Mechanical properties of different designs of RPD fabricated with selective laser melting and conventional casting.

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Abstract

Statement of Problem: With the increase in use of SLM to fabricate dental prosthesis, is there a compromise in mechanical properties when compared to casted dental prosthesis.

Purpose: The aim of this study is to mechanical test removable dental prosthesis (RPD) with 2 different means of fabrication, SLM and conventional casting with castable resin printed by SLA and by 2 different clasp designs, c-clasp and RPI.

Materials and Methods: A total of 9 RPD frameworks were fabricated, divided by 3 for the 3 groups, C-clap casted, C-clasp SLM, and RPI casted. A digital design was made on CAD software and an STL file was generated. A castable resin and the SLM were fabricated by the same STL file. Each RPD was tested for 10,000 cycles of insertion and removal, and retentive forces measured.

Results: There was no significant difference between all 3 groups with the SLM C-clasp having the highest initial retentive force followed by the RPI.

Conclusion: SLM may be used for economic advantages to fabricate dental prosthesis without the compromise of mechanical properties found in the casted dental prosthesis.

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Preface

First, I would like to thank Allah for everything he has blessed me with. Second, I would like to thank my major advisor and committee members for their support, time and knowledge on this research project. I would also like to thank my co-residents for always being supportive and helpful through the years, and Dr. Alejandro J Almarza and Sara Trbojevic for their time and efforts in setting up the testing in this project and being readily available for support. Finally, I would like to thank Strategy milling LLC and RTG dental lab, for their generous support in materials for this research project.

1.0 Statement of Problem:

CAD/CAM technology has improved many aspects in dentistry. From diagnostic records, evaluation, designing prosthesis and manufacturing. It has made many of these processes more efficient, accurate and economic which has led to the focus of major companies in developing the digital side of dentistry. With the increase in partial edentulism worldwide, there has been an increase in the use of removable partial dentures due to the acceptable efficiency and affordability when compared to other treatments. In certain situation, a removable partial denture is the only acceptable treatment option. The conventional method of fabricating partial denture with a metal framework is time consuming and labor intensive. The incorporation CAD/CAM to removable partial denture is done in either of the 3 ways known to the author. The castable pattern is 3D printed (Additive manufacturing) and casted the traditional method, the entire framework is 3D printed from metal alloy powder or milling (Subtractive manufacturing).

With the advantages in CAD/CAM overall, the aim of this study is to compare the mechanical properties of printed vs casted metal to investigate if there are any significant effect that will impact clinical decisions.

2.0 Specific Aims

Aim 1: To test the mechanical properties of casted vs printed (SLM) metal framework on an Instron machine to mimic the insertion and removal process for approximately 4 times a day for 6.8 years (10,000 cycles).

Aim 2: To determine the effect of removal and insertion on retentive forces of C-clasp vs RPI clasp designs.

Aim 3: To determine if there is a difference, is it clinically significant and would it affect clinical decisions.

3.0 History of Removable Partial Dentures

The first documented use of removable partial dentures (RPD) was in 1711 by Heister. It was done by carving a block of bone or ivory and fitted by constant placement and removal without impressions and models (Heister, 1711). Pierre Fauchard first published a scientific article, in 1728, that described a technique of fabricating a partial restoration. His description of connecters to be rigid and firm against bending and strains, was one of the first fundamentals in fabricating partial dentures that still stand today.

In 1746, Mouton first described the idea of retentive clasps and was later documented in 1817 by Delabarre. Bonwill, in 1899, documented his technique of clasping abutments with gold circumferential clasps that were soldered to the major connect. He also documented the use of rest seats, where the partial is supported by the abutment tooth.

In 1880, Balkwill was the first to describe and document the palatal connectors to be used in maxillary partial dentures. Balkwill explained the mechanical reason for the partial to resist torsional strain and give sufficient rigidness.

With the components of the partial dentures developed through the years, the focus then shifted to the development of different designs of partial dentures using treatment tools. Henrichsen, in 1914 was the first to describe a bar clasp mentioned as "infrabulge" where the clasps project from below to engage the height of contour. It only gained popularity when Roach discussed it in 1930. In 1936, Stone explained the tripping action of bar clasps, which gave them an advantage over c-clasps. The bar clasps are pushed rather than dragged, which required greater force to dislodge. Surveying was needed to design and analyze models to design RPD's treatment planning. Roth and Weinstein came up with the first commercially available instrument to survey models in 1921.

Before the 1950, most of the articles were from expert opinions about their theories and techniques that wasn't supported with scientific evidence. A lot of the concepts developed back then are still valid in the process of RPD fabrication.

3.1 Components of Removable Partial Denture

Components of an RPD all contribute to the function and efficiency of the prosthesis. Major Connectors connect the parts of the prosthesis cross-arch. All direct and indirect retainers' components are attached to the major connector (McCracken 2016). Rest seats transmit vertical forces from the prosthesis to the abutment (Cecconi et al 1972). A Direct retainer is a component that engages an abutment to resist movement away basal seat tissue (Langer 1978). Indirect retainers help prevent dislodgment of the prosthesis away from the tissue, especially in distal extension. The components should be placed on the opposite side of the fulcrum, as far away from the distal extension as possible. Rest seats, as well as guide planes are defined as indirect retainers.

Different designs and combinations of components in RPD's have been studied and suggested based on classification and force distribution.

3.2 Classification of Partially Edentulous Arches

Classification systems are used to guide the clinician on treatment plans and decisions based on the complexity. The Kennedy classification of partially edentulous are the most widely accepted classification among clinicians and laboratory technicians (Fig 1) (Kennedy E 1928). The Kennedy classification require rules to be able to be applied efficiently in different situations. Applegate set-forth eight rules that help apply the Kennedy classification (Table 1) (Applegate 1960). The most common Kennedy classification is 1 and 2 with the most common abutments being the premolars (McCracken 2016).

3.3 Design of Removable Partial Denture

The importance of design is the consideration of biomechanics of the prosthesis. The goal is to achieve movement control to maximize functionality and efficiency while minimizing damage to the soft and hard tissue. Therefore, whether the prosthesis is tooth supported or tooth- tissue supported will influence the design of the prosthesis (Cecconi 1971). Increasing rigidity of major connectors distributes the forces across the arch and increasing the coverage area reduces forces to the abutment teeth (Kaires, 1956). Multiple occlusal rests, also helps distributing vertical forces to multiple abutments, especially with a distal extension terminal abutment (Frechetter 1956). Altered cast technique should be used in distal extension to compensate for the movement of the bases when taking an impression (Holmes 1965 and Leupold 1966). I-bar clasp reduces the forces on an abutment, which is required in the case of distal extension partials (Kratochivl 1963). The most ideal, biomechanical design to reduce forces on the abutment tooth in a distal extension is a mesial rest-proximal plate-I bar (RPI) (Krol 1973). Contraindication of I-bar due to insufficient vestibular depth, soft tissue undercut and unideal position of the height of contour lead to the development of mesial rest-proximal plate-Akers clasp (RPA) (Krol 1981). Parallel guide planes along with clasps provide retention and stability for the prosthesis. (Frank 1977).

For long-term success, there needs to be a consideration to the design of the prosthesis based on the Kennedy classification, amount of teeth involved, periodontal status, occlusion, and oral hygiene with cautious execution of the fabrication process.

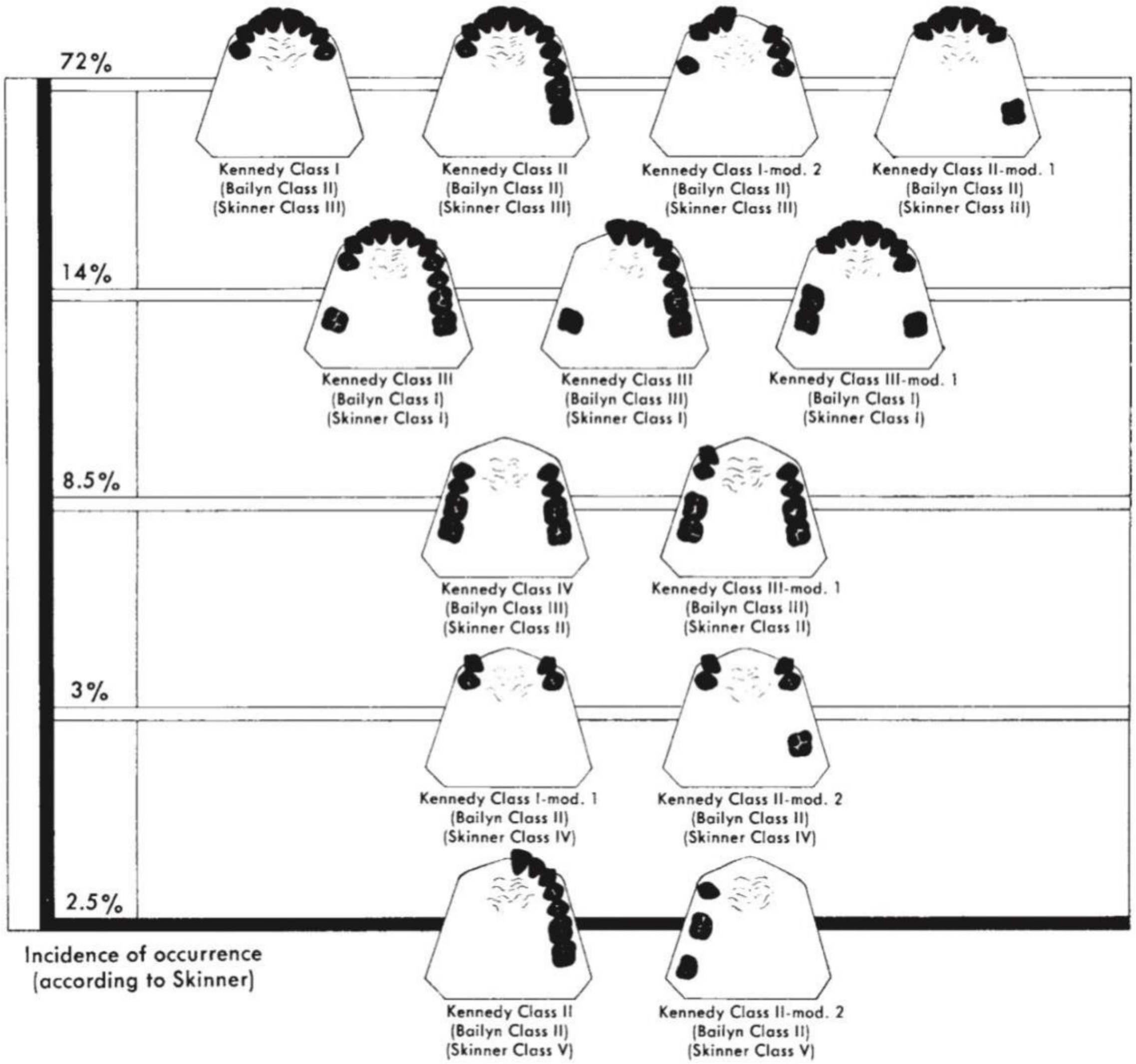

Figure 1 Kennedy Classification including Bailyn and Skinner's Classification. Skinner's incidence of occurance included.(McCracken 2016)

Table 1 Applegate's Rules for Applying The Kennedy Classification.

1.	Classfication should follow rather than precede any extractions of teeth that might alter the original classification.
2.	If a third molar is missing and not to be replaced, it is not considered in the classification
3.	If a third molar is present and is to be used as an abutment, it is considered in the classification.
4.	If a second molar is missing and is not to be replaced, it is not considered in the classification.
5.	The most posterior edentulous area always determines the classification
6.	Edentulous areas other than those determining the classification are referred to as modifications and are designated by their number.
7.	The extent of the modification is not considered only the number of additional edentulous areas
8.	There can be no modification areas in Class IV arches.

4.0 Treatment with Removable Partial Dentures

With the evident increase in aging population, the number of edentulous or partial edentulous patients are increasing drastically. (Petersen 2005). Replacement of missing teeth to restore function and esthetics is of significant importance due to the comorbid factors, like poor nutrition, cardiovascular disease, diabetes, and other systemic disorders, that exist with edentulism (Felton 2009). Removable partial dentures are a reliable treatment that are more economic when compared to implant therapy and fixed dental prosthesis for the replacement of the edentulous ridge (Grant 1994). However, with RPD's worn in the USA, 65% had at least 1 defect, with lack of stability and retention being amongst the highest defects recorded (Hummel 2002). The conventional technique of fabricating the metal framework in RPDs is through the lost wax technique (LWT)(Firtell 1985). Wax is applied to the stone cast to the design specified by the dentist, which is then invested and casted with cobalt-chromium(Dootz 1965). The laboratory procedure could be time consuming, costly, compared to more advanced techniques, and human errors are easily introduced.(William 2004 and 2006). One of the most common mechanical failures of a metal framework in RPD's is the loss of retention, fatigue and fracture of the clasps due to the repeated removal and insertion (Saito 2002). A more recent digital method of fabricating metal framework could be more beneficial in both the mechanical and economical aspect of the fabrication.

5.0 CAD/CAM Removable Partial Dentures

Advancements in CAD/CAM technology has shown very promising results in all parts of dentistry (Alghazzawi 2015). It is widely accepted in the fabrication of fixed prosthesis, either tooth supported or implant supported. For RPD metal framework fabrication, both subtractive (SM) and additive (AM) manufacturing has been used. The SM technique has shown to be not an ideal way due to high rate of wear to the manufacturing tools, difficulty in creating complex geometry with undercuts and may be uneconomical (Lebon 2016). Additive manufacturing can be divided into 7 categories: stereolithography(SLA), material jetting, material extrusion, binderjetting, powder bed fusion(PBF), sheet lamination, and direct energy deposition. PBF is the most commonly used for 3D metal printing in dentistry. There are 3 types of PBF: Selective laser sintering (SLS), selective laser melting (SLM), and electron beam melting (EBM). SLS is partial melting phenomenon which is characterized by high porosity (Revilla-Leon 2019). SLS has been replaced by the newer technology SLM, which is complete melting phenomenon with very minimal porosity, although will require post-build heat treatment (Vandenbroucke 2007). The Cobalt-chromium used in dentistry for AM of metals are primary composed of Co 60-65%, Cr 26-30% and Mo 5-7%, very similar to the conventional LWT (Koutsoukis 2015).

5.1 Selective Laser Melting (SLM) Dental application.

SLM technology has shown promising results in dentistry. With the high precision and durability, SLM has been the primary source of AM for metals in dentistry.

5.1.1 SLM in Fixed Dental Prosthesis.

Most studies of SLM were done for fixed prosthesis and showed very acceptable accuracy with fit and marginal adaptation. Previous studies were done to evaluate different manufacturing technologies (milling, SLM and EBM) on a titanium full-arch implant-supported prosthesis. The results of the studies showed acceptable values in terms of screw stability, strain and stress analyses, and marginal misfit. (Barbin 2019). An in vitro study was done to evaluate the distortion of the manufacturing process of SLM and EBM. Their results showed no significant difference between SLM and EBM and that both showed acceptable ability to manufacture implant-supported prosthesis metal frameworks (Revilla-León et al in 2018). Most studies show a clinically acceptable fit and marginal adaptation of AM in metal fixed prosthesis. (Ucar 2009, Quante 2008, Kim 2014). When evaluating the ceramic bond strength, most studies reported the superiority of

AM CoCr metal alloys, surpassing the minimum acceptable strength required to bond ceramic to metal. (Xiang 2012, Wu L 2014, Wang H 2016). A published review comparing AM to conventional casting and milling of metals in implant dentistry showed that the literature supported AM as a reliable method to manufacture frameworks concluding that more studies are needed to assess the long-term clinical outcomes for biological and mechanical complications. (Revilla-León 2020)

5.1.2 SLM in Removable Prosthesis

Studies done for SLM in removable prosthesis are mostly done on the fit of the prosthesis. A study looked at the fit of RPD clasps fabricated with 4 different fabrication techniques, wax inject printing combined with LWT, SLM, wax milling with LWT and resin milling. They looked at both the horizontal and vertical dimensions by using light microscopy. They concluded that all RPDs fabricated by using casting in their technique showed higher discrepancies due to greater distortion (Arnold 2018). When comparing CLW and SLM, a study used polyvinyl siloxane and measured in four zones: Buccal, lingual, marginal and central using digital microscope at 50x micrometers and found that SLM showed better fit but was not statistically significant (Bajunaid 2019). Casting shrinkage is a problem that is not present in SLM which might make the difference in fit. A study used PVS to measure average gap and maximum gaps between frameworks and models and concluded that SLM achieved a clinically acceptable adaptation, however, with large span with more retainers and clasps, casting showed a more superior adaptation than SLM (Chen 2019). A review of 20 studies reported that the fit of RPD fabricated digitally was acceptable, and the recent introduction of color maps may be a better assessment of fit because its more objective and quantitative versus the use of polyvinyl siloxane or similar materials. (Al Mortadi 2020)

5.1.3 Mechanical Properties of SLM

Most articles reviewed showed promising results in regard to mechanical properties of SLM. A lot of the articles reported on the favorable mechanical properties of SLM compared to casting.

A study evaluated porosity, microstructure, and Vickers hardness on 3 groups of metallic specimens prepared using casting, milling and SLM. Results showed no porosity detected for the SLM and milling compared to casting and SLM had the highest Vickers hardness value compared to casting and milling. (Y.S. Al Jabbari et.al 2014)

When evaluating the microstructure, mechanical properties and metal elution of Cobalt-Chromium-Molybdenum alloy fabricated by SLM it was reported that SLM showed higher yield strength, ultimate tensile strength and elongation compared to cast alloy. (Takaich et al. in 2013) The metal elution was smaller in SLM than that of casting, thus, SLM is a very promising technique of metal fabrication. Similar study reported higher yield strength and tensile strength when compared to casting. (Jevremovic et al in 2012). One study investigated SLM structural features inter-grown on different length scales ranging from nano- to macro levels on their mechanical properties and found there were defects, but despite the defects, the yield and the ultimate tensile strength were higher than that of casted dental alloy (Qian et al in 2015). A review showed limited internal porosities with SLM, and that mechanical properties depends on different angulation between building and tensile directions, where zero angle showed the highest tensile strength and elongation after fracture which shows that SLM has enhanced mechanical properties when compared to casting. (Koutsoukis et al in 2014). When evaluating a metal alloy prosthesis, SLM showed promising mechanical properties and hence, when evaluating the means of failure of metal alloy in conventional casting, SLM may have an advantage on durability and longevity.

5.1.4 Direct retainers fabricated by SLM.

One of the most common failures seen in RPDs are the direct retainers. After 6 years, the fracture and deformations of retainers, mainly clasps, were very high. They were the second highest cause of failure overall after abutment teeth failure and the first mechanical failure of the RPD (Saito et al 2002). In a retrospective study of 174 clasp-retained RPD, the most technical failure were clasps fracture at 16.1% (Behr et al 2012). CoCr consistently distorts when inserted and withdrawn from undercuts. The effect of the path of insertion and removal is evident when the path is none ideal showing more distortion and mechanical disadvantages even with an angulation of 10 degrees only from the ideal path of insertion (Marie et al 2019). When comparing clasps fitness and retentive force fabricated by repeated laser sintering and milling, the laser-sintered frameworks had a rough surface and heat treatment did not affect the surface roughness. Heat treatment did however affect the retentive forces, showing the greatest retentive force among all clasps tested (Torii et al 2018). A study reported that clasps fabricated by SLM had a significantly higher fatigue strength if build direction was at 90 degrees, than cast clasps, compared to when built at 0 and 45 degrees. At all directions, the yield strength and ultimate tensile strength were all significantly higher than casting. The 0 and 45 degrees resulted in permanent deformations and a decrease in force were observed from early stage. They concluded that there are several factors, such as surface roughness, crystal orientations, residual stress, and molten boundaries that effect the mechanical properties of CrCo fabricated by SLM which they showed in their build direction (Kajima et al 2016)

6.0 The Purpose of this Study

The purpose of this study was to test and evaluate the loss of retention through permanent deformation of removable partial denture fabricated by SLM vs cast CoCr and different clasp designs (RPI-bar vs C-Clasp). This is done by cyclic loading of every prosthesis and measuring the mean force required to vertically dislodge the prosthesis from the CoCr master model. The null hypothesis is that there is no difference between SLM vs Cast CoCr and C-clasp vs RPI-bar clasp design in permanent deformation and loss of retention after 10,000 cycles of insertion and removal.

7.0 Material and Methods.

An in vitro study was carried out with 3 study groups (Table 2). A total of 9 removable partial dentures were fabricated for this study. The 9 samples were divided by 3, resulting in 3 samples for each group. Due to manufacturing difficulty, unsatisfactory product resulted from the RPI manufactured by SLM and deemed unfit for testing. Groups were divided based on design and means of fabrication.

Table 2: The 4 study groups to be tested.

	C-Clasp	RPI
Cast	3	3
SLM	3	0

7.1 Designs of RPD

First group design had a mandibular Kennedy class I bilateral distal extension with abutments on 1st premolars (21 and 28), rest seat and guide planes distal of #21 and 28, two circumferential clasps engaging a mesiobuccal 0.02-inch undercut on the terminal abutments and a lingual reciprocating arm with a lingual plate as the major connector. Second group design was a mandibular Kennedy class I bilateral distal extension with abutments on 1st premolars (21 and 28), rest seat on mesial and guide planes on distal of #21 and 28, two I-bar clasps engaging a mesio-buccal (greatest mesiodistal prominence) 0.01-inch undercut on the terminal abutments (RPI system) with a lingual plate as the major connector.

All designs were completed in a design software (Dental System; 3Shape). A standard tessellation language (STL) file was generated for the fabrication of all partial dentures. (Figure 2)

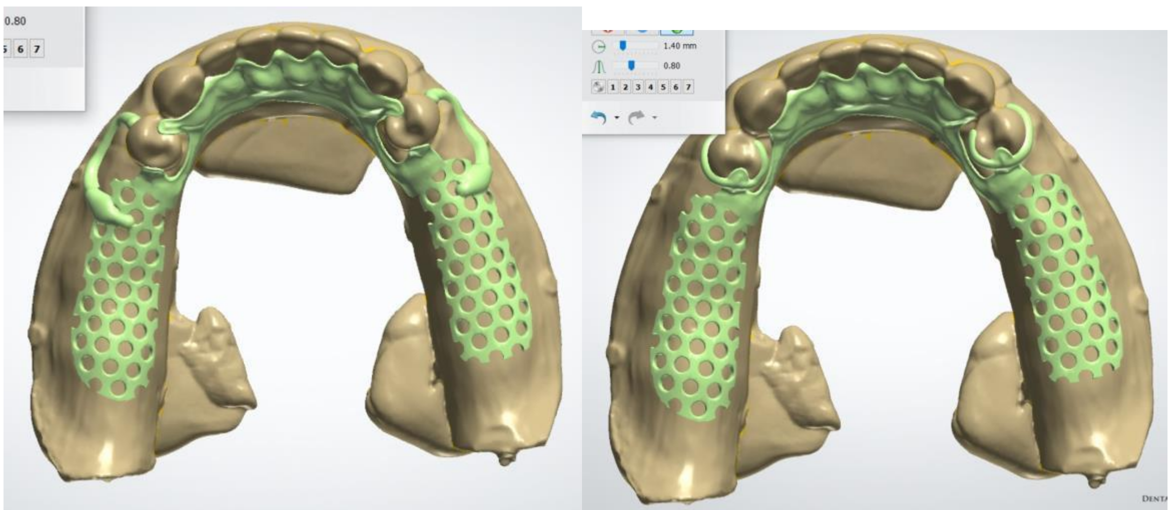

Figure 2 RPI design (Right) and C-clasp (Left)

7.2 Fabrication of RPD

The first method of fabrication used was the SLM. The design STL file was exported to an SLM machine (DMP Dental 100, 3D Systems) to print 3 RPD framework from each design at 30 microns for print layer thickness. CoCr alloy power (LaserForm CoCr (C), 3D Systems) was used following the manufacturer's recommendation with a nitrogen atmosphere set at 90 PSI at a

60 degree build angle. Finding a single alloy that could be used for both casting and printing was not available. It was a very close composition of both the powder and the alloy used to cast (Table 3). When printing was completed, the build-plate was sintered at 800C for 35 minutes (Accu-Therm 150- Jelenko), removed and set to cool to room temperature. Supports were removed and the partials were finished and polished with diamond burs, stone wheel and silicon burs. They were electroplated (Eltropol 300, Bego) for 5 minutes twice in a solution composed of ethylene glycol >25%(C2H6O2) and Sulfuric acid 5-10%(H2SO4) (Wirolyt, Bego).

The fabrication of RPI design through SLM fabrication method failed after several attempts of changing direction and designs, thus deemed unreliable for testing purposes and therefore only 3 SLM C-Clasp partials were fabricated.

The second method of fabrication used was printing a castable resin pattern (NextDent Cast, 3D systems) from an SLA printer (NextDent 5100, 3D systems) (Figure 3A). The castable resin was invested and casted by a very experienced dental technician in a dental laboratory that has decades of experience with casting and finishing removable partial denture frameworks (RTG, New York). The resin pattern was invested and burnout for 5 hours, then casted using CoCr (Vitallum 2000) and set to bench cool for 20 minutes then finished and polished with diamond, silicon and stone burs. (Figure 3B).

Table 3 Casted and SLM printed alloy composition

Vitallum 2000	Co 63.4; Cr 29.0; Mo 5.2; rest Si, Mn, C, N
LaserForm CoCr (C)	Co 62-67; Cr 28-30; Mo 5-6; Rest Si, Mn, C, Ni, Fe, Cd, Be, Pb

Figure 3: (**A**)(Left) SLA printed castable resin pattern (**B**)(Right) After resin being casted with Vitallum 2000 and (**C**) (Bottom) RPD seated on master model

7.3 Master Model.

The master model was created from a typodont that was adjusted to represent mandibular bilateral distal edentulism. The only teeth present were from 1st premolar to 1st premolar. A putty impression (Aquasil Ultra+, Dentsply Sirona) of the typodont was taken and poured with type III stone (Microstone, Whip Mix Corp) following the manufacturer's instructions. The stone model was then scanned (D2000; 3Shape) in a software (Dental System; 3Shape) to generate an STL file. The STL file was exported to a milling center (Strategy Milling LLC, Pennsylvania) to fabricate the milled CoCr model (figure 4). The purpose of milling a CoCr model to use for testing was to prevent any distortion or wear of the model while testing that could significantly affect the results. The CoCr model was then scanned (D2000, 3shape) to generate the digital master model where all the designs were made on. All surveying, and evaluating undercuts were done digitally.

Figure 4: Milled CoCr master model used for mechanical testing.

7.4 Mechanical Testing.

With a total of 9 RPDs ready to be tested, each were mounted individually on a universal testing machine (Instron, 5566) set at an ideal path of insertion (Figure 5). For measuring change in retentive forces, a tensile test was carried out and the change in force was plotted for 10,000 cycles at a cross head speed of 4mm/s simulating 6.8 years of insertion and removal 4 times a day. The dynamic vertical displacement was carried out such that the clasp engaged the undercut and was pulled upwards until the clasp disengages the abutment. The mean load required to disengage the abutment was calculated with the first 10 cycles then 10 cycles of every 1000 cycles until 10000 cycles were completed.

Figure 5 Universal testing machine (Instron) with master model and sample mounted.

8.0 Results

The results of the current study display the mean load (N) required to remove the RPD from the master model of the 3 groups tested (Table 3). No significant change in load was evident of the 3 groups at the end of the testing cycle (10,000 cycles). SLM had the highest retentive force initially and at the end of the testing cycle when compared to the casted C-Clasp and casted RPI but was not significantly different. When comparing the C-clasp and RPI, the RPI initial retentive force was higher, however, as the C-clasp gained slightly more load by the end of the cyclic testing there was no significant difference. All 3 groups maintained the retentive force, with the casted C-clasp gaining slightly higher force as the testing cycles went on but was not significantly different (Figure 6). All samples within each group had similar mean load (N) (Table 4).

Table 4 The mean load (N) of the 3 groups CC-Cast C-Clasp, SLM- Selective Laser Melting, and CI- Cast RPI

Cycles Count	Mean Load N CC	Mean Load N SLM	Mean Load N CI
1 - 10	28.4	34.6	31
1001-1010	25.5	34.6	32.1
2001-2010	29.4	35.2	32.7
3001-3010	27.2	34.4	32.4
4001-4010	30.4	34.4	32.2
5001-5010	30	35.5	32.8
6001-6010	31.6	34.3	32.3
7001-7010	31.6	34.5	32.5
8001-8010	30.4	34.7	31.8
9001-9010	31.9	34.7	32.9
10001-10010	31.8	34.4	32.3

Table 5 The mean load (N) of all 12 samples of the 3 groups CC-Cast C-Clasp, SLM- Selective Laser Melting, and CI- Cast RPI

Cycles Count	Mean Load N (CC-A)	Mean Load N (CC-B)	Mean Load N (CC-C)	Mean Load N (SLM-A)	Mean Load N (SLM-B)	Mean Load N (SLM-C)	Mean Load N (CI-A)	Mean Load N (CI-B)	Mean Load N (CI-C)
1 - 10	27.2	29.4	28.6	35.2	34.5	34.1	29.5	32	31.5
1001-1010	21.6	27.1	27.8	35.2	34.1	34.5	32.2	32.4	31.7
2001-2010	27.7	29.3	31.3	35.3	34.7	35.5	32.9	31.7	33.4
3001-3010	20.8	28.4	32.3	34.5	33.8	34.8	32.5	32.5	32.3
4001-4010	30.6	29.7	31	34.4	34.7	34.2	32.2	32.1	32.2
5001-5010	32.2	32.5	30.4	34.2	35.1	34.3	33.9	32.2	32.3
6001-6010	30	29.8	30.2	34.1	34.7	34.2	31.8	32.1	32.9
7001-7010	31	32.1	31.7	34	35.3	34.1	32	32.9	32.7
8001-8010	31.8	30	29.4	34.6	34.8	34.8	32.5	31.3	31.5
9001-9010	32.5	31.6	31.6	34.3	35.1	34.7	34.2	31.9	32.6
10001-10010	31.9	31.4	32	34.2	34.7	34.2	33	31.5	32.4

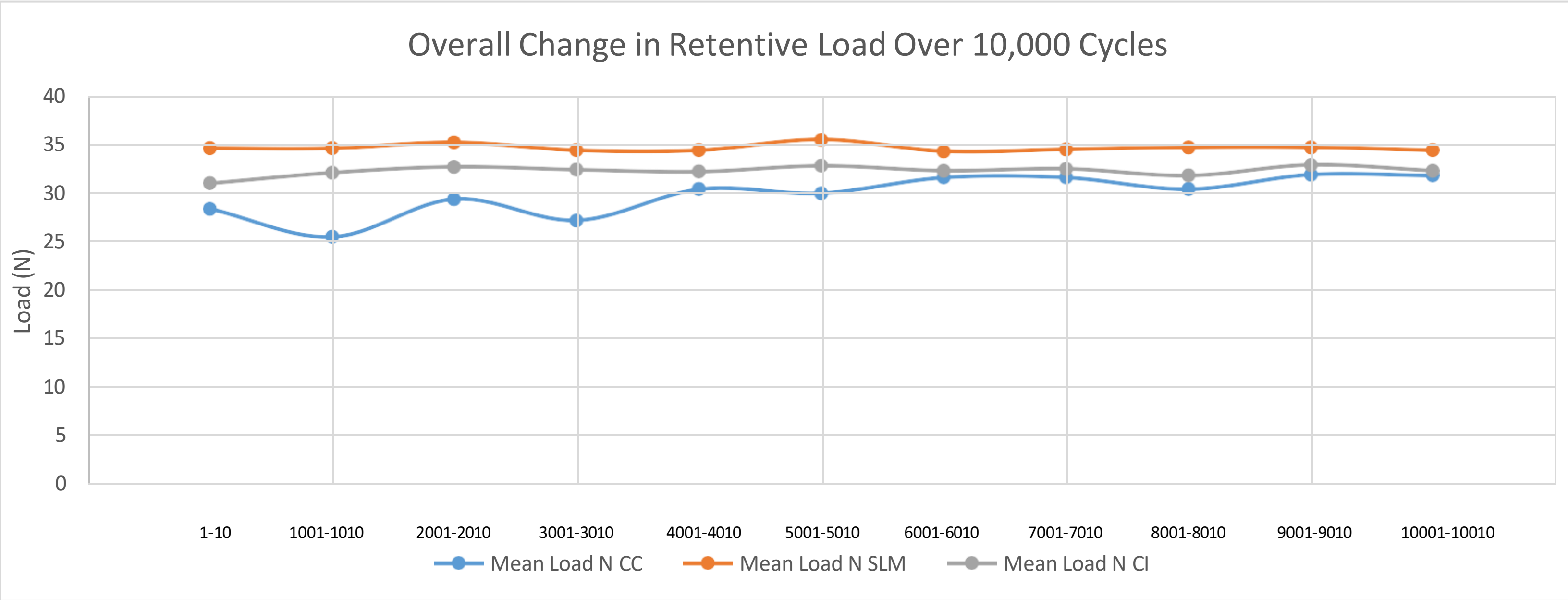

Figure 6 Overall change in retentive load over 10,000 cycles

9.0 Discussion

This study was carried out to examine the reliability of digital means of fabricating RPD metal frameworks and if the different designs of clasps has any effect. The RPI design fabricated by SLM did not have an acceptable fit and the clasps did not engage the abutments. The design was adjusted and the thickness of the RPD was increased and build orientation was changed in order to achieve an acceptable prosthesis but were unsuccessful. The author does not believe the design was the issue, as the castable resin pattern were printed from the exact same design and casted to an acceptable fit and retention of the RPD with an RPI design. The manufacturer's instructions were followed for pre and post processing, however the prosthesis was deemed unfit for testing. Further testing is needed to produce an acceptable RPI design RPD using SLM. The final sample count was 9, divided equally by the 3 groups, casted C-Clasp, SLM C-Clasp and casted RPI.

Approximately 19 N of retention may be necessary to prevent the removal of the RPD while chewing sticky food (Tokue et al 2013, Vallittu PK 1995, Mahmoud A 2005). All 3 groups tested achieved over 19 N of load to remove the RPD initially and at the end of the 10,000 cycles showing acceptable retention for function. It must be taken into consideration that this was carried out in a dry environment with a Co-Cr abutment tooth which might cause higher frictional resistance, which in turn, may have increased the force values.

Past studies showed conflicting results with SLM technology. Tan et al compared titanium clasps fabricated by SLM, CNC milling and conventional casting through 10,000 cycles of testing to compare retentive forces and permanent deformation. When measuring the fit, they were all similar with no significant difference. However, when comparing the retentive forces, SLM had the highest of the other 2 groups but rapidly reduced after 2000 cycles until the fracture of all specimens after only 4000 cycles. The author concluded that SLM should be further improved to fabricate RPD titanium clasps before clinical application. One of the advantages of SLM is the reduction in porosity compared to the casting technique which will have a positive effect on the mechanical properties (Xin XZ et al 2013). When investigating the microstructure of SLM vs casted, B. Qian et al found that SLM specimens, despite having defects, resulted in yield and ultimate tensile strength higher than the casted dental alloy. Yager et al found that the yield strength and maximum elastic deformation were similar from casted and SLM printed clasps which could explain why, in the current study, there were no significant difference in the initial load (N) and the end load after going through the cycles between the casted and SLM groups.

Contrary to most studies, this study showed the force increased at the beginning of the testing cycles with the cast C-clasp. Rodrigues et al showed similar results, in that there was an increase in force values during testing. Their explanation that it is caused by the clasps' prolonged cold working because the insertion path was strictly defined by the universal testing machine and by the guide planes on the abutment teeth. With an ideal path of insertion in this study, it is expected to maintain retentive forces when compared to the oral cavity in patients, who are unlikely to maintain an ideal path of insertion in 10,000 cycles of insertion and removal. Marie et al had similar results, in that an initial increase in force was recorded. The probable cause could be attributed to work hardening. They compared ideal path of insertion and a 10-degree deviation path of insertion and found there was an affect in retentive forces, were 10 degrees had higher initial retentive forces and more clasp distortion resulting in faster decline in retention. In a review by Koutsoukis et al showed that SLM had an advantage over casting in, time-consumption, waste material, and shaping ability with precision, while maintaining and in some studies improving mechanical properties. In some studies, the build angle of SLM fabricated prosthesis showed significant effect on the mechanical properties. The build angle with the clasps parallel to the build plate showed the most superior properties. (Takaichi et al 2013, Koutsoukis 2015, Kajima, 2016). In this current study, the build angle was 60 degrees to get the position of the clasps parallel to the build plate. Kajima et al tested CoCr fabricated by SLM and casting and concluded that SLM with clasps parallel to the build plate resulted in higher yield, ultimate tensile, and fatigue strength when compared to casting.

When comparing the casted C-clasp to the RPI design, no significant difference was seen in this study as was reported in other studies in an ideal removal and insertion direction. (La Vere 1993).

In this current study, SLM RPD had the highest retentive force and was maintained through the 10,000 cycles compared to the casted RPD but was not significantly different. These results coincide with past studies that showed comparable properties between casted and SLM fabricated prosthesis.

10.0 Conclusion

This study showed there is no significant difference between SLM and casting RPD, and no significant difference in the design of clasps, C-clasp vs RPI, in tensile strength after 10,000 cyclic load tests. As past studies have concluded, SLM demonstrated to be very promising in the fabrication of dental prosthesis. The main advantage is being more economical and less time-consuming, especially at high volume, when compared to casting without compromising on fit and mechanical properties.

11.0 Limitation

This was an in-vitro study, which was a different environment than the oral cavity. Cyclic testing mimics the insertion and removal but lacks a lot of other factors that are present in the oral cavity, like saliva, temperature change, nonideal path of insertion and removal etc. How will these factors favor one fabrication method vs another is still unknown and needs long term studies of RPD wearing in patients. With the use of master model fabricated from CoCr, the coefficient of friction is different than enamel which may affect the retentive forces.

The casted frameworks were fabricated by printing a castable pattern from and SLA printer, which is not necessarily what the lab (RTG) would do. Testing the actual frameworks that will be worn by patients could be a more beneficial to compare. The reason that the patterns were printed rather than use the stock wax patterns used by the lab, is to maintain the exact same design when comparing the 2 fabrication methods. A slight change in thicknesses and design in the RPD might favor one fabrication method over the other.

The sample size was small in this study meaning that the statistical significance could not be calculated. Also, the samples were of one design, Kennedy class 1. A design more complex with more modifications, could affect the results as the more geometric complex the prosthesis is, the more it is prone to inaccuracies. The testing was done in an ideal path of insertion, which is not the case with patients. The constant change in the path of insertion may have an effect of the RPD fabrication methods. Further long and short-term clinical studies are needed for the RPD fabrication in SLM

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