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Comparison of Fitness of Casted Cr-Co with Selective Laser Sintering (SLS) Technology of Cr-Co and CAD/CAM Milled Acetal Major Connector Materials

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Abstract:

Newly developed materials and manufacturing processes offer different treatment modalities, such new treatment options need investigation and comparison to achieve long lasting, hygienic and health preserving prosthesis. This study was aimed to compare the fitness of three different materials Casted Cobalt Chromium, Selective Laser Melting Cobalt Chromium and Milled Polyoxymethylene (POM) Acetal. SLS Co-Cr shows superior fitness qualities that Acetal and Casted Co-Cr respectively.

Keywords: Cobalt Chromium alloy, Acetal, SLS, CAD/CAM, Fitness, public health, framework, removable denture

INTRODUCTION

Traditional casting, also referred to as lost-wax casting, has been the main process for producing metallic dental restorations for more than 70 years. However, the introduction of computer-aided design and manufacturing (CAD/CAM) techniques at the beginning of the 1970s marked a turning point by bringing about automated production processes. Most dental restorative fabrication methods used subtractive manufacturing up until the early 1980s, either by casting or milling **(van Noort, 2012).**

Over the course of the last few decades, digital dentistry has been progressively rolled out, with various technological advancements being developed and used at varying times. Its primary objective is to enhance and improve the practice of dentistry through the utilization of digital tools and techniques, with the objectives of providing improved accuracy and precision, enhancing the patient experience, increasing efficiency and productivity, enhancing communication and collaboration between dental professionals, and ultimately improving treatment outcomes **(Haidar, 2023).**

Therefore, when people talk about "Applied Digital Dentistry," they are referring to the utilization of advanced digital technologies in dental practices and laboratories. These digital technologies are intended to improve the precision, effectiveness, and overall quality of dental treatments and procedures. These technologies can be implemented in a range of dental specialties, such as restorative dentistry, orthodontics, implant dentistry, and cosmetic dentistry, thereby boosting our capacity to devise extremely precise and individualized treatment strategies for each individual patient. **(Ubale and Uddanwadiker, 2018).**

The computer-aided manufacturing (CAM) digital technologies can be broken down into two distinct categories: Subtractive and Additive **(Kajima et al., 2016)**. The subtractive method involves reducing the framework of an object from a block to the final shape planned by CAD. This reduction can be accomplished by spark erosion or milling processes, depending on the specifics of the procedure **(Bilgin et al., 2016)**. The process of adding material falls under the category of additive methods, which can be further subdivided into SLA (Stereolithography), DLP (Digital Light Projection), PolyJet/ProJet (Jet Printing), SLM (Selective Laser Melting), SLS (Selective Laser Sintering), and DLMS (Direct Laser Metal Sintering). Already, the SLM technique is being utilized in the process of fabricating the metal frameworks for detachable partial dentures (RPDs) **(Kajima et al., 2016)**.

Using a laser that melts metal powder layer by layer in accordance with the instructions provided by CAD software, the SLS technique may produce three-dimensional metal parts **(Torabi et al., 2015).** The frameworks created by the SLS approach have an effectiveness that is comparable to that of the traditional method in terms of precision, the quality of the fit, and function. On the other hand, there aren't a lot of research either in vitro or in vivo that evaluate the SLS technology **(Kim et al., 2018)**.

The development of Osseo integrated implants forty years ago was one of the most significant scientific achievements in clinical dentistry that offers esthetical and near natural restoration **(Mohammed Musadaq et al., 2023)**. Creating a removable partial denture for partially edentulous patients that doesn't show the ugly display that's associated with traditional clasp assembly is one of the primary challenges **(Shala et al., 2016)**. Dentist's skill in fabricating an esthetic denture is reflected on the patients self-esteem **(Alghriari et al., 2021)**. In conditions as visually demanding as these, a traditional clasp type partial denture that contains a rotational path of insertion is one of the many approaches that have been developed to find a solution to this aesthetic situation **(King, 1978)**, Twin Flex Clasp **(Belles, 1997)**, use of extra-coronal adhesive attachments **(Marinello et al., 1991)**, painting of clasps with tooth- colored resin **(De Rossi et al., 2001)**, use of lingually positioned clasps, engagement of mesial rather than distal undercuts **(Beaumont, 2002)**, use of precision attachments **(Donovan et al., 2001)**, approach to clasps through the gingiva rather than through the occlusal **(Chu and Chow, 2003)**.

Research in the field of polymer science has led to the discovery of an alternative substance that is known as "Acetal Resin." The polymerization of formaldehyde results in the formation of acetal resin, which is a thermoplastic techno-polymer with a crystalline structure that is devoid of monomers and is also known by its acronym, Polyoxymethylene (POM) **(Fitton et al., 1994)**. A chain of alternating methyl groups is what makes up the homopolymer known as polyoxymethylene (POM). This chain is held together by an oxygen molecule. Due to the fact that this material has been demonstrated to have superior biocompatibility, it has becoming increasingly popular for usage in artificial valve occluders and total hip replacements. It has been used into a dental implant system to serve as a component that can absorb tension **(Kirsch and Ackermann, 1989)**.

MATERIALS AND METHODS

Class I Kennedy classification lower partial denture design was chosen for this study. Such design was selected according to the prevalence of missing teeth pattern among Iraqi patients who were visited College of Dentistry / Baghdad University seeking removable partial denture treatment **(Zainab et al., 2021)**. After history taking, diagnosis of the patient and clinical evaluation, a primary impression was taken using a stock tray and alginate impression material. Upon removal of the impression from the mouth, impression was inspected for defects such as air entrapment and short extension of the borders under good lighting before it is rinsed. Dentistry is predominantly a field of surgery, involving exposure to blood and other potentially infectious materials therefore requires a high standard of infection control

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(Al-khafaji et al., 2013). The impression should be rinsed with cold water to remove any saliva or blood **(Nandini et al., 2008)**, because dentist and dental technician are in risk of cross-contamination **(Abass and Ibrahim, 2012)** disinfected with 2% glutaraldehyde solutions **(Dapello-Zevallos et al., 2022)**. The impression was poured using type 3 dental stone according to the manufacturer instruction. After setting, the primary cast was removed from the impression, checked for any defects such as bubbles entrapment and then trimmed. A spacer was formed by softening a wax sheet of 2 mm and adapted on the remaining teeth to block-out the undercuts, stoppers were made on the last two distal abutments through the wax to allow for even distribution of the impression material during impression taking (Figure 1), a coat of separating medium was applied on the remaining edentulous areas and a light cure tray plate was adapted on the cast for fabrication of the special tray. The special tray then was finished using stone burs. Tray adhesive was applied on the inner side of the special tray to allow adhesion of the polyvinyl siloxane material. Final impression was taken by addition silicon after border molding of the edentulous area using ISO Functional tracing compound **(Fokkinga et al., 2017)**.

Figure 1: Wax as spacer.

After checking the impression for under or over extension **(Jayaraman et al., 2018)**, disinfection using 3% hydrogen peroxide **(Azevedo et al., 2019)** and pouring, a master cast stone model was formed and trimmed (Figure 2).

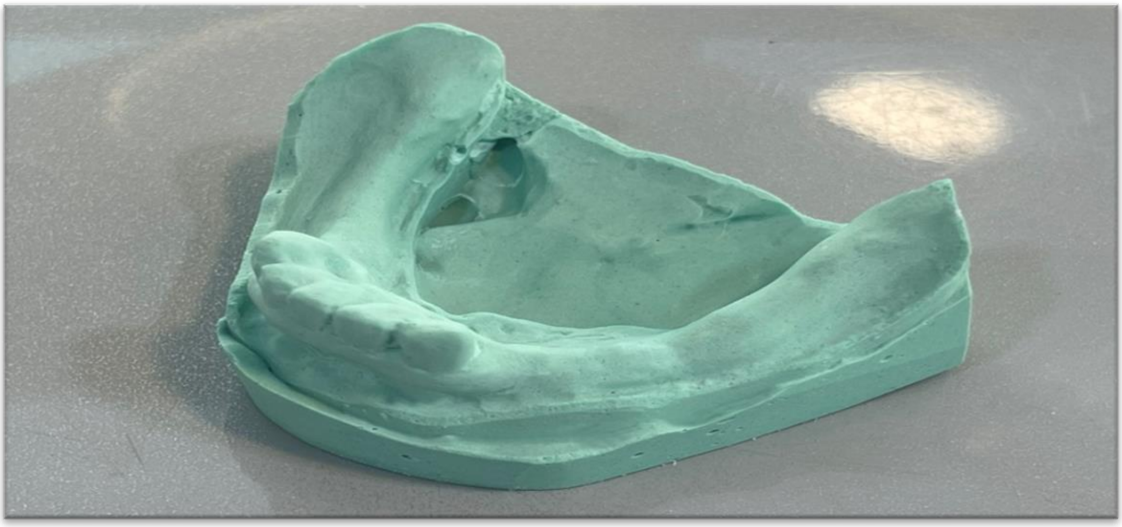

Figure 2: Master cast after poring and trimming.

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The master cast was scanned using intraoral scanner then the scanned data were saved as standard tessellation language (STL) file format. The data were uploaded to the Exocad partial denture designing software was used to design a linguoplate major connector lower partial framework according to the case indication and designing parameters **(Khalaf Al-Rawi, 2015)**. After completion of the design the corresponding partial framework STL was exported to be ready for processing and testing (Figure 4).

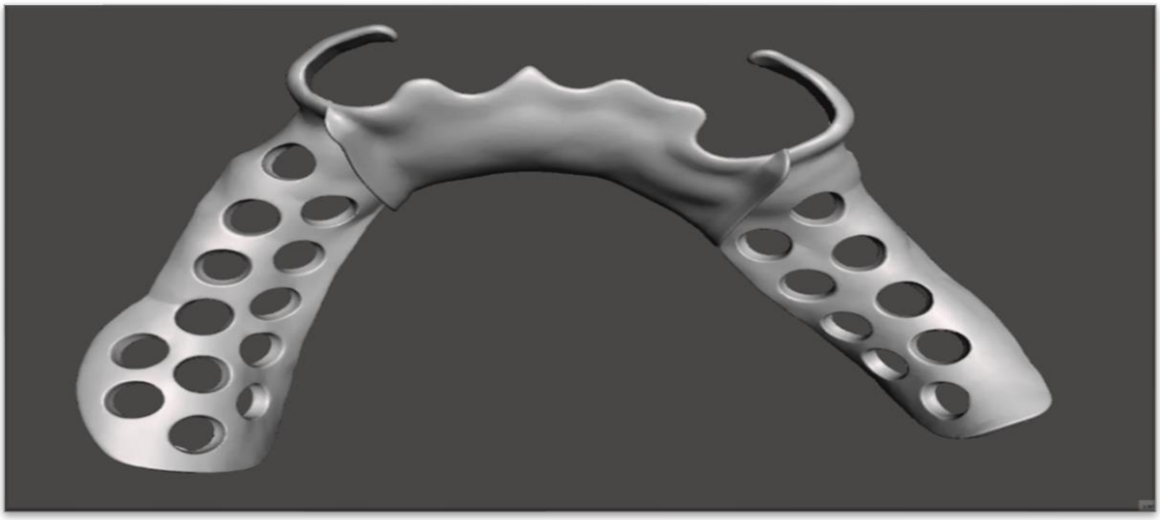

Figure 3: STL file for the Frame Design.

Acetal Specimens' Design and Preparation

The Acetal specimens were fabricated directly by exporting the STL files that coordinated to the Acetal specimens to the CAM software, after arranging the specimens according to the manufacturer instruction the CAM software process a strategy for milling the specimens. An Acetal Block with 98mm diameter and 20mm hight was used. Milling the specimens was done using the milling machine (Figure 4).

Figure 4: Acetal Specimens after milling**.**

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After milling specimens, they were cut from the block using fine tapered carbide bur no.23, supports were removed and minor refinement was done for the surface using silicon polishing bur to completely remove the sprues (Figure 5).

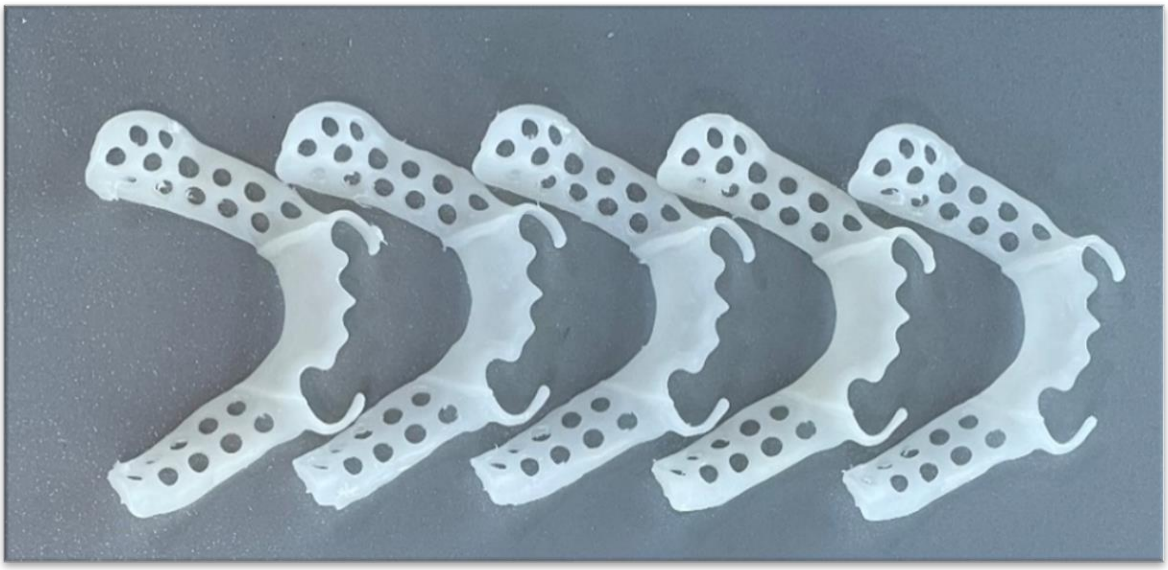

Figure 5: Acetal Specimens after milling and finishing.

Conventionally Casted Cobalt-Chromium Specimens' Design and Preparation

The STL files that coordinates the Cobalt Chromium specimens' dimension are exported to the CAM software to be milled using wax castable material. After milling the sprues were removed from the wax specimens and finished using silicon burs for a fine and smooth surface. According to (Takahashi et al., 1977) the specimens were sprued to the crucible former using sprue wax. Phosphate bonded casting investment powder and were used as a casting material. Firstly, a 100ml of liquid (60ml of investment liquid and 40ml of distilled water, ratio 3:2) was poured into the mixer bowel then a 500g of investment powder was poured on the liquid, a hand mixing with spatula for 30 seconds was done to ensure that all the investment particles are fully wetted with liquid (Figure 6), then the bowel was attached to the mixer and mixed for one minutes with 350 RPM under vacuum in a vacuum mixer according to the manufacturer instructions to avoid any air bubbles entrapment during mixing (Figure 7A).

Figure 6: Hand mixing of investment powder with liquid.

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After completion of the mixing the bowel was detached and the mixed investment material was poured slowly on the side of the crucible former to avoid air bubble entrapment over the wax specimens to form the mold, a vibrator was used on the lowest vibrating speed during the pouring process to remove any air bubbles (Figure 7B).

Figure 7: (A) Crucible former after pouring, **(B)** Mold in burnout furnace.

The crucible former was left for one hour to set (Figure 8A), when the investment material was completely set the rubber ring was removed to release the mould, then it was inserted into a burnout at room temperature, the furnace temperature was gradually increased until reaching a 400C, the mould was kept for 30 minutes, then the temperature was also increased slowly to reach 900 C with a holding time of 45 minutes (Figure 8B), this was done to ensure a complete burnout of the wax castable material without residue according to the manufacturer instruction (Rejab, 2008).

Figure 8: (A) Crucible former after pouring, **(B)** Mold in burnout furnace.

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After complete burnout of the castable material and reaching the desired internal temperature, the mould was taken out from the furnace and immediately put on the casting machine, a Co-Cr shots was heated using a high intensity flame torch (Figure 9) until it reaches 1300℃ and fully melted it was injected to the mould using conventional casting centrifuge (Figure 2.10A). The exact temperature was checked by using industrial laser thermometer gun.

Figure 9: Heating of the metal using flame torch**.**

After injection, the mould was kept aside for few hours to allow it cooling until reaching the room temperature (Figure 10B), the injected metal specimens were divested by sandblasting machine using Alumina Oxide under 3 bar pressure (Figure 11).

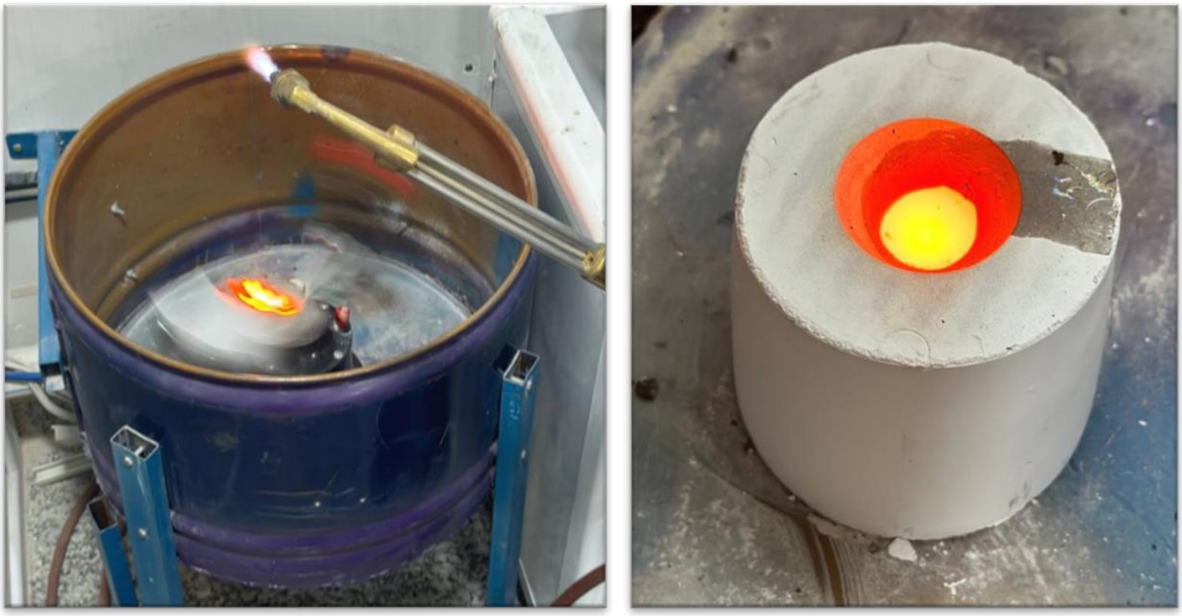

Figure 10: (A) Casting procedure, **(B)** Mold after casting procedure.

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Figure 11: Divesting the specimens.

Sprues were cut and finished with suitable metal grinding wheels; final shape was checked with calliper to ensure the correct dimensions after finishing (Figure 12).

Figure 12: Casted Co-Cr specimens.

Selective Laser Sintering Cobalt-Chromium Specimens' Design and Preparation

The STL files that coordinated to the SLS Co-Cr were imported to Voxeldance Additive Software, the software then analyses the imported files and creates supports which held the frames during printing process. Using SLS machine the printing process was performed in a nitrogen medium with a laser intensity of 10 kilowatts and a density of 1.964 J/mm^2 (ED). A CoCrMoW powder alloy with particle size between 15-50 microns was used and a layer thickness of 25 microns.

The Co-Cr powder was applied to stainless steel plate of the machine then the machine starts melting the Co-Cr powder a layer by layer, until the objects are fully printed according to manufacturer instructions. After completion of printing, samples were removed from the printing platform using cutting wheels.

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Heating Treatment (Post – Heat Treatment)

In order to eliminate the residual stresses that caused by laser local thermal impulses and to increase the mechanical properties through re-organizing the microstructure of the Co-Cr, the specimens were heat treated in a furnace heating with a temperature of 960C for 90 minutes in a nitrogen atmosphere **(Ghadhban, 2022)**. After treatment the supports were removed using metal grinding wheels, then specimens were checked for respective dimensions by vernier calliper (Figure 13)

.

Figure 13: SLS Co-Cr finished specimens.

Surface Fitness Test

After designing and complete fabrication of the different frameworks, finishing was limited only to sprues and supports removal, making sure the intaglio surface left untouched was necessary for accurate comparison. Due to the reflective nature of the Acetal materials, scan aiding powder was applied on all the surfaces to achieve a non-reflective surface to facilitating the scanning procedure. Each frame was scanned using an intraoral scanner, by holding the frame with tweezers (Figure 14) the scanning procedure is done by scanning the intaglio surface from one end passing through the major connector and to the other end of the mesh in a continuous pattern according to the manufacturer instructions' scanning procedure. After completion the scanned frame was saved as STL file, each group was named after the material been used and given a number from 1 to 5 that refers to the number of specimen (e.g.: Casted Co-Cr 3).

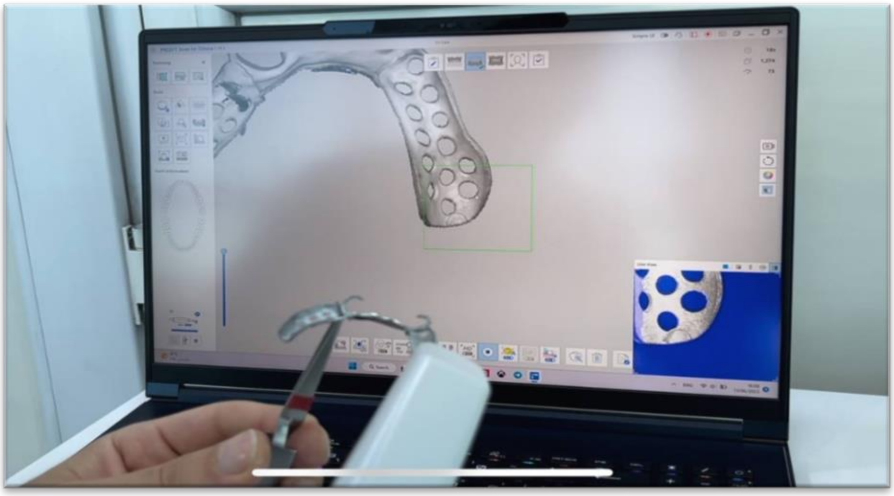

Figure 14: Scanning procedure.

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Specimen Testing

Medit Design is an application by developed by Medit which have multiple features that aids in the clinical and laboratory design of restorations. One features of the application is the “Fitness tool”, which is used to evaluate the fitness of restorations. Fitness tool works by scanning the intaglio surface of the restoration and saving it as STL file, then uploading both the scanned restoration’s data and its original design data to the application, the fitting surface STL of the framework is superimposed with the fitting STL file the original designed restoration in three dimensions (Figure 15).

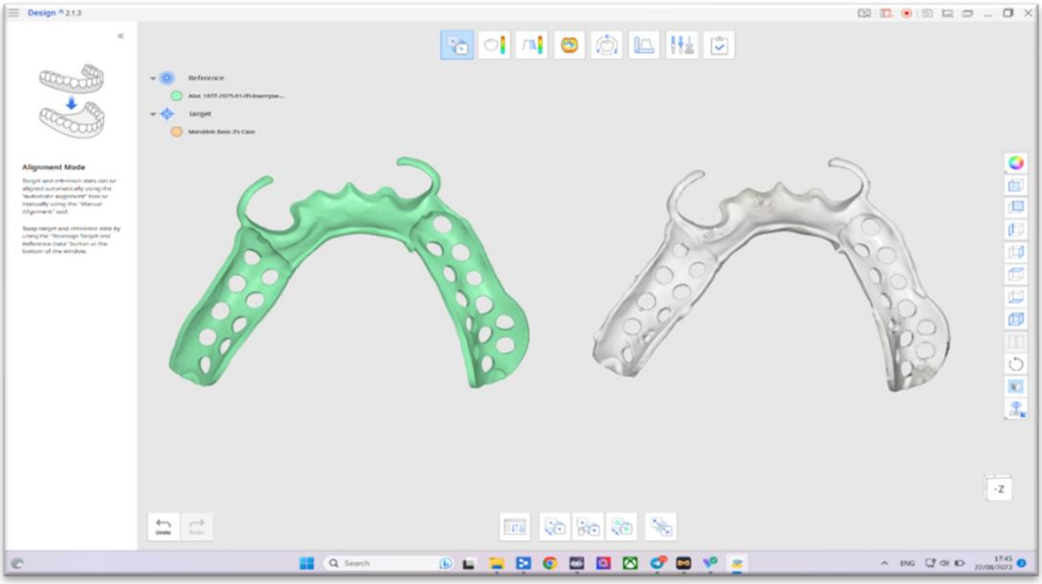

Figure 15: Original design of the framework on the left and scanned intaglio surface on the right.

The “Auto Alignment” feature is capable of aligning these two surfaces digitally by utilizing similar points between the two STLs and colors appear indicating the various sizes of gaps or indentations between the fabricated framework and the original design data. In other words, this technique shows the value of surface discrepancies as a map of colors where each color represents a value of the differences between the two surfaces, for instance in millimeters.

These discrepancies and “Auto Alignment” features are based on more than 600 points of comparison (Figure 16). This offers a huge step change to the number of points it is possible to compare using analogue methods **(Mortadi et al., 2020)**.

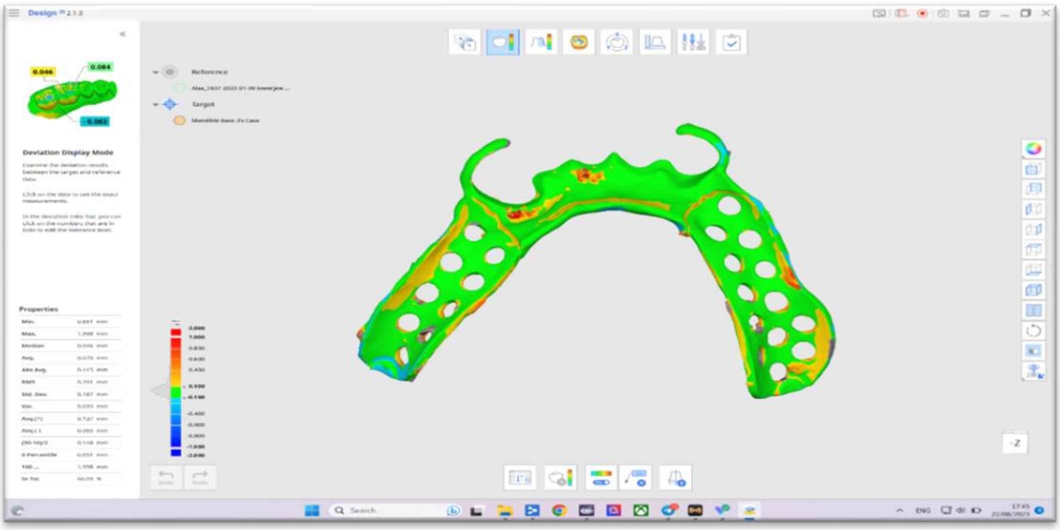

Figure 16: Color map of the aligned meshes.

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For the comparison between the different materials a deflection of -0.1 to 0.1 is set to be represented by green color **(Mortadi et al., 2020)**, any deflection more than or less than the previous value is represented by orange and blue respectively, then the application calculated the total percentage of fitness between fabricated and original designed data (Figure 17).

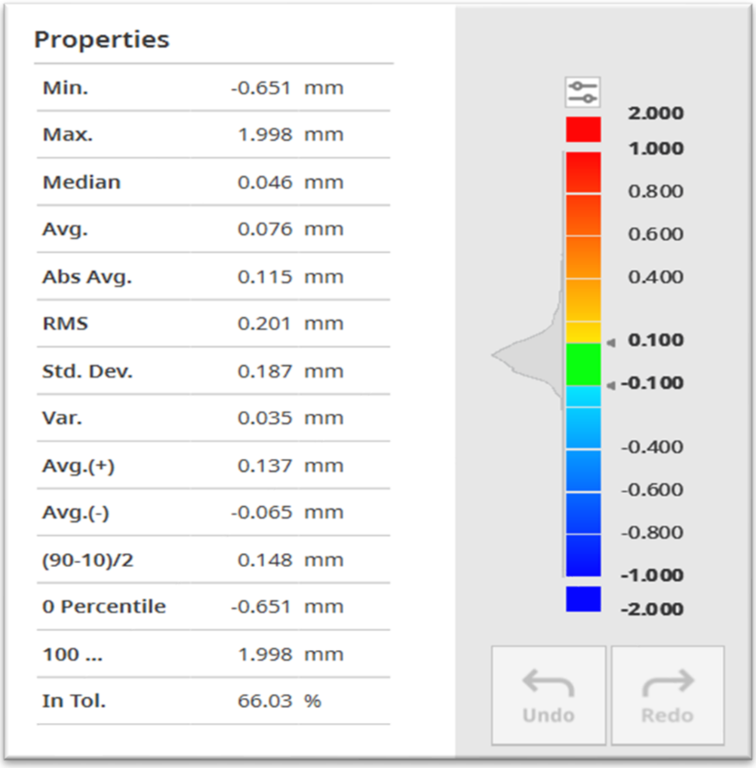

Figure 17: Coloured chart and percentage of fitness.

Each framework a total of 15 specimens was compared one by one individually to the original design data and percentage of fitness was calculated and noted.

RESULTS

Table 1: Descriptive statistics of adaptation.

Descriptives						
Material	**N**	**Mean**	**Std. Deviation**	**Range**	**Minimum**	**Maximum**
Casted Co-Cr	**35**	**0.7169**	**0.03008**	**0.10**	**0.66**	**0.76**
SLS Co-Cr	**35**	**0.8143**	**0.02062**	**0.08**	**0.78**	**0.86**
Acetal	**35**	**0.762**	**0.0585**	**0.19**	**0.66**	**0.85**

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From the descriptive statistics in (Table 1) we notice that the (SLS Co-Cr) has the higher mean (0.8143) which indicates a higher adaptation, and the (Acetal) has the second highest mean (0.7169) while the (Conventionally Casted Co-Cr) has the lowest mean (0.7169) which means lowest adaptation.

The stander deviation shows that the (SLS Co-Cr) has the lowest value (0.02062) which means that it is more homogeneous than the (Conventionally Casted Co-Cr and Acetal). The range is the difference between the maximum and the minimum value. The lowest value indicates a more homogeneous data. Table 2: ANOVA for adaption.

	SS	df	MS	F	Sig.
Between Groups	0.166	2	0.083	52.528	0.000
Within Groups	0.162	102	0.002		
Total	0.328	104			

The table shows that the F test is significant (sig.=0.000) which is less than (0.05) and that means there are significant differences between the materials.

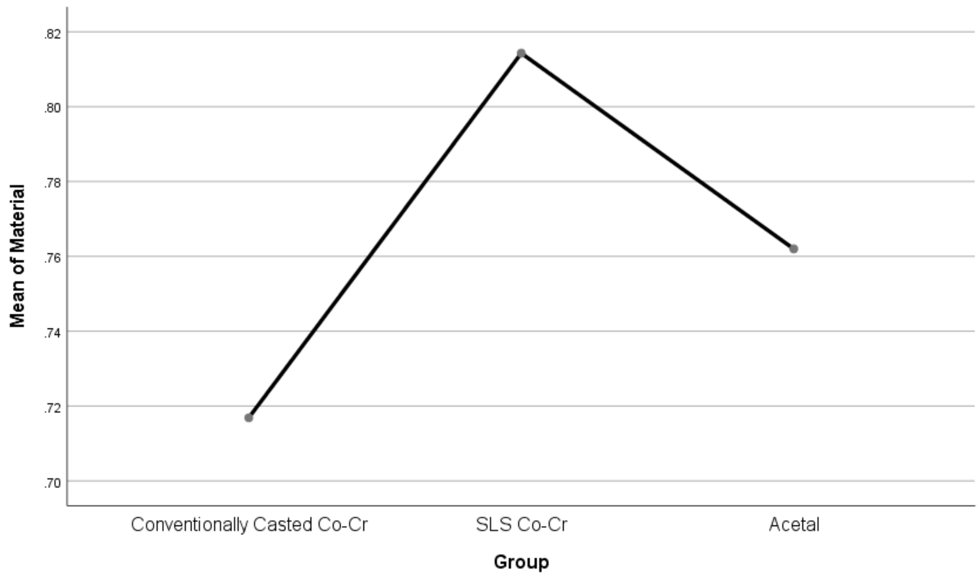

Figure 18: Plot chart for Roughness test.

Hypothesis Testing:

it is required to test the following null hypothesis.

H_o: M1=M2=M3 - The Null Hypothesis assuming there is no difference among the means of the three types of materials.

H_1: M1≠M2≠M3 - The alternative hypothesis is the opposite of $H_{o.}$

The result in table above shows that the significant level (p-vale) is = 0.14 Since it is larger than 0.05, then we accept the null hypothesis that is there are no difference between the group means. And no need for LSD test.

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DISCUSSION

Findings on this study suggest that SLS Co-Cr shows highest fitness compared to Acetal and Casted Co-Cr respectively when comparing the intaglio surface of these frames with their original digital design. The literature that is currently accessible on the subject of the fit of SLS frameworks is somewhat inconsistent **(Rues et al., 2023)**.

Similar to our findings **(Bajunaid et al., 2019)** examined the compatibility of RPD frameworks fabricated using SLS and those fabricated using lost-wax casting. There was a trend for SLS performing slightly better than its competitors.

In contrary to our findings, **(Arnold et al., 2018)** With a light microscope, they measured the distances that existed between the SLS-fabricated clasps and the abutment teeth in order to determine how well they fit together. They came to the conclusion that the SLS-fabricated samples were a significant amount less accurate than the cast samples. **(Ye et al., 2017)** Assessing the thickness of the silicone sheet allowed us to measure how well RPD frameworks fit in vivo. According to the findings of the experiment, casting performed significantly better SLS which only measured the local fit and not the overall fit (the distance between the retentive parts). **(Soltanzadeh et al., 2019)** examined the differences and similarities between RPD frameworks and a master model.

In spite of the fact that clinically acceptable adaptation was achieved by both traditional and 3D printing methods, the conventionally casted Co-Cr groups demonstrated superior overall fit and accuracy. Another study indicated that the SLS printed and cast Co-Cr frameworks adapted similarly to their environments **(Chen et al., 2019)**.

When comparing four different types of frameworks, another study indicated that SLS performed worse than casting in two of the configurations, but there were no significant differences discovered in the other two configurations. The authors did admit, however, that it is feasible that the outcomes of the SLS might be improved even further by optimizing parameters such as building orientation, support design, laser spot size, laser scan path, and velocity **(Rues et al., 2023)**.

Because they use tooth-colored clasps that blend in well and are kinder on soft tissues and supporting dentition, CAD/CAM fabricated acetal partials offer an attractive and comfortable alternative to cast-metal and SLS partials. This is accomplished via the use of tooth-colored clasps. As a result of utilizing a CAD/CAM method to mill a shade-matched acetal frame from a single block of resin, the finished product is an appliance that is more exact in its fit, more comfortable, and smaller. Milled acetal partials have demonstrated that they are a viable clinical option for practitioners looking for new ways to help partially edentulous patients who are not candidates for traditional dentures, traditional partials, or implants. This is because milled acetal partials are made of a material called acetal, which is a form of acetic acid **(Saeed et al., 2020)**.

An "in vitro" study that compared traditionally casted frameworks to those that were milled argued that the fitting of 15 RPDs that were designed using a lab scanner and a commercial dental CAD fabricated from PEEK frameworks were better fitting than those that were traditionally casted. The findings of this study are comparable to the findings of the "in vitro" study. **(Ye et al., 2018)**. In addition to this, when compared to the traditional method, the CAD/CAM technology resulted in much smaller gap distances in all of the clasp zones **(Ozawa et al., 2015)**.

It was also noted that the clasps manufactured by direct milling (CAD/CAM) had a much better fit when compared to the clasps manufactured using traditional methods. **(Torii et al., 2018)**.

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A study by **(Ismail, 2019)**, When compared with the time of denture insertion, the following conclusions were reached: the Acetal frameworks designed and fabricated by CAD/CAM Technology showed a significant increase in masticatory efficiency when used after the first follow up period, but showed no significant value when used after the second follow up period. When compared to the Cobalt-Chromium partial denture, he also claimed that the present results reported high patient satisfaction with the Acetal RPDS that was designed and built utilizing the CAD/CAM Technology. In addition, he indicated that traditional cobalt chromium RPDs may be replaced with acetal RPDs for the treatment of partially edentulous individuals because acetal RPDs are a novel and advantageous therapeutic alternative.

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