc, USA) (Figure 3.3). This allowed for the fabrication of standard working casts. Nine working casts were poured with Type IV gypsum dental stone (Silky-Rock, WhipMix Corporation, USA), mixed according to the manufacturer's instructions. All the models were poured using the same silicone-base mould by one technician, on the same day. Each model was numbered in numerical order.

Figure 3.1 Kennedy Class II maxillary arch.

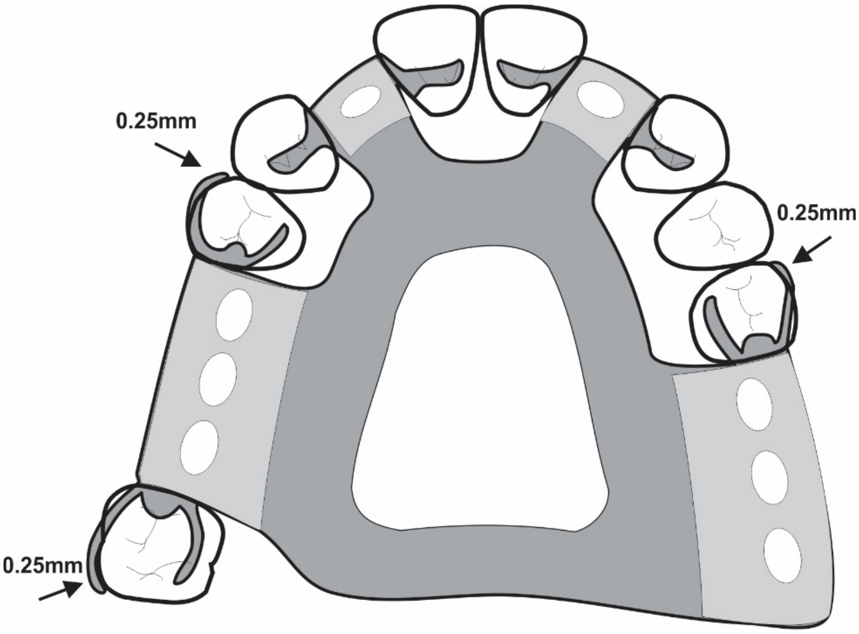


Figure 3.2 Design for the maxillary Kennedy Class II partial denture

Figure 3.3 Silicone-based mould of master cast

3.1.1. Surveying

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

3.2. Framework Fabrication

3.2.1. Conventional technique

Three working casts (numbered 1 – 3) were sent to a commercial laboratory for the fabrication of conventionally fabricated cast Co-Cr frameworks, together with instructions to produce three finished metal frameworks as per the attached design, to be returned on each cast. Wax patterns were moulded on each model.

3.2.2. Digital technique

Six casts were scanned using a D2000 extra-oral scanner (3Shape North America). Each individual scan was digitally designed (figure 3.4) using 3Shape designing software (3shape, Denmark, version 2.19.2.0) and a pattern designed on each in accordance with the design depicted in Figure 3.2. The completed design was exported into a standard tessellation language (.stl) file.

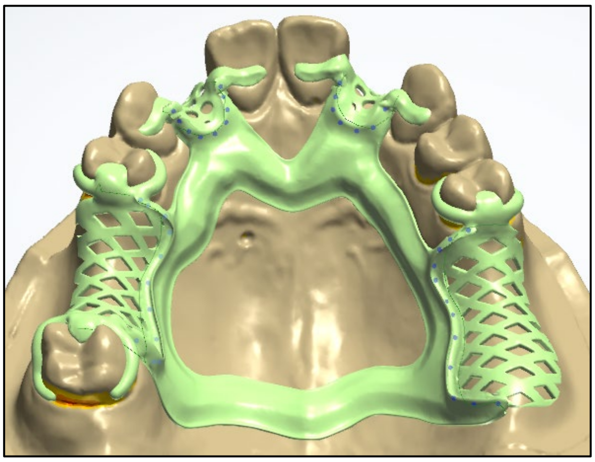


Figure 3.4 Digital design of Co-Cr RPD Milled framework

Casts used for the milled framework were numbered 4 – 6. Three digital patterns were milled from a resin burnout block (Yamahachi, Japan) using the Imes-iCore Coritec 350 Pro plus milling unit (Germany). Each resin framework (figure 3.5) was measured using the reflex microscope at pre-determined points on the framework. Thereafter, the milled frameworks were sent to the same laboratory, together with its corresponding cast, with instructions to cast and finish the frameworks. One laboratory technician fabricated all the frameworks.

Figure 3.5 Milled resin framework

Printed framework

Casts used for the printed framework were numbered 7 – 9. The digital pattern was printed in resin (Nextdent, 3 S systems, Netherlands) (Figures 3.6 and 3.7) using a 3D printer (Moonray, Sprintray, North America). After the printing process, each printed framework was washed with isopropyl alcohol for 15 minutes to ensure all uncured resin was removed. Each resin framework was measured using the reflex microscope at pre-determined points on the framework. Thereafter, the printed framework was sent to the same laboratory, together with its corresponding cast, with instructions to cast and finish the framework, by one laboratory technician.

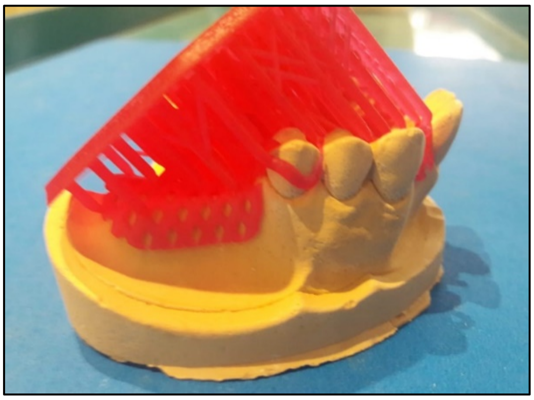


Figure 3.6 Printed framework with support

Figure 3.7 Printed framework with sprue

3.3. Measurements

For determining the accuracy of the models, 3 pre-determined reference points were identified (Figure 3.8).

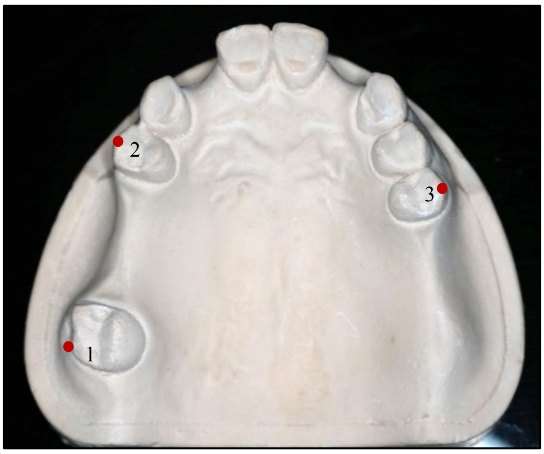


Figure 3.8 Pre-determined points to determine accuracy of the duplicated models

In the second stage of the study, six pre-determined points were identified; the tip of each clasp arm (including the reciprocal arm) and the respective point on the model (Figures 3.9 and 3.10). These measurements were of the printed and milled frameworks, and all of the cast frameworks. All points were measured using a reflex microscope (Consultantnet Ltd, Cambridge, UK) which measures in 3 dimensions to an accuracy of 4 μm.

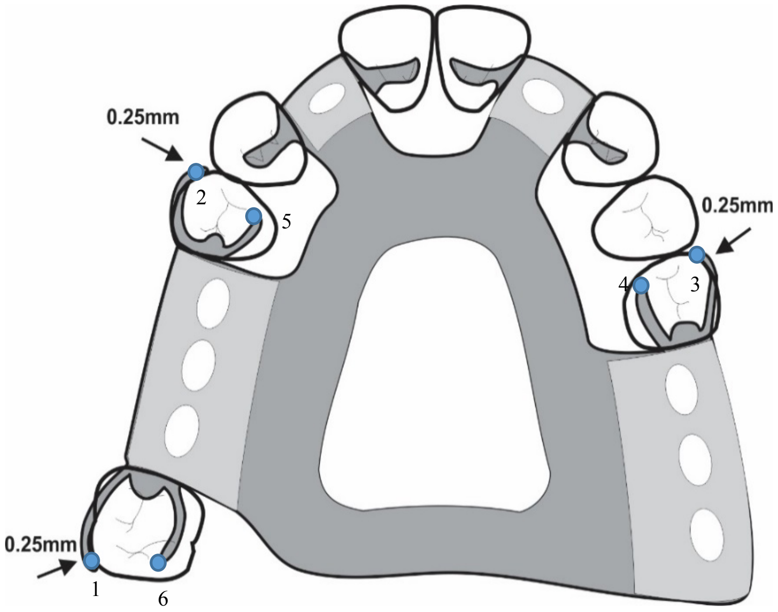


Figure 3.9 Pre-determined points to determine accuracy of frameworks

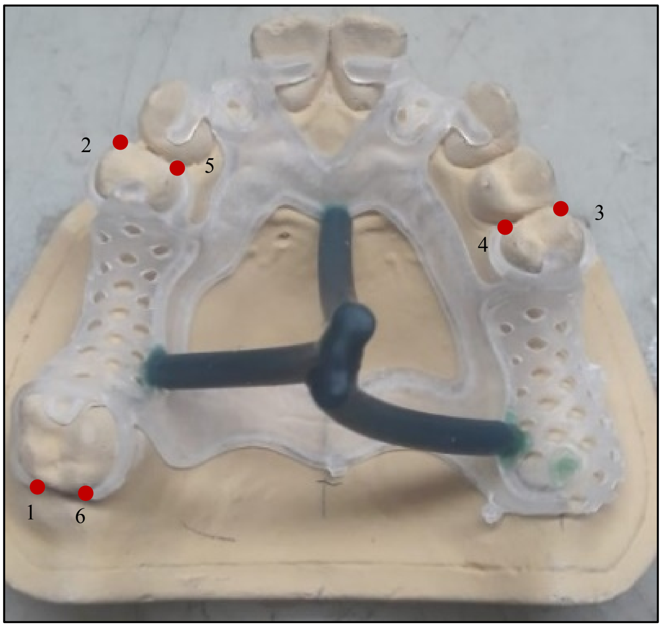


Figure 3.10 Points on the model corresponding to the clasp tips of the framework

The third stage of the study evaluated the accuracy of the rest seats of the cast framework to its corresponding cast. Five pre-determined points were identified; the maximum curvature of points on the tangent of curvature for occlusal rests and the lowest curvature of cingulum rests and its corresponding point on the framework (Figure 3.11).

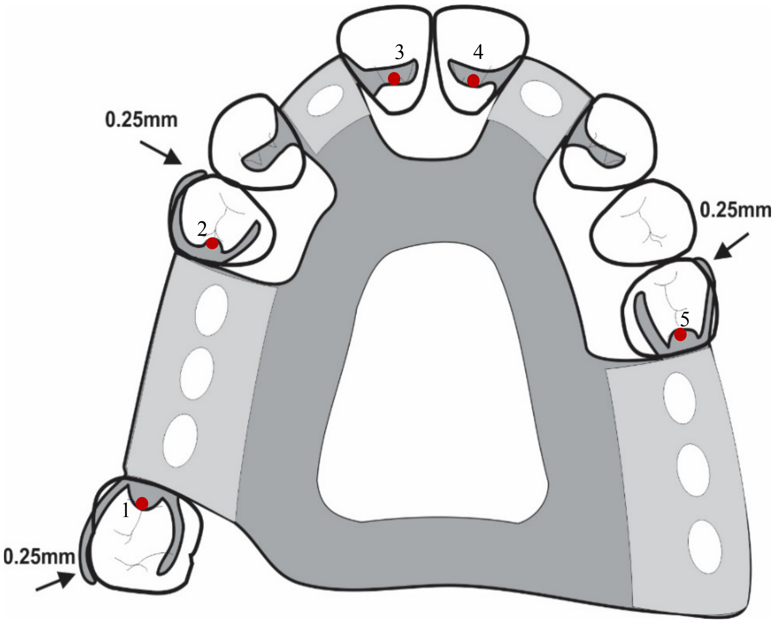


Figure 3.11 Pre-determined points on cast framework at the maximum curvature of the rest; the corresponding points on the model are at the maximum curvature of the rest seat.

3.4. Data Analysis

The sample size estimation was selected from previous studies that inspected internal discrepancy of 2 or 3 types of framework components (Arnold *et al*., 2018; Wu *et al*., 2012; Bibb *et al*., 2006a; Bibb *et al*., 2006b; Williams *et al*., 2006; Eggbeer *et al*., 2005).

To determine whether the mean of the observations could be used for further analysis, an intra-rater reliability test between all measurement occasions was used using the 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 to 4μm, 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 for the casts and cast frameworks, on 6 separate occasions. Then the mean of measurements made on more than one occasions that gave either good or excellent correlation coefficients could be used for further analysis. Each metric was compared between workflows using one-way Analysis of Variance (ANOVA) (or the t-test for two workflows). Where the data did not meet the assumptions for a one-way ANOVA, a non-parametric alternative, the Kruskal-Wallis test and the Wilcoxon rank sum test were used.

4. RESULTS

The intra-rater reliability for the measurement occasions was assessed using the ICC on the following scale for values:

Less than 0.5: poor
Between 0.5 and 0.75: moderate
Between 0.75 and 0.90: good
Greater than 0.90: excellent

4.1. Accuracy of models

Three horizontal linear distances were measured on each model. The ICCs for different day combinations are shown in Table 4.1. It was possible to find excellent correlation as shown by the shaded areas in the table and illustrated in Figures 4.1 to 4.3.

Table 4.1 Intraclass Correlation Coefficients for horizontal linear measurements on different days for the standard cast

	Day 1,2,3	Day 1,2	Day 1,3	Day 2,3	Day 4,5,6	Day 4,5	Day 4,6	Day 5,6	Day 1,4	Day 1,5	Day 1,6	Day 2,4	Day 2,5	Day 2,6	Day 3,4	Day 3,5	Day 3,6
Standard Cast Point 1 - 2	0,46	0,46	0,78	0,21	-0,02	0,52	-0,46	-0,15	0,74	0,18	-0,14	0,54	0,65	-0,25	0,32	-0,01	0,08
Standard Cast Point 2 - 3	-0,29	0,03	-0,31	-0,55	-0,18	0,17	-0,37	-0,27	0,67	0,00	-0,29	-0,02	0,64	-0,41	-0,39	-0,36	0,85
Standard Cast Point 1 - 3	-0,01	-0,28	0,46	-0,11	0,08	-0,28	0,08	0,48	0,76	-0,12	0,21	-0,33	0,39	0,10	0,27	0,16	0,78

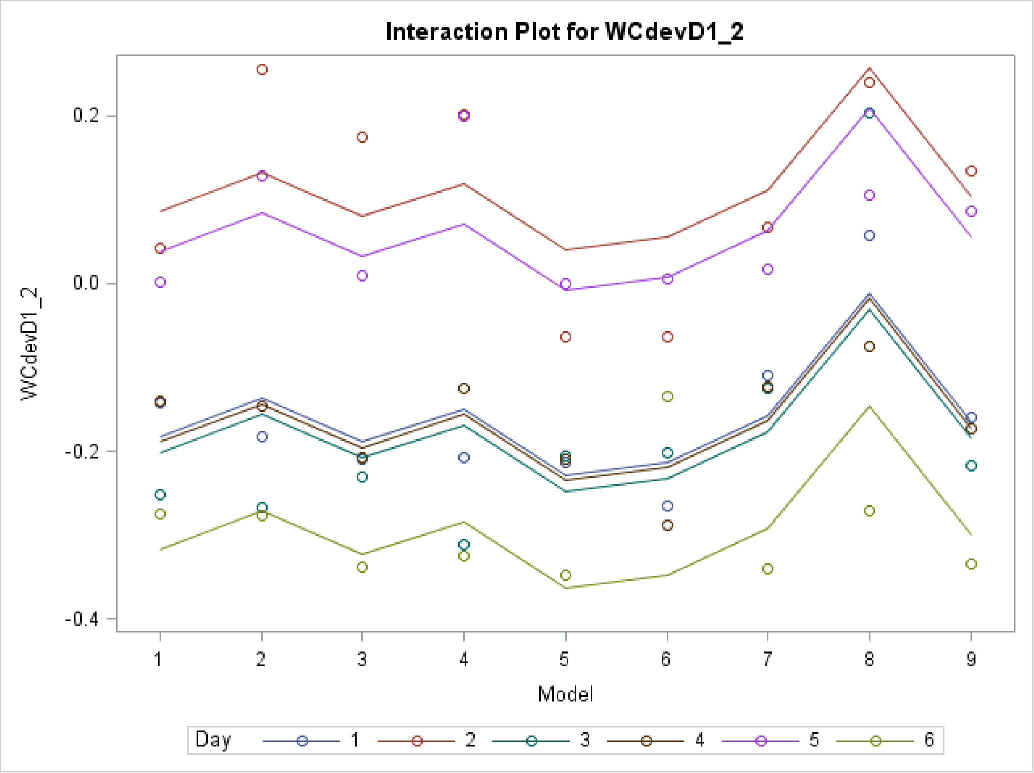


Figure 4.1 Interaction plot for standard casts points 1 – 2. Days 1 and 3 had an ICC category of excellent.

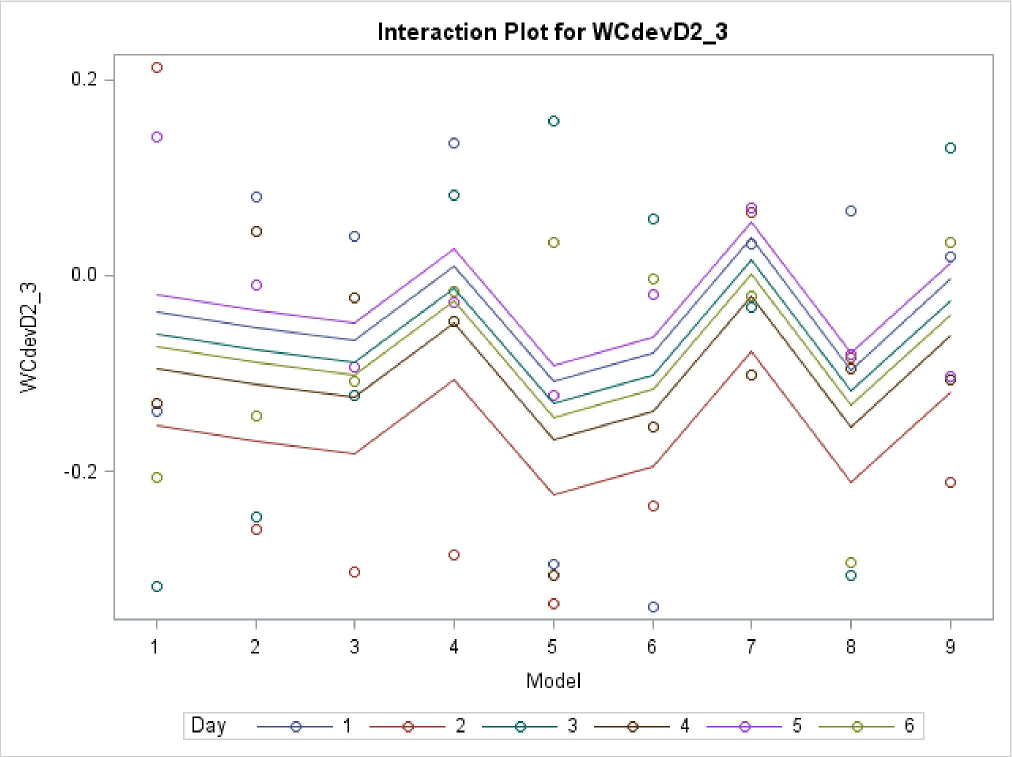


Figure 4.2 Interaction plot for standard casts points 2 – 3. Days 3 and 6 had an ICC category of excellent.

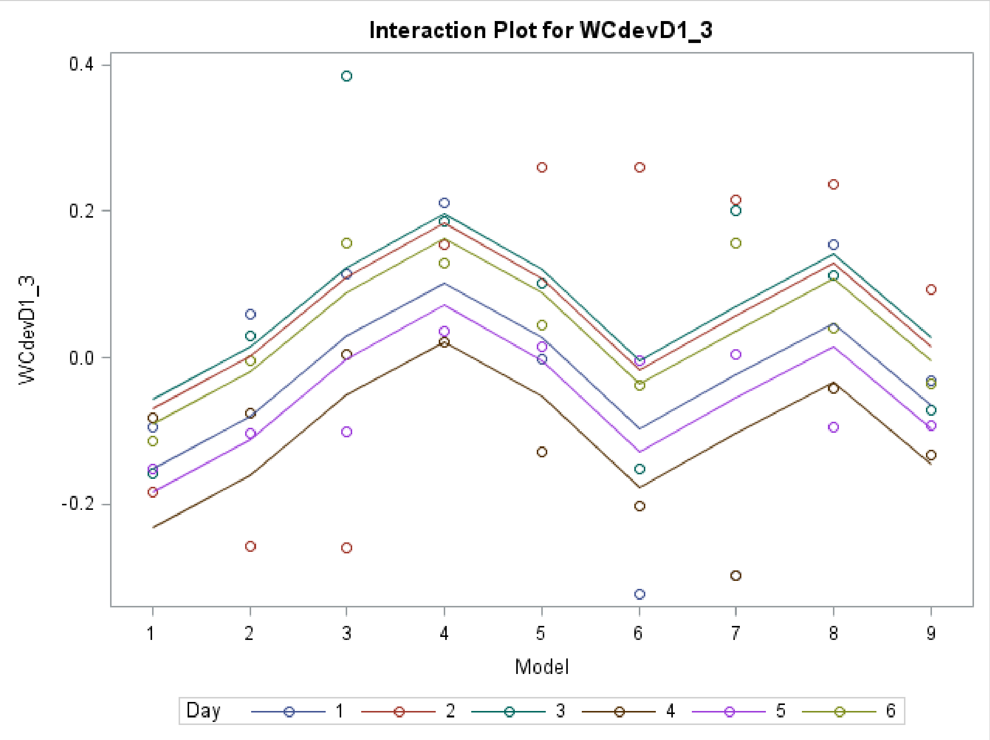


Figure 4.3 Interaction plot for standard casts points 1 – 3. Days 1 and 4 and 3 and 6 had ICC categories of excellent.

The descriptive statistics for the standard models at the different points are shown in Table 4.2.

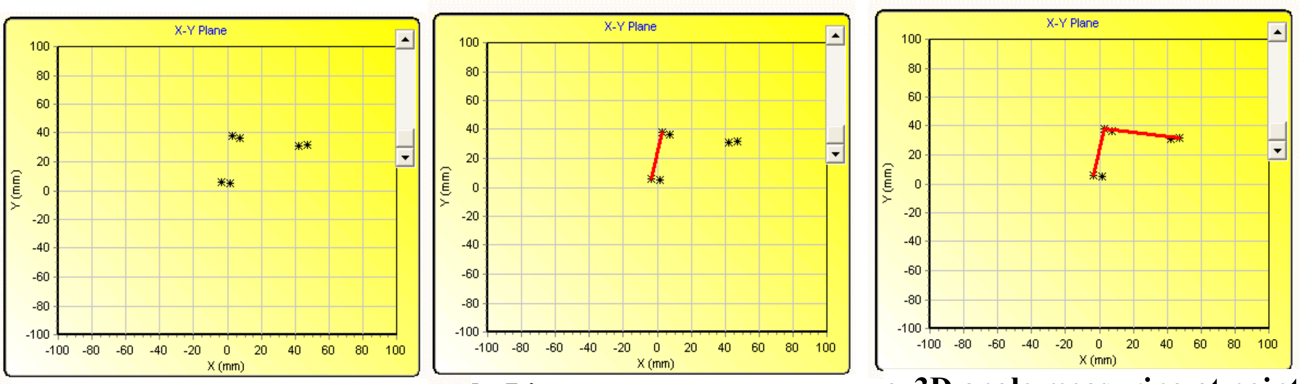
Table 4.2 Descriptive analysis of standard casts

Variable	Workflow	N	Mean	Std Dev	Median	25th Pctl	75th Pctl	Min	Max
Standard Cast Point 1 – 2, from days 1 and 3	Milled Resin	3	-0,234	0,025	-0,233	-0,259	-0,209	-0,259	-0,209
	Printed Resin	3	-0,058	0,167	-0,117	-0,188	0,131	-0,188	0,131
	Wax	3	-0,214	0,016	-0,220	-0,225	-0,196	-0,225	-0,196
Standard Cast Point 2 – 3, from days 3 and 6	Milled Resin	3	0,052	0,038	0,033	0,027	0,096	0,027	0,096
	Printed Resin	3	-0,082	0,197	-0,027	-0,300	0,082	-0,300	0,082
	Wax	3	-0,191	0,074	-0,196	-0,262	-0,115	-0,262	-0,115
Standard Cast Point 1 – 3 from days 3 and 6	Milled Resin	3	0,045	0,129	0,073	-0,096	0,158	-0,096	0,158
	Printed Resin	3	0,067	0,116	0,076	-0,053	0,179	-0,053	0,179
	Wax	3	0,049	0,206	0,013	-0,136	0,271	-0,136	0,271

The one-way ANOVA was insignificant (p=013; p=0.13; p-0.98) for standard cast points 1 – 2, 2 – 3, 1 – 3 respectively.

4.2. Sacrificial patterns and corresponding cast frameworks

Pre-determined points were recorded on the sacrificial patterns (Figure 4.4)



a. Predetermined points

b. Linear measurement between points 1 and 2

c. 3D angle measuring at points 1-2-3

Figure 4.4 Measurements with the reflex microscope on resin framework

Measurements on the sacrificial pattern could only be recorded on the first three days, as the pattern was then cast to a metal framework. The sacrificial patterns were compared to each other. The shaded areas in Table 4.3 represent the excellent correlation for the ICC. These were then used for further analyses, as per Table 4.4.

Table 4.3 Intra- Intraclass Correlation Coefficients for horizontal linear measurements on different days for the sacrificial pattern

	Day 1,2,3	Day 1,2	Day 1,3	Day 2,3
Sacrificial Pattern Point 1 - 2	0,27	0,25	0,02	0,52
Sacrificial Pattern Point 2 - 3	0,95	0,94	0,94	0,96
Sacrificial Pattern Point 1 - 3	0,34	0,88	0,02	-0,03
Sacrificial Pattern Angle 1 – 2 – 3	0,65	0,60	0,66	0,70
Sacrificial Pattern Angle 1 – 3 – 2	0,96	0,96	0,96	0,94
Sacrificial Pattern Angle 2 – 1 – 3	0,71	0,52	0,68	0,85

Table 4.4 Descriptive analysis of milled and printed patterns

	Printed patterns							**Milled patterns**						
Points measured with good/excellent ICC	**Pattern 1**	**Pattern 2**	**Pattern 3**	**Difference Pattern 1-2**	**Difference Pattern 1-3**	**Difference Pattern 2-3**	**Mean difference**	**Pattern 1**	**Pattern 2**	**Pattern 3**	**Difference Pattern 1-2**	**Difference Pattern 1-3**	**Difference Pattern 2-3**	**Mean difference**
Points 1 -2	33,360	33,550	33,378	0,190	0,018	0,172	**0,127**	33,760	34,185	34,623	0,425	0,864	0,439	**0,576**
Points 2 - 3	46,401	46,127	46,418	0,274	0,017	0,292	**0,194**	44,727	45,873	45,572	1,146	0,845	0,301	**0,764**
Points 1 - 3	58,944	58,742	59,522	0,201	0,578	0,780	**0,520**	58,441	58,477	58,461	0,036	0,020	0,016	**0,024**
Angle 1 - 2 - 3	94,940	94,085	94,229	0,856	0,711	0,145	**0,570**	94,089	94,482	93,205	0,393	0,885	1,277	**0,851**
Angle 1 - 3 - 2	33,525	33,525	34,786	0,000	1,260	1,260	**0,840**	36,352	35,882	36,270	0,470	0,082	0,388	**0,313**
Angle 2 - 1 - 3	51,026	51,059	51,451	0,033	0,425	0,392	**0,283**	50,962	49,704	50,580	1,258	0,382	0,876	**0,839**
Overall Mean							**0,423**							**0,561**

The sacrificial patterns (milled and printed) were compared to each other and a Wilcoxon Rank Sum found no significant differences (linear and 3D) with p = 0.14.

The actual differences between the patterns and their models are shown in Table 4.5.

Table 4.5 Actual differences between the resin patterns and their models

	Printed patterns: Differences from model							**Milled patterns: Differences from model**						
Points measured with good/excellent ICC	**Pattern 1**	**Pattern 2**	**Pattern 3**	**Difference Pattern 1-2**	**Difference Pattern 1-3**	**Difference Pattern 2-3**	**Mean difference**	**Pattern 1**	**Pattern 2**	**Pattern 3**	**Difference Pattern 1-2**	**Difference Pattern 1-3**	**Difference Pattern 2-3**	**Mean difference**
Points 1 -2	-0.195	-0.162	-0.232	0.033	0.037	0.070	**0.047**	-0.093	-0.028	0.042	0.066	0.135	0.069	**0.090**
Points 2 - 3	0.413	0.152	-0.157	0.261	0.570	0.309	**0.380**	-0.075	-0.999	-0.250	0.924	0.175	0.750	**0.616**
Points 1 - 3	-0.469	0.130	-0.670	0.598	0.202	0.800	**0.533**	-0.241	0.070	-0.090	0.311	0.151	0.160	**0.207**
Angle 1 - 2 - 3	-0.833	-0.175	-0.210	0.658	0.623	0.035	**0.439**	-0.277	0.598	0.535	0.875	0.812	0.063	**0.583**
Angle 1 - 3 - 2	1.601	1.270	0.273	0.331	1.328	0.997	**0.885**	-0.873	-0.682	-0.540	0.192	0.333	0.142	**0.222**
Angle 2 - 1 - 3	-0.382	-0.710	-0.458	0.328	0.076	0.252	**0.219**	-1.273	-0.018	0.078	1.256	1.351	0.096	**0.901**
Overall Mean							**0.417**							**0.436**

The accuracy of the casting frameworks between the conventional lost wax technique and the burnout of the resins (milled and printed) were recorded. The ICCs comparing sacrificial patterns to cast frameworks (Table 4.6) and between the cast frameworks (Table 4.7) identified the combination of days to be used.

Table 4.6 Intraclass Correlation Coefficients for horizontal linear measurements on different days measuring sacrificial pattern to cast framework

	Day 1,2,3	**Day 1,2**	**Day 1,3**	**Day 2,3**
Sacrificial pattern to framework 1 – 2	0,37	-0,03	-0,06	0,96
Sacrificial pattern to framework 2 – 3	0,90	0,83	0,91	0,95
Sacrificial pattern to framework 1 – 3	0,56	0,82	0,62	0,33
Sacrificial pattern to framework 1 – 2 – 3	-0,26	-0,92	-0,69	0,47
Sacrificial pattern to framework 1 – 3 – 2	-0,03	-0,61	-0,47	0,61
Sacrificial pattern to framework 2 – 1 – 3	0,38	0,77	0,18	0,09

The actual mean difference of cast frameworks from their respective sacrificial patterns (milled, printed, wax) were calculated (table 4.7 and table 4.8). The first casting from one of the milled patters was mis-cast, hence there were only 2 cast frameworks.

Within the sacrificial pattern to cast framework, a one-sample t-test found no statistical difference at any points.

Table 4.7 Intraclass Correlation Coefficients for horizontal linear measurements on different days between the cast framework

	Day 1,2,3	Day 1,2	Day 1,3	Day 2,3	Day 4,5,6	Day 4,5	Day 4,6	Day 5,6	Day 1,4	Day 1,5	Day 1,6	Day 2,4	Day 2,5	Day 2,6	Day 3,4	Day 3,5	Day 3,6
Cast framework 1 – 2	0,98	0,97	0,98	0,97	0,95	0,99	0,99	0,99	0,99	0,99	0,99	0,98	0,98	0,97	0,97	0,96	0,99
Cast framework 2 – 3	0,97	0,96	0,94	0,99	0,99	0,99	0,98	0,99	0,99	0,95	0,94	0,98	0,99	0,99	0,97	0,99	0,99
Cast framework 1 – 3	0,94	0,96	0,94	0,91	0,97	0,99	0,97	0,96	0,94	0,93	0,95	0,96	0,97	0,95	0,90	0,89	0,97
Cast framework 1 – 2 – 3	0,76	0,73	0,65	0,90	0,95	0,95	0,94	0,97	0,90	0,76	0,72	0,93	0,99	0,96	0,89	0,91	0,98
Cast framework 1 – 3 – 2	0,90	0,91	0,86	0,88	0,98	0,98	0,98	0,98	0,98	0,96	0,95	0,96	0,99	0,96	0,90	0,90	0,95
Cast framework 2 – 1 – 3	0,60	0,40	0,33	0,87	0,80	0,67	0,67	0,99	0,85	0,34	0,30	0,59	0,84	0,85	0,65	0,98	0,98

Table 4.8 Actual mean difference of cast framework from printed and milled sacrificial patterns.

	Cast framework from Printed patterns							**Cast framework from Milled patterns**					
Points measured with good/excellent ICC	**Framework 1**	**Framework 2**	**Framework 3**	**Difference Framework 1-2**	**Difference Framework 1-3**	**Difference Framework 2-3**	**Mean difference**	**Framework 2**	**Framework 3**	**Difference Framework 1-2**	**Difference Framework 1-3**	**Difference Framework 2-3**	**Mean difference**
Points 1 -2	33,533	32,842	33,466	0,691	0,066	0,625	**0,461**	34,659	33,776	34,659	33,776	0,883	**0,883**
Points 2 - 3	46,853	46,547	46,434	0,306	0,418	0,113	**0,279**	45,209	45,215	45,209	45,215	0,005	**0,005**
Points 1 - 3	58,881	59,113	59,367	0,232	0,485	0,254	**0,324**	57,584	58,421	57,584	58,421	0,838	**0,838**
Angle 1 - 2 - 3	94,618	94,655	94,561	0,037	0,056	0,093	**0,062**	94,864	93,416	94,864	93,416	1,448	**1,448**
Angle 1 - 3 - 2	33,215	33,944	34,363	0,729	1,148	0,419	**0,765**	35,230	36,296	35,230	36,296	1,066	**1,066**
Angle 2 - 1 - 3	51,466	51,822	51,257	0,356	0,209	0,565	**0,377**	50,196	50,823	50,196	50,823	0,627	**0,627**
Overall Mean							**0,378**						**0,811**

Table 4.9 Actual mean difference of cast framework from wax patterns

	Conventional Cast framework from Wax patterns						
Points measured with good/excellent ICC	**Framework 1**	**Framework 2**	**Framework 3**	**Difference Framework 1-2**	**Difference Framework 1-3**	**Difference Framework 2-3**	**Mean difference**
Points 1 -2	34,360	34,514	33,179	0,154	1,181	1,335	**0,890**
Points 2 - 3	45,969	45,103	45,466	0,865	0,503	0,362	**0,577**
Points 1 - 3	58,712	58,301	58,291	0,411	0,421	0,011	**0,281**
Angle 1 - 2 - 3	92,599	93,484	93,485	0,886	0,886	0,001	**0,591**
Angle 1 - 3 - 2	36,147	36,222	35,632	0,075	0,515	0,590	**0,394**
Angle 2 - 1 - 3	52,257	50,311	51,158	1,946	1,099	0,847	**1,297**
Overall Mean							**0,672**

A t-test and Wilcoxon Rank Sum found no significant differences in the pattern to framework group between the different points and angles respectively. Within the cast framework group, there was no statistical difference using the Kruskal-Wallis test.

4.3. Accuracy of sacrificial pattern and cast framework to standard model

A mixed combination of days was used for the ICC for the sacrificial pattern to its model (Table 4.10).

Table 4.10 Intraclass Correlation Coefficients for horizontal linear measurements on different days measuring sacrificial pattern to standard model

	Day 1,2,3	**Day 1,2**	**Day 1,3**	**Day 2,3**
Sacrificial Pattern to model Point 1 - 2	-0,29	0,28	-0,36	-0,46
Sacrificial Pattern to model Point 2 - 3	0,55	0,29	0,36	0,84
Sacrificial Pattern to model Point 1 - 3	0,00	0,66	-0,41	-0,17
Sacrificial Pattern to model Angle 1 - 2 - 3	0,56	0,54	0,67	0,41
Sacrificial Pattern to model Angle 1 - 3 - 2	0,87	0,87	0,85	0,87
Sacrificial Pattern to model Angle 2 - 1 - 3	0,32	-0,24	0,76	0,28

The accuracy of the sacrificial pattern (milled, printed and wax) were recorded to its corresponding standard model (Table 4.11). The accuracy of the cast frameworks from their respective patterns is shown in Table 4.12. There were only 2 castings from the milled patterns as the first attempt was a mis-cast.

Table 4.11 Accuracy of sacrificial pattern to its corresponding model

	Printed patterns: Differences from model							Milled patterns: Differences from model						
Points measured with good/excellent ICC	**Pattern 1**	**Pattern 2**	**Pattern 3**	**Difference Pattern 1-2**	**Difference Pattern 1-3**	**Difference Pattern 2-3**	**Mean difference**	**Pattern 1**	**Pattern 2**	**Pattern 3**	**Difference Pattern 1-2**	**Difference Pattern 1-3**	**Difference Pattern 2-3**	**Mean difference**
Points 1 -2	-0,195	-0,162	-0,232	0,033	0,037	0,070	**0,047**	-0,093	-0,028	0,042	0,066	0,135	0,069	**0,090**
Points 2 - 3	0,413	0,152	-0,157	0,261	0,570	0,309	**0,380**	-0,075	-0,999	-0,250	0,924	0,175	0,750	**0,616**
Points 1 - 3	-0,469	0,130	-0,670	0,598	0,202	0,800	**0,533**	-0,241	0,070	-0,090	0,311	0,151	0,160	**0,207**
Angle 1 - 2 - 3	-0,833	-0,175	-0,210	0,658	0,623	0,035	**0,439**	-0,277	0,598	0,535	0,875	0,812	0,063	**0,583**
Angle 1 - 3 - 2	1,601	1,270	0,273	0,331	1,328	0,997	**0,885**	-0,873	-0,682	-0,540	0,192	0,333	0,142	**0,222**
Angle 2 - 1 - 3	-0,382	-0,710	-0,458	0,328	0,076	0,252	**0,219**	-1,273	-0,018	0,078	1,256	1,351	0,096	**0,901**
Overall Mean							**0,417**							**0,436**

Table 4.12 Accuracy of the cast frameworks to their respective patterns.

	Cast framework from Printed patterns							Cast framework from Milled patterns			
Points measured with good/excellent ICC	**Framework 1**	**Framework 2**	**Framework 3**	**Difference Framework 1-2**	**Difference Framework 1-3**	**Difference Framework 2-3**	**Mean difference**	**Framework 2**	**Framework 3**	**Difference Framework 2-3**	**Mean difference**
Points 1 -2	33.533	32.842	33.466	0.691	0.066	0.625	**0.461**	34.659	33.776	0.883	**0.883**
Points 2 - 3	46.853	46.547	46.434	0.306	0.418	0.113	**0.279**	45.209	45.215	0.005	**0.005**
Points 1 - 3	58.881	59.113	59.367	0.232	0.485	0.254	**0.324**	57.584	58.421	0.838	**0.838**
Angle 1 - 2 - 3	94.618	94.655	94.561	0.037	0.056	0.093	**0.062**	94.864	93.416	1.448	**1.448**
Angle 1 - 3 - 2	33.215	33.944	34.363	0.729	1.148	0.419	**0.765**	35.230	36.296	1.066	**1.066**
Angle 2 - 1 - 3	51.466	51.822	51.257	0.356	0.209	0.565	**0.377**	50.196	50.823	0.627	**0.627**
Overall Mean							**0.378**				**0.811**

Table 4.13 Accuracy of cast frameworks from resin patterns to their corresponding models

	Cast framework from Printed patterns: Differences from model							Cast framework from Milled patterns: Differences from model			
Points measured with good/excellent ICC	**Framework 1**	**Framework 2**	**Framework 3**	**Difference Framework 1-2**	**Difference Framework 1-3**	**Difference Framework 2-3**	**Mean difference**	**Framework 2**	**Framework 3**	**Difference Framework 2-3**	**Mean difference**
Points 1 -2	-0.291	0.142	-0.256	0.433	0.035	0.398	**0.288**	-0.271	0.401	0.672	**0.672**
Points 2 - 3	-0.062	-0.388	-0.324	0.326	0.262	0.064	**0.217**	-0.258	-0.014	0.244	**0.244**
Points 1 - 3	-0.083	-0.050	-0.068	0.033	0.015	0.018	**0.022**	0.991	0.046	0.944	**0.944**
Angle 1 - 2 - 3	-0.569	-0.564	-0.577	0.005	0.008	0.013	**0.008**	-0.013	0.534	0.547	**0.547**
Angle 1 - 3 - 2	1.730	1.440	0.641	0.290	1.089	0.799	**0.726**	0.420	-0.489	0.909	**0.909**
Angle 2 - 1 - 3	-1.589	-0.730	-0.406	0.859	1.183	0.324	**0.789**	-0.304	-0.133	0.171	**0.171**
Overall Mean							**0.342**				**0.581**

Table 4.14 Accuracy of conventionally cast framework to its corresponding model

	Conventional Cast framework from Wax patterns: Differences from model						
Points measured with good/excellent ICC	**Framework 1**	**Framework 2**	**Framework 3**	**Difference Framework 1-2**	**Difference Framework 1-3**	**Difference Framework 2-3**	**Mean difference**
Points 1 -2	-0,204	0,235	0,279	0,440	0,483	0,044	**0,322**
Points 2 - 3	-0,818	-0,025	0,131	0,793	0,950	0,157	**0,633**
Points 1 - 3	-0,378	-0,055	0,175	0,323	0,552	0,229	**0,368**
Angle 1 - 2 - 3	0,734	-0,302	-0,486	1,036	1,220	0,184	**0,813**
Angle 1 - 3 - 2	-0,249	-0,264	0,259	0,015	0,508	0,522	**0,348**
Angle 2 - 1 - 3	-1,532	0,499	-0,814	2,031	0,718	1,313	**1,354**
Overall Mean							**0,640**

A t-test was used for measuring points between the sacrificial patterns (combined data) and the standard model revealed a significant difference for points 1 – 2 (p = 0.14), whereas the Wilcoxon Rank Sum found no significant differences between the angles.

When comparing the milled pattern to its corresponding model, a one-sample t-test found no significant difference between all the points. A significant difference (p = 0.010) was found within the printed group at the point 1 – 2. The other points were insignificant.

The cast framework to standard model groups found no statistical difference using the Kruskal-Wallis test.

4.4. Accuracy of rest seats to standard model

The accuracy of the rest seat on the framework to its corresponding rest preparation on the model were recorded. The ICCs for different day combinations are shown in Table 4.15. Excellent correlation is indicated by the shaded areas

Table 4.15 Intraclass Correlation Coefficients for horizontal linear measurements on different days for the rest seat to corresponding rest preparation

	Day 1,2,3	Day 1,2	Day 1,3	Day 2,3	Day 4,5,6	Day 4,5	Day 4,6	Day 5,6	Day 1,4	Day 1,5	Day 1,6	Day 2,4	Day 2,5	Day 2,6	Day 3,4	Day 3,5	Day 3,6
Rest seat to model 1 - 2	0,72	0,60	0,67	0,87	0,97	0,98	0,96	0,96	0,83	0,77	0,80	0,46	0,46	0,49	0,40	0,37	0,46
Rest seat to model 1 - 3	0,55	0,58	0,58	0,39	0,95	0,95	0,93	0,98	-0,21	-0,06	-0,01	0,17	0,37	0,24	-0,20	0,07	0,09
Rest seat to model 1 - 4	0,64	0,69	0,79	0,45	0,86	0,92	0,88	0,76	0,04	-0,12	0,31	0,13	0,12	0,28	0,18	0,03	0,49
Rest seat to model 1 - 5	0,47	0,75	0,18	0,72	0,87	0,84	0,86	0,86	0,60	0,71	0,83	0,78	0,90	0,88	0,56	0,68	0,37
Rest seat to model 2 - 5	0,18	0,19	0,19	0,16	0,75	0,68	0,81	0,77	0,49	0,24	0,37	0,54	0,15	0,21	0,62	0,82	0,79
Rest seat to model 2 - 3	0,09	-0,36	-0,32	0,61	0,39	0,31	0,69	0,14	-0,16	0,18	0,21	0,40	0,51	0,03	0,39	0,48	0,33
Rest seat to model 2 - 4	-0,44	-0,16	-0,25	-0,71	0,51	0,40	0,51	0,57	0,18	0,16	0,31	0,03	-0,31	-0,23	-0,17	-0,02	-0,21
Rest seat to model 3 - 5	0,30	0,29	0,73	-0,06	0,82	0,87	0,79	0,81	0,82	0,82	0,56	0,10	0,24	0,15	0,61	0,78	0,42
Rest seat to model 4 - 5	0,62	0,88	0,34	0,43	0,94	0,91	0,97	0,92	0,82	0,79	0,75	0,87	0,78	0,76	0,50	0,64	0,53
Rest seat to model 3 - 4	0,25	0,02	0,50	0,06	0,40	0,75	0,24	0,39	0,77	0,74	-0,02	-0,07	0,18	0,09	0,63	0,87	0,51

Table 4.16 Actual rest seat differences between framework and model

Points measured with good/excellent ICC	Rest seats: Differences from model			
	Cast framework from Printed patterns	Cast framework from Milled patterns	Conventional Cast framework from Wax patterns	Mean over all frameworks
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
Mean	0,262	0,179	0,195	0,212

The analysis of the differences between the rest seats of the frameworks to their corresponding model was carried out by a Kruskal-Wallis test and no significant differences were found.

4.5. Mean differences comparing the patterns, their cast frameworks and their models

An overall comparison analysis between the pattern groups and their cast frameworks and between these and their models is shown in Table 4.17

Table 4.17 Comparison analysis between all the groups and its respective framework and model

Points measured with good/excellent ICC	Mean differences of Patterns and Frameworks					Mean differences of Patterns and Frameworks to their models				
	Printed patterns	Milled patterns	Cast framework from Printed patterns	Cast framework from Milled patterns	Conventional Cast framework from Wax patterns	Printed patterns to model	Milled patterns to model	Cast framework from Printed patterns to model	Cast framework from Milled patterns to model	Conventional Cast framework from Wax patterns to model
Points 1 -2	0,127	0,576	0,461	0,883	0,890	0,047	0,090	0,288	0,448	0,322
Points 2 - 3	0,194	0,764	0,279	0,005	0,577	0,380	0,616	0,217	0,172	0,633
Points 1 - 3	0,520	0,024	0,324	0,838	0,281	0,533	0,207	0,022	0,660	0,368
Angle 1 - 2 - 3	0,570	0,851	0,062	1,448	0,591	0,439	0,583	0,008	0,364	0,813
Angle 1 - 3 - 2	0,840	0,313	0,765	1,066	0,394	0,885	0,222	0,726	0,606	0,348
Angle 2 - 1 - 3	0,283	0,839	0,377	0,627	1,297	0,219	0,901	0,789	0,202	1,354
Overall Mean	0,423	0,561	0,378	0,811	0,672	0,417	0,436	0,342	0,409	0,640

4.6. Cost analysis

A cost analysis was performed to compare the labour, cost and time associated with the construction of each framework (Table 4.18).

Table 4.18 Cost analysis per framework

		Milling	**3D Printing**	**Wax + Cast**
Time	Design	15 min	15 min	45 min
	Manufacturing	4 hours	4 hours	
Cost	Design	R445,00	R445,00	-
	Resin	R517,50	R103,50	-
Labour	Cast	4 hours	3.5 hours	9 hours
	Cost	R2 875,00	R2 875,00	R2 875,00

5. DISCUSSION

Changes in dental technology have included the introduction of CAD/CAM systems. Present-day technological advancements have allowed for the fabrication of removable dentures.

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 CAD/CAM RPD frameworks (Arnold *et al*., 2018; Bibb *et al*., 2006b). However, these studies have subjectively described the clinical outcome, with insufficient information regarding the acceptable clinical measurement.

Eggbeer and colleagues (2005) are documented as the first to build a resin RPD framework using stereolithography. These frameworks were then cast in a Co-Cr alloy using conventional methods. Further reports (Williams *et al*. 2006; Bibb *et al.* 2006b) have shown that the theoretical possibility of applying digital technologies to denture framework production had become a functional reality, but once again the clinical acceptability was determined subjectively.

This study attempted to first establish the accuracy of duplicated standard casts to a master cast, and then to determine the accuracy of digitally designed resin frameworks produced by two different methods, and the accuracy of their cast equivalents to frameworks produced by the conventional method. In addition the time and costs between the workflows was determined.

5.1. Intra-rater reliability

Measurements were made using the reflex microscope which is able to measure in three dimensions, by placing a point of light. This requires manipulation of the light point in three dimensions, and can therefore be subject to operator error. Speculand *et al.* (1988) showed that it was possible to generate reproducible results with an operator measurement error of less than 0.15 mm for linear distances as well as the microscope under measuring by 0.28% or by up to 0.14 mm per 50 mm. Therefore in this study, all measurements were made on at least three different occasions, and an Intraclass Correlation Coefficient calculated to determine the correlation between the different days' measurements. It was found that only certain pairs of measurements correlated for some measurements and in others, there was correlation over more than two days. Therefore only those multiple measurements that showed good or excellent correlation were used for analysis.

5.2. Accuracy of models

An accurate and dimensionally stable impression is an essential step for manufacturing well-fitting indirect restorations and RPDs. The first part of the study evaluated the accuracy of standard models to a master model. Results in this study showed a difference between the standard models and master cast ranging from -0.33 to 0.271 mm. Negative values may be associated with gypsum expansion, which is similar to findings from Michalakis *et al*. (2012) who reported on expansion that may reach approximately 0.2%. In this study, there were no statistically significant differences between the duplicated models. Although Cho *et al*. (2015) found improved accuracy of a digital impression compared with a conventional impression, this was for a single crown. Using the digital workflow as in the present study still reuires a duplicate model, and the accuracy and consistency of duplication used here was shown to be acceptable.

5.3. Digitally manufactured resin frameworks

Different methods have been described in generating a digital RPD (Williams *et al*., 2006; Eggbeer *et al*., 2005; Williams *et al*., 2004). The early work by Williams and colleagues (2004) and Eggbeer and colleagues (2005) defined the techniques and concept development for digital RPDS. Even though Eggbeer et al. (2005) compared only 1 specimen for each type of production method and the evaluation of the framework fit was subjective, this low level of evidence was the only published research at the time.

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 the 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.

5.4. Cast frameworks

The mean of the differences of all measurement points between the cast frameworks from their printed patterns was 0.377 mm and between the cast frameworks from their milled patterns, was 0.627 mm.

The mean of the differences 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. Clearly wax will burn out more readily, but there may be differences in the burnout between the printed and milled materials. Second, the investment procedures will 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 this is more accurate.

Discrepancies of fit have been reported in the literature, with no consensus other than the fact that it accepted that there will be degree of misfit which is clinically acceptable. Some studies have attempted to quantify this, and Dunham et al (2006) summarised 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. The results from this present study, are therefore all within this range, with the discrepancy of 0.342 mm for the frameworks cast from the printed pattern providing the best result.

5.5. Rest seat adaptation/accuracy

This study attempted to quantitatively highlight the horizontal discrepancy between rests and rest seats. Most of the occlusal rests (76%) by Dunham *et al*., (2006) did not contact the intended surface and Eggbeer *et al*. (2005) referred to a clinically acceptable gap as being 0.311 mm. The results in this study revealed that the mean of the differences between the frameworks from the printed patterns and the models for the rest seats was 0.262 mm; from the frameworks from the milled patterns and the models for the rest seats was 0.179 mm; and frameworks from the wax patterns and the models for the rest seats was 0.195 mm. The overall mean for all frameworks was 0.212 mm. All of these are well within the clinically accepted differences.

5.6. Cost analysis

The preliminary cost 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, 7 hours and 45 minutes.
A detailed cost analysis was not carried out, but this would need to take into account not only the time but the cost of materials as well.

Apart from the time factor, it has been pointed out that the advantages offered with digitally constructed frameworks include the ability to clinically try and modify a framework prior to casting (Soltanzadeh *et al*., 2019).

5.7. Limitations

Whilst this study has attempted to quantify and compare the accuracies of three different workflows to produce a metal framework for an RPD, 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.

6. CONCLUSIONS

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

It is recommended that further economic analyses be carried out, as well as further studies using these digital workflows, to determine the clinical acceptability of the methods.

7. REFERENCES

Ali Z, Baker SR, Shahrbaf S, Martin N, N, Vettore MV. Oral health-related quality of life after prosthodontic treatment for patients with partial edentulism: a systematic review and meta-analysis. J Prosthet Dent. 2019; 121: 59 – 68.

Ali M, Nairn RI, Sherriff M, Waters NE. The distortion of cast cobalt chromium alloy partial denture frameworks fitted to a working cast. J Prosthet Dent. 1997; 78: 419 – 424.

Al Jabbari YS. Physico-mechanical properties and prosthodontic applications of Co-Cr dental alloys: a review of the literature. J Adv Prosthodont. 2014; 6:138 – 145.

Almufleh B, Emami E, Alageel O, de Melo F, Seng F, Caron E, Abi Nader S. et al. Patient sastisfaction with laser-sintered removable partial dentures: A crossover pilot clinical trial. J Prosthet Dent. 2018; 119: 560 – 567.

Anusavice K, Shen C, Rawls H. Eds. Phillips' Science of Dental Materials. 12th Ed. St. Louis, Mo. USA. Elsevier/Saunders 2013.

Aquilino SA, Shugars DA, Bader JD, White BA. Ten-year survival rates of teeth adjacent to treated and untreated posterior bounded edentulous spaces. J Prosthet Dent. 2001; 85: 455 – 460.

Arnold C, Hey J, Schweyen R, Setz JM. Accuracy of CAD-CAM-fabricated removable partial dentures. J Prosthet Dent. 2018; 119(4):586 – 592.

Bergman B, Hugoson A, Olsson C-O. Caries, periodontal and prosthetic findings in patients with removable partial dentures: a ten-year longitudinal study. J Prosthet Dent. 1982; 48: 506 – 514.

Bibb R, Eggbeer D, Williams R. Rapid manufacture of removable partial denture frameworks. Rapid Protot J. 2006a; 12(2):95 – 99.

Bibb RJ, Eggbeer D, Williams RJ, Woodward A. Trial fitting of a removable partial denture framework made using computer-aided design and rapid prototyping techniques. Proc Inst Mech End H. 2006b; 62:793 – 797.

Campbell SD, Cooper L, Craddock H, Hyde TP, Nattress B, Pavitt SH, Seymour DW. Removable partial dentures: The clinical need for innovation. J Prosthet Dent. 2017; 118(3):273 – 280.

Carr AB, Brown DT. McCracken's removable partial prosthodontics. 12th Ed. Singapore, Elsevier Mosby. 2011.

Chandler JA, Brudvik JS. Clinical evaluation of patients eight to nine years after placement of removable partial dentures. J Prosthet Dent. 1984; 51: 736 – 737.

Cho SH, Schaefer O, Thompson GA, Guentsch A. Comparison of accuracy and reproducibility of casts made by digital and conventional methods. J Prosthet Dent. 2015; 113: 310 – 315.

Craig RG, Hanks CT. Reaction of fibroblasts to various dental casting alloys. J Oral Pathol. 1988; 17: 341 – 347.

Dunham D, Brudvik JS, Morris WJ, Plummer KD, Cameron SM. A clinical investigation of the fit of removable partial denture clasp assemblies. J Prosthet Dent. 2006; 95(4):323 – 326.

Eggbeer D, Bibb R, Williams R. The computer-aided design and rapid prototyping fabrication of removable partial denture frameworks. J Engineering in Medicine. 2005; 219:195 – 202.

Ender A, Attin T, Mehl A. *In vivo* precision of conventional and digital methods of obtaining complete-arch dental impressions. J Prosthet Dent. 2016; 115: 313 – 320.

Frank RP, Brudvik JS, Leroux B. Relationship between the standards of removable partial denture construction, clinical acceptability and patient satisfaction. J Prosthet Dent. 2000; 83:521 – 527.

Fenlon MR, Juszczyk AS, Hughes RJ, Walter JD, Sherriff M. Accuracy of fit of cobalt-chromium removable partial denture frameworks on master casts. Eur J Prosthodont Restor Dent. 1993; 1(3): 127 – 130.

Hoods-Moonsammy VJ, Owen CP, Howes D. A comparison of the accuracy of polyether, polyvinyl siloxane and plaster impressions for long-span implant-supported prostheses. Int J Prosthet. 2014; 27(5): 433 – 438.

Kim DY, Kim CM, Kim JH, Kim HY, Kim WC. Evaluation of marginal and internal gaps of Ni-Cr and Co-Cr alloy copings manufactured by microstereolithography. J Adv Prosthodont. 2017: 9: 176 – 181.

Kim HR, Jang SH, Kim YK, Son JS, Min BK, Kim KH, Kwon TY. Microstuctures and mechanical properties of Co-Cr dental alloys fabricated by three CAD/CAM-based processing techniques. Materials. 2016; 9: 1 -14.

Kim SY, Kim MJ, Kwon HB. Accuracy of dies captured by an intraoral digital impression system using parallel confocal imaging. Int J Prosthod. 2013; 26(2): 161 – 163.

Klineberg I, Palla S, Trulsson M. Contemporary relevance of occlusion and mastication. Int J Prosthodont. 2014;27(5):411 – 412.

Koyama S, Sasaki K, Yokoyama M, Sasaki T, Hanawa S. Evaluation of factors affecting the continuing use and patient satisfaction with removable partial dentures over 5 years. J Prosthodont Res. 2010; 54: 97 – 101.

Kruth JP, Vandenbrouche B, Van Vaerenbergh J, Naert I. Digital manufacturing of biocompatible metal frameworks for complex dental prostheses by means of SLS/SLM. In: P.J. Da Silva Bartolo (Ed.), Proceedings of the 2nd International Conference on Advanced Research in Virtual and Rapid Prototyping (VRAP) 2005, 28 September – 1 October 2005, Leiria, Portugal. Leiden, the Netherlands: Taylor and Francis/Balkema publishers. 2005. P. 139 – 145.

Lang LA, Tulunoglu I. A critically appraised topic review of computer-aided design/computer-aided machining of removable partial denture frameworks. Dent Clin N Am. 2014; 58:247 – 255.

Lee JW, Park JM, Park EJ, Heo SJ, Koak JY, Kim SK. Accuracy of a digital removable partial denture fabricated by casting a rapid prototyped pattern: A clinical study. J Prosthet Dent. 2017; 118: 468 – 474.

Lima JMC, Anami LC, Araujo RM, Pavanelli CA. Removable partial dentures: Use of rapid prototyping. J Prosthodont. 2014; 23:588 – 591.

Mangano F, Gandolfi A, Luongo G, Logozzo S. Intraoral scanners in dentistry: a review of the current literature. BMS Oral Health. 2017; 17 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5727697/ - accessed 20 February 2020

McCabe JF, Walls AWG. Applied Dental Materials; Ninth Edition. Blackwell, Munksgaard. 2013

Michalakis KX, Asar V. Delayed linear dimensional changes of five high strength gypsum products used for the fabrication of definitive casts. J Prosthet Dent. 2012; 108(3): 189 – 195.

Papaspyridakos P, Chen CJ, Gallucci GO, Doukoudakis A, Weber HP, Chronopoulos V. Accuracy of implant impressions for partially and completely edentulous patients: a systematic review. Int J Oral Maxillofac Implants. 2014; 29(4): 836 – 845.

Phillips RW. Skinner’s Science of dental materials.. 8th Edition. Philadelphia, USA, WB Saunders Company. 1982.

Powers JM, Wataha JC. Dental Materials: Properties and manipulation, 10th Ed. Singapore, Elsevier Mosby, 2012.

Rehmann P, Orbach K, Ferger P, Wöstmann B. Treatment outcomes with removable partial dentures: a retrospective analysis. Int J Prosthodont. 2013; 26: 147 – 150.

Saad AS, Abbas FS, Elgharabawy SH. Clinical evaluation of removable partial denture constructed from 3D printed resin pattern designed using CAD CAM technology. Alexandria Dent J. 2019; 44: 1 – 7.

Santos EC, Shiomi M, Osakada K, Laoui T. Rapid manufacturing of metal components by laser forming. Int J Mach Tools and Manuf. 2006; 46:1459 – 1468.

Sheiham A, Steele JG, Marcenes W, Finch S, Walls AW. The impact of oral health on stated ability to eat certain foods; findings from the National Diet and Nutrition Survey of Older People in Great Britain. Gerodontol. 1999; 16(1): 11 – 20.

Soltanzadeh P, Suprono MS, Kattadiyil M, Goodacre C, Gregorius W. An in vitro investigation of accuracy and fit of conventional and CAD/CAM removable partial denture frameworks. J Prosthodont. 2019; 28: 547 – 555.

Speculand B, Butcher GW, Stephens CD. Three-dimensional measurement: The accuracy and precision of the reflex microscope. 1988; 26(4): Abstract only.

Stern MA, Brudvik JS, Frank RP. Clinical evaluation of removable partial denture rest seat adaptation. J Prosthet Dent. 1985: 53:658 – 662.

Vanzeveren C, D’Hoore, Bercy P, Leloup G. Treatment with removable partial dentures: a longitudinal study. Part I. J Oral Rehab. 2003a; 30: 447 – 458.

Vanzeveren C, D’Hoore, Bercy P, Leloup G. Treatment with removable partial dentures: a longitudinal study. Part II. J Oral Rehab. 2003b; 30: 459 – 469.

Vermeulen AHBM, Keltjens HMAM, van’t Hof MA, Kayser AF. Ten-year evaluation of removable partial dentures: Survival rates based on retreatment, not wearing and replacement. J Prosthet Dent. 1996; 76: 267 – 272.

Wataha JC, Messer RL. Casting alloys. Dent Clin N Am. 2004; 48:499 – 512.

Williams RJ, Bibb R, Eggbeer D, Collis J. Use of CAD/CAM technology to fabricate a removable partial denture framework. J Prosthet Dent. 2006; 96:96 – 99.

Williams RJ, Bibb R, Rafik T. A technique for fabricating patterns for removable partial denture frameworks using digitized casts and electronic surveying. J Prosthet Dent. 2004; 91:85 – 88.

Wöstmann B, Budtz-Jørgensen E, Jepson N, Mushimoto E, Palmqvist S, Sofou A, Öwall B. Indications for removable partial dentures: a literature review. Int J Prosthodont. 2005; 18: 139 – 145.

Wu J, Wang X, Zhao X, Zhang C, Gao B. A study on the fabrication method of removable partial denture framework by computer-aided design and rapid prototyping. Rapid Protot J. 2012; 18(4):318 – 323.

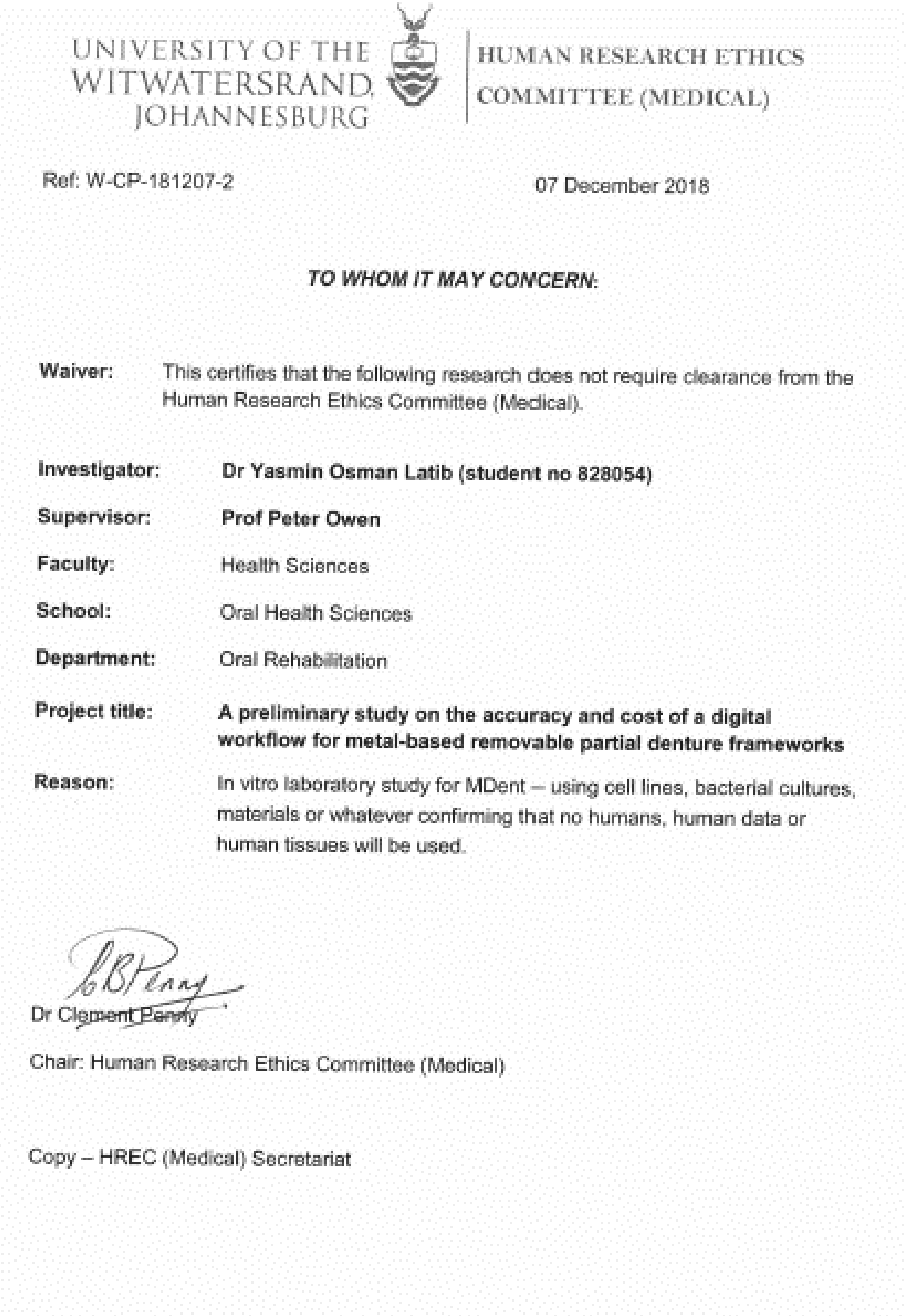
Ye H, Ning J, Li M, Niu L, Yang J, Sun Y, Zhou Y. Preliminary clinical application of removable partial denture frameworks fabricated using computer-aided design and rapid prototyping techniques. Int J Prosthodont. 2017; 30:348 – 353.

Zlatarić DK, Čelebić A, Valentić-Peruzović M. The effect of removable partial dentures on periodontal health of abutment and non-abutment teeth. J Periodontol. 2002; 73: 137 – 144.

Zlatarić DK, Čelebić A, Valentić-Peruzović M. Jerolimov V, Pandurić J. A survey of treatment outcomes with removable partial dentures. J Oral Rehabil. 2003; 30: 847 – 854.

8. APPENDICES

8.1. APPENDIX 1. ETHICS WAIVER CERTIFICATE



UNIVERSITY OF THE
WITWATERSRAND,
JOHANNESBURG

HUMAN RESEARCH ETHICS
COMMITTEE (MEDICAL)

Ref: W-CP-181207-2

07 December 2018

TO WHOM IT MAY CONCERN:

Waiver:	This certifies that the following research does not require clearance from the Human Research Ethics Committee (Medical).
Investigator:	**Dr Yasmin Osman Latib (student no 828054)**
Supervisor:	**Prof Peter Owen**
Faculty:	Health Sciences
School:	Oral Health Sciences
Department:	Oral Rehabilitation
Project title:	**A preliminary study on the accuracy and cost of a digital workflow for metal-based removable partial denture frameworks**
Reason:	In vitro laboratory study for MDent – using cell lines, bacterial cultures, materials or whatever confirming that no humans, human data or human tissues will be used.

Dr Clement Penny

Chair: Human Research Ethics Committee (Medical)

Copy – HREC (Medical) Secretariat

8.2. APPENDIX 2. FACULTY PROTOCOL APPROVAL

UNIVERSITY OF THE
WITWATERSRAND,
JOHANNESBURG

Private Bag 3 Wits, 2050
Fax: 027117172119
Tel: 02711 7172076

Reference: Mrs Sandra Benn
E-mail: sandra.benn@wits.ac.za

14 December 2018
Person No: 828054
PAG

Dr Y Osman Latib
Postnet Suite 69
Private Bag X 9951
Sandton
2196
South Africa

Dear Dr Yasmin Osman Latib

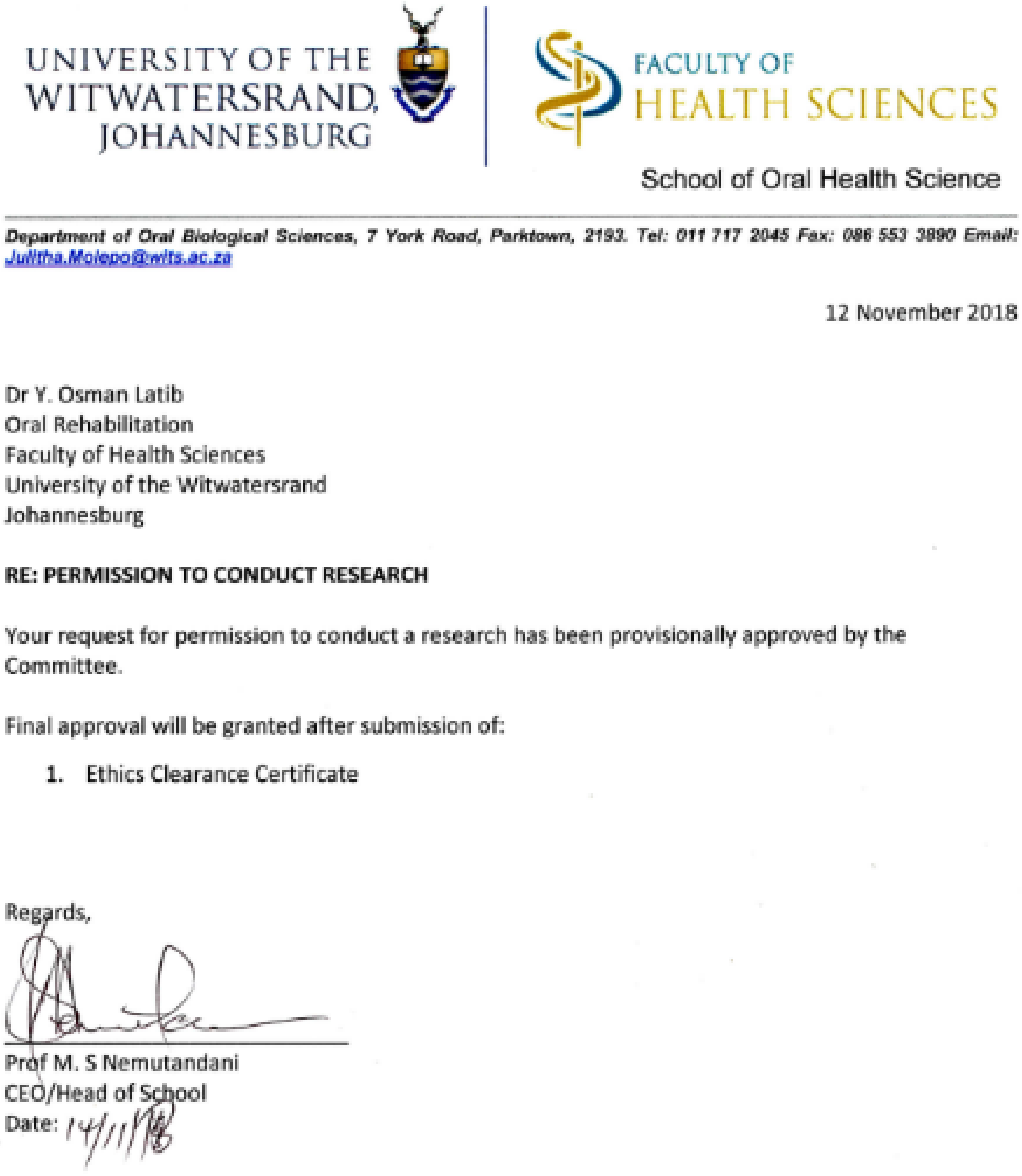
Master of Dentistry: Approval of Title

We have pleasure in advising that your proposal entitled *A preliminary study on the accuracy and cost of a digital workflow for metal-based removable partial denture frameworks.* has been approved. Please note that any amendments to this title have to be endorsed by the Faculty's higher degrees committee and formally approved.

Yours sincerely

Mrs Sandra Benn
Faculty Registrar
Faculty of Health Sciences

8.3. APPENDIX 3. RESEARCH PERMISSION LETTER



UNIVERSITY OF THE
WITWATERSRAND,
JOHANNESBURG

FACULTY OF
HEALTH SCIENCES

School of Oral Health Science

Department of Oral Biological Sciences, 7 York Road, Parktown, 2193. Tel: 011 717 2045 Fax: 086 553 3890 Email: Julitha.Molepo@wits.ac.za

12 November 2018

Dr Y. Osman Latib
Oral Rehabilitation
Faculty of Health Sciences
University of the Witwatersrand
Johannesburg

RE: PERMISSION TO CONDUCT RESEARCH

Your request for permission to conduct a research has been provisionally approved by the Committee.

Final approval will be granted after submission of:

1. Ethics Clearance Certificate

Regards,

Prof M. S Nemutandani
CEO/Head of School
Date: 14/11/18

8.4. APPENDIX 4. TURNITIN REPORT

Filters used:

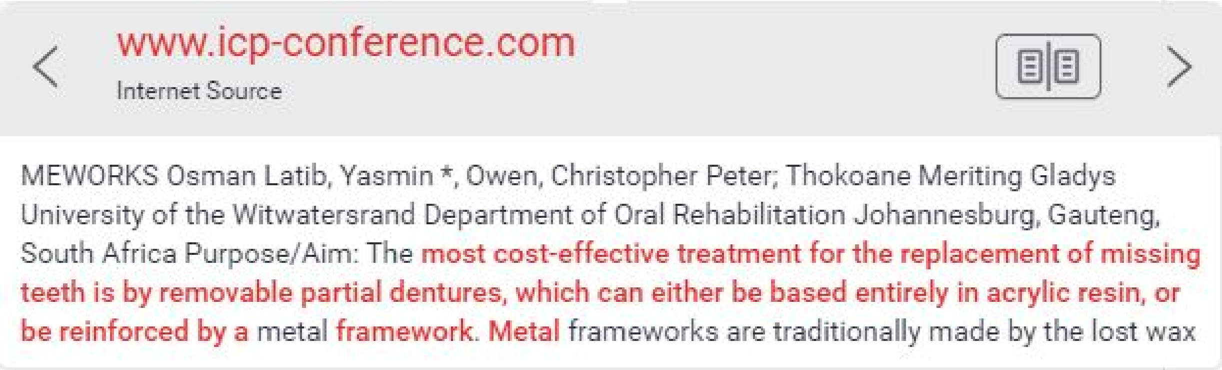
Exclude Quotes

Exclude Bibliography

Exclude sources of less than 2%.

Report summary:

Similarities:



MEWORKS Osman Latib, Yasmin *, Owen, Christopher Peter; Thokoane Meriting Gladys University of the Witwatersrand Department of Oral Rehabilitation Johannesburg, Gauteng, South Africa Purpose/Aim: The most cost-effective treatment for the replacement of missing teeth is by removable partial dentures, which can either be based entirely in acrylic resin, or be reinforced by a metal framework. Metal frameworks are traditionally made by the lost wax

www.icp-conference.com

Internet Source

acrylic resin, or be reinforced by a metal framework. Metal frameworks are traditionally made by the lost wax casting method. This is a lengthy and labour-intensive process that comprises many steps. A digitally constructed prosthesis can allow for the elimination of waxing on a comparatively rough refractory cast, which may reduce the potential for errors and result in better quality control in the dental laboratory and lead to improved framework fit. The

Hongqiang Ye, Jing Ning, Man Li, Li Niu, Jian ...

Publication

MAY BE REPRODUCED OR TRANSMITTED IN ANY FORM WITHOUT WRITTEN PERMISSION FROM THE PUBLISHER. Ye et al There is no standard method for quantitative evalu- ation of clinical fitness of an RPD framework. Stern et al 12 and Dunham et al 13 have proposed similar ap- proaches to quantify the space between the rest and the rest seat, which can reflect the clinical fitness of RPD frameworks. Accordingly, the investment casting RPD

Hongqiang Ye, Jing Ning, Man Li, Li Niu, Jian ...

Publication

exity of structures, the variety of component materials, and the wide variety of designs. To the knowledge of the present authors, no commonly accepted criteria ex- ist for RPD frameworks. Therefore, a visual inspection and a pressing test, commonly accepted in clinical practice and used previously, 11 were used to evalu- ate clinical fitness of RPD frameworks. In addition, gaps between the occlusal rest and the rest seat were duplica

Hongqiang Ye, Jing Ning, Man Li, Li Niu, Jian ...

Publication

pplied in a clinical setting, and the clinical results were evaluated. To date, few studies have discussed the clini- cal fitness and accuracy of RPDs, particularly the quantitative evaluation, owing to the complexity of structures, the variety of component materials, and the wide variety of designs. To the knowledge of the present authors, no commonly accepted criteria ex- ist for RPD frameworks. Therefore, a visual inspection and a pressing test, commonly