# "COMPARATIVE EVALUATION OF THE RETENTION OF SINGLE UNIT METAL COPINGS FABRICATED BY CONVENTIONAL CASTING, 3D MILLING AND DIRECT METAL LASER SINTERING TECHNIQUES -AN IN VITRO STUDY"

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**IN**

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**BRANCH I**

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# LIST OF ABBREVIATIONS USED

| Sr. No. | Abbreviations | Full form |
|---|---|---|
| 1 | ANOVA | Analysis of Variance |
| 2 | CAD/CAM | Computer aided designing and computer aided machining |
| 3 | Co-Cr alloy | Cobalt chromium alloy |
| 4 | °C | Degrees Celsius |
| 5 | 3D | 3-Dimensional object |
| 6 | DMLS | Direct Metal Laser Sintering |
| *7* | *et al.* | And others |
| 8 | FDP | Fixed Denture Prosthesis |
| 9 | Fig. | Figure |
| 10 | gm | Gram |
| 11 | i.e. | That is |
| 12 | min | Minutes |
| 13 | µm | Micrometre |
| 14 | No. | Number |
| 15 | N | Newton |
| 16 | Ni-Cr alloy | Nickel chromium alloy |
| 17 | PFM | Porcelain Fused to Metal |
| 18 | p | Probability value |
| 19 | SD | Standard Deviation |
| 20 | SLM | Selective Laser Melting |
| 21 | S. No. | Serial Number |
| 22 | sec | Second |
| 23 | sig | Significance |
| 24 | STL | Standard Tessellation Language |

# INTRODUCTION

***The true function of philosophy is to educate us in the principles of reasoning and not to put an end to further reasoning by the introduction of fixed conclusions.***

**- George HenryLewes**

The main goal of fixed prosthetic treatment is to provide patient precisely fitting prosthesis. Complete crown is frequently used for restoration in prosthetic dentistry for strengthening severely damaged and endodontically treated tooth structure. These crowns are made up of variety of materials like all metal crowns, porcelain fused to metal crowns or zirconia crowns; but regardless of its material and construction, success of these prosthesis depends upon its longevity. For the good prognosis of crowns amongst many important factors one is the retention. Retention is the ability of the restorations to resist dislodgement against forces opposite to the direction of placement.

Retention is affected by appropriate tooth preparation and proper adaptation of the prosthesis to the tooth. The adaptation of the prosthesis is influenced by many variables, resulting from the technical procedures employed during fabrication.[1]

Amongst all the materials for fabrication of prosthesis, cobalt chromium (Co-Cr) alloys are widely accepted and used for the fabrication of removable partial dentures, porcelain fused to metal crowns and metal frameworks.[2] These alloys comes under long term proven material as these are having good mechanical strength, high young's modulus, high corrosion resistance and high biocompatibility properties. This Co-Cr material comes into light because of its low cost and variety of methods of fabrication and above mention properties.

The traditional technique for fabricating the metal framework is the lost-wax technique, which was introduced by Taggart in 1907. However, to make prosthesis with this method clinician must need to take an impression with proper retraction and again time is required for technicians to make cast from that impression. This process is followed by number of laboratory steps like making wax pattern, investing and casting finishing and polishing it. These procedures requires experienced hands. Some of the disadvantages of this technique includes distortion of wax patterns, irregularities in the cast metal, complex procedures and time-consuming processing.[3,4,5] It is reported in literature that removing wax pattern from die with a shoulder margin causes a 35um average gap in margin area prior to investing of casting. Hence, casting technology is undergoing a radical shift and newer methods of fabrication of prosthetic restorations are being introduced. Two fabrication methods are introduced i.e. Computer Aided Designing- Computer Aided Manufacturing (CAD-CAM) milling or Direct Metal Laser Sintering (DMLS) technique. After the introduction of CAD-CAM systems, manufacturing of improved quality of restoration has become possible. [6]

Advantages of these newly introduced systems involves uniform quality of restoration with less time due to elimination of various process like waxing, carving and casting.

CAD-CAM technologies can be of subtractive type or additive type. Subtractive technique i.e. Computed Aided Milling (CAM) technology, milling involves taking a block of material and cutting away for fabricating the prostheses.[7]Additive technique i.e. Direct Metal Laser Sintering (DMLS), in contrast to milling involves adding material layer by layer to build the final product . Basically four different 3D printing technologies (additive process) are being used in dental industry: Stereo lithography apparatus, digital light projection, jet and direct metal laser sintering (DMS or DMLS or just MLS). Each system varies in the materials available, how these materials are solidified and how they can be used. The DMLS process is performed by two different methods, powder deposition and powder bed method, they differ in the way each layer of powder is applied. The powder bed method is more popular presently, as they offer faster speed. It involves several advantages over the conventional CAD-CAM milling technique and also saves the raw materials and requires fewer tools to reduce the cost.[8]Therefore there are large differences in the manufacturing process resulting in differences of microstructural characteristics of metal copings fabricated by different methods.[9,10]

Comparison of retention forces with various fabrication methods and materials in double crowns was done by Guven et al.[11] In their study, there were ten groups, each consisting of six samples, were evaluated. The highest initial and final retention force values were found in the laser sintered crown 4° group (32.89 N-32.65 N) and the lowest retention force values were found in the zirconia 6° group.

As Co-Cr alloys fabricated with different manufacturing techniques produces different microstructural characteristics and related mechanical properties[12], the aim of this study was to evaluate and compare retention of single unit Co-Cr copings fabricated by three different techniques conventional casting, 3D milling and direct metal laser sintering.

# AIMS AND OBJECTIVES

## AIM

To evaluate and compare the effect of three different casting procedures; conventional casting, 3D milling and Direct Metal Laser Sintering on retention of single unit metal copings.

## OBJECTIVES

### Objective 1

To evaluate retention of single unit metal copings fabricated by conventional casting, 3D milling and Direct Metal Laser Sintering on retention of single unit metal copings.

**Objective 2**

To compare retention of single unit metal copings fabricated by conventional casting, 3D milling and Direct Metal Laser Sintering on retention of single unit metal copings**.**

# REVIEW OF LITERATURE

***In science, read, by preferences, the newest works; in literature, the oldest. The classic literature is always modern.***

**-Edward G. Bulwer-Lytton**

**Potts RG, Shillingburg HT, Duncanson MG (1980)**[13] conducted a study to evaluate the effect of preparation designs on retention and resistance. Retention prevents removal of a cast restoration along the path of insertion or long axis of the tooth preparation. Resistance prevents dislodgement of the restoration by forces directed in an apical or oblique direction and prevents any movement of the restoration under occlusal forces. Test dies were made for each of five preparation designs: three-quarter partial veneer crown without axial grooves, three-quarter partial veneer crown with axial grooves, seven-eighths partial veneer crown without axial grooves, seven-eighths partial veneer crown with axial grooves and complete veneer crown without grooves. The preparations had axial walls 6 mm in length with a 6-degree taper. Axial grooves, when present, were approximately 5.5 mm long and 1 mm in diameter. Five preparation designs were tested for retention and resistance. Retention values for all partial veneer crowns were significantly lower than those for the complete veneer crown. They concluded that resistance values increased significantly with the addition of grooves and/or extension of axial surface coverage. Addition of grooves and/or extension of axial surface coverage produced small increases in retention values but marked increases in resistance values.

**Witwer DJ, Storey RJ, Von Fraunhofer JA (1986)[14]** in their study on effect of surface texture and grooving on the retention of cast crown, determined the effects of the tooth surface and grooving on the retention of cast prosthesis, with and without circumferential grooving, when luted with zinc phosphate and zinc poly-carboxylate cements. After luting of casting, it was held under digital pressure for 10 minutes. Samples were tested for tensile strength. The findings of study was, optimum cast crown retention was obtained for zinc phosphate cement with grooved crowns and smooth surface finish.

**Gabriel R. Zuckerman (1988)[1]** in his article ‘Factors that influence the mechanical retention of the complete crown’had mentioned that retention of the complete crown was influenced by a complex relationship developed between the crown preparation and the adaptation of the restoration. If mechanical retention is to be established, the axial walls of the tooth preparation and the restoration must contact before the crown seats completely. The force required to overcome the frictional resistance of the contacting surfaces of the tooth and restoration produces additional retention. Frictional retention is a product of the surface configuration of the parts and the size of the area in contact.

**Juntavee N, Millstein PL (1992)**[15] in their experimental study, effect of surface roughness and cement space on crown retention studied that, the effects of varying luting agent space and internal surface roughness with different types of cores and cements.180 amalgam and 180 composite cores were cemented into standardized stainless steel retainers. Cores and retainers were divided into 12 groups according to core type, core diameter, and retainer roughness. Each group was further subdivided according to cement, zinc phosphate (ZOP), resin and glass ionomer cement (GIC). Subgroups were divided into thermal-cycled and no thermal-cycled groups. Thermal cycling was done at $5^0$ to $55^0$ C, and repeated 500 times. Cores were separated from their retainers in an Instron testing machine at a crosshead speed of 0.02 cm/minute. Results of study were, zinc phosphate and resin luting agents were more retentive than glass ionomer luting agents for all core materials. Amalgam cores were most retentive. Resin and ZOP cements were equally retentive with amalgam cores. Retainers with rough internal surfaces were most retentive.

**Wataha JC (2002)**[2] in his article had given extensive historical look at prosthodontic alloys and the nomenclature for alloys and it was followed by a discussion of the most important physical properties of alloys for clinical practice. There he mentioned Co-Cr alloys contain at least 60 wt.% cobalt and are always in multiple-phase. The chromium content was generally at least 30 wt.% and carbon is often added to strengthen the alloy. Co-Cr alloys are now great in use as alternative to Ni-Cr alloys because of their allergic reactions. Also these alloys can be used for wide variety of restorations like full cast, metal-ceramic or removable partial denture restorations, their most common use is for removable partial denture frameworks.

**Ucar Y, Akova T, Akyil Musa, Brantkey William (2009)[3]** evaluated and compared the internal fit of laser-sintered Co-Cr alloy crowns with base metal restorations prepared from another Co-Cr alloy and a Ni-Cr alloy using conventional casting techniques. Twelve specimens were prepared from each alloy. Fit of crowns was evaluated using 2 different techniques: (1) weighing the light-body addition silicone that simulated a cement material (2) measuring the internal gap width on a die for longitudinally sectioned specimens. The internal gap width was measured with the aid of computer software, using a 1-mm scale for each image. Result of this study was that there is no significant difference (P = 0.42) among the 3 alloy groups evaluated for the internal gap width of sectioned crown specimens.Clinical Implication :- Laser sintering of Co-Cr alloy crowns seems to be a promising Technique.

**Chandrashekhar Sajjan, Kamath Giridhar, K. Suhas Rao (2010)[16]** conducted a study to evaluate the retention of complete crowns which was luted with two different cements and were prepared with five different tapers. Eighty extracted human maxillary premolar teeth with sound surfaces were selected using dial vernier calliper. Co–Cr alloy metal copings were luted with glass ionomer and zinc phosphate cement. Retention was measured (MPa) by pull out test on a universal testing machine. Data were extracted and statistically analysed. The conclusion of their study were the use of glass ionomer cement did not result in increased retentive strength over zinc phosphate cement in spite of the chemical bonding of glass ionomer to tooth structure. Increasing the taper of the preparation from 0°, 3°to 6° did not affect the retention of crowns within different cement groups. Increasing the taper to 9° or 12° decreased the retention of crowns significantly.

**Anders ortorp, Johnson David, Mohsen Alaa, Per Vult von Steyern (2011)[17]** in their in vitro study evaluated and concluded marginal and internal fit of three-unit FPDs of Co-Cr fabricated by four different techniques. A total 32 FPDs were fabricated i.e. 8 in each group. Four techniques were conventional lost-wax method (LW), milled wax with lost-wax method (MW), milled Co–Cr (MC) and direct laser metal sintering (DLMS). The FDPs were cemented on their cast and standardised-sectioned. The cement film thickness of the marginal and internal gaps were measured in a stereomicroscope. The best results were given by DLMS group followed by milled wax lost wax method, and milled Co-Cr group. The significant difference was present between milled Co-Cr and DLMS. The biggest misfit was present in all the four types of groups at the occlusal level and best fit of crowns were at axial walls and in the deepest part of chamfer preparation..

**Ya-qing Li, Wang H, Wang YJ, Chen JH (2012)[18]** studied and evaluated the relationship between the surface roughness of prepared teeth and the internal adaptation and retention of complete coverage restorations after preparation with diamond rotary cutting instruments of different grit sizes. Teeth prepared with the finer grit rotary instruments have smoother tooth surfaces and crown restorations with better internal adaptation. The grit size of the diamond rotary cutting instruments does not affect the removal force between the complete coverage crown and the prepared tooth. Clinical Implication:- Preparing teeth with diamond rotary cutting instruments, following a sequence of grit sizes from coarse, to medium, to fine (53 to 63 μm) is recommended.

**Aysegul G. Gurbulak, Kilic K, Eroglu Z, Gercekcioglu E, Kesim B (2013)**[19] measured the in vitro retention force of double conical crowns fabricated by combination methods like galvano forming and conventional casting in their study they prepared right maxillary second premolar to make metal die made up of Ni-Cr which was made by conventional casting. Retention forces were calculated using a universal testing device and concluded that, the use of different combinations of galvano forming and casting techniques in the fabrication of conical crowns significantly affected retention force.

**Pietruski Jan, Sajewicz E, Sudnik J, Pietruska MD (2013)**[20] assessed retention forces in their study in conical crowns in different material combinations for that they prepared two sets of samples first group was Primary crown – gold casting alloy, secondary crown – gold casting alloy Primary crown – gold casting alloy, secondary crown – made of pure gold by electroforming in each group there were three sub group of cone angles $2^0$, $4^0$ and $6^0$ degree making 72 samples in total. These crowns were cemented with Nimetic-cem cement. Separating cycles were carried out with force of 75 N. They concluded that the higher the angle value, the lower the average of the retentive force, dispersion of retention values is similar in material combination casting alloy/electroforming as compared to casting alloy/casting alloy, the conical crown made by the casting method from the precious alloy is better option of both tested in view of its high stability but only with cone angle 6°. When cone angle is 2° or 4°, stability of retention force with the passage of time is higher in combinations with electroformed outer crowns as compared to casted ones.

**Venkatesh vijay, Vidyashree Nandini (2013)**[8] reviewed direct metal laser sintering as it is newer technology, they discussed process of laser sintering for making metal crowns and fixed partial dentures with understanding of their pros and cons in their article. They also enlisted four additive or 3D printing technology that are used in dental industry those are stereo lithography apparatus, digital light projection, jet and direct metal laser sintering (DLMS or DMLS or just MLS).Each system varies in materials how these materials are solidifies and how these materials used .They mentioned that the technique is easy to use, produces accurate restorations, simplified post processing procedures, free of porosity unlike conventional castings and improved electromechanical characteristics.

**Takaichi A, Suyalatu, Nakamoto T, Joko N, Nomura N, Tsutsumi Y (2013)**[9] evaluated microstructure and mechanical properties of Co-Cr alloys fabricated by direct laser melting. They performed scanning electron microscopy with energy-dispersed X-ray spectroscopy (SEM-EDS), X-ray diffractometry (XRD), and electron back-scattered diffraction pattern analysis and the mechanical properties were evaluated using a tensile test. Cylindrical and dumbbell specimens were fabricated for testing microstructural and mechanical properties respectively**.** A unique microstructure was formed in the build, and fine cellular dendrites were formed in the elongated grains parallel to the building direction. Compositional analysis by EDS revealed that Cr and Mo were enriched at the cellular boundary. Mechanical anisotropy was confirmed in the build due to the unique microstructure, the yield strength, ultimate tensile strength and elongation were higher than those of the cast alloy and satisfied the type 5 criteria in ISO22764.

**Ki-back Kim, Woong-chul Kim, Hae-young Kim, Ji-Hwan Kim (2013)**[21]evaluated and compared marginal fit of three units FPD fabricated using DMLS system and conventional lost wax technique. Total 20 FPD were fabricated.

The study resulted into the mean values of at three different points were significantly larger in DMLS group. So, they concluded the marginal fit of DMLS system appeared significantly lower that of the conventional casting and this slightly larger than acceptable range. Clinical application of this study was that further improvement of DMLS technique should be requires.

**Eswaran B, Azhagarasan NS, Miglani S, Illango T, Krishna GP, Gajapathi B (2013)**[22] conducted a study and evaluated marginal and internal gap of Co–Cr copings fabricated from conventional wax pattern, 3D printed resin pattern and DMLS technique in this study they standardized CNC machined stainless steel model with taper of 6 degree and chamfer finish line. The results obtained for both marginal and internal gap were tabulated and statistically analysed. The copings obtained from DMLS technique showed statistically significant minimum value followed by cast copings obtained using 3D printed resin pattern. The cast copings obtained from inlay casting wax pattern showed maximum vertical marginal gap. The results of the internal gap present between the coping and the master model showed statistically significant difference between cast copings obtained using inlay casting wax and cast copings obtained using 3D printed resin pattern.

**Tamac E ,Toksavul S, Toman M (2014)**[5] studied the clinical marginal and internal adaptation of metal ceramic crowns fabricated by three different techniques. They took total sixty metal ceramic crowns in forty two patients. These sixty crowns were fabricated by three different techniques CAD-CAM milling and DMLS direct metal laser sintering, traditional casting. Patients were randomly chosen for each group. After fabrication of crowns before luting two silicon replicas of internal surface of crown was made first with light body and second with medium body silicone. These replicas were sectioned buccolingually and mesiodistally and measurements were made with reflected light binocular stereomicroscopy at 20* magnification three different regions: axial wall, axio-occlusal angle and occlusal surface. Results of this study was no statistically significant differences were found among the 3 groups for measurements at the marginal gap and the axial wall region. Statistically significant differences were found among the 3 groups at the axio-occlusal and occlusal surface. The mean values of group DMLS were significantly higher than those of groups CAD-CAM milled and traditional casting at the axio-occlusal and occlusal surface region. Clinical implication of study:- Traditional casting, computer-aided design and computer-aided manufacturing technology and laser sintering technology can be used to fabricate metal framework for metal ceramic crowns in daily clinical application.

**Al Jabbari, Koutsoukis T, Barmpagadaki X , Zinelisd S (2014)[10]** explained detail characteristics of Co–Cr alloys in their study metallurgical and interfacial characterization of PFM Co–Cr dental alloys fabricated via casting, milling or selective laser melting in X-ray radiography it revealed the presence of porosity only in the CST group. Different microstructures were identified among the groups. The hardness values were 320 ± 12 HV, 297 ± 5 HV and 371 ± 10 HV and statistically significant differences were evident among the groups. Co–Cr dental alloys fabricated via casting, milling or SLM techniques show significant differences in microstructure and hardness.

**Danilo Gonzaga B. de França**, **Morais MH, Das Neves FD, Barbosa GA (2014)[23]** compared the fit accuracy of CAD/CAM-fabricated zirconia and cobalt-chromium frameworks and conventionally fabricated cobalt-chromium frameworks.

CAD/CAM and conventional casting techniques were evaluated in this study. Sixteen frameworks were fabricated with zirconia and Co-Cr alloy as follows (n=4): CAD/CAM-fabricated zirconia frameworks (ZirCAD group), CAD/CAM-fabricated Co-Cr frameworks (CoCr CAD group), conventionally fabricated Co-Cr alloy frameworks with pre-machined Co-Cr abutments with plastic sleeves and Co-Cr bases (CoCrUCci group), and conventionally fabricated Co-Cr frameworks with castable abutments (CoCrUCcl group). The definitive fit and passive fit values were compared among groups. It can be concluded that CAD/CAM fabricated Co-Cr frameworks may exhibit decreased vertical misfit compared with CAD/CAM-fabricated zirconia frameworks. The passivity of the frameworks was not influenced by the manufacturing technique or the material used. CAD/CAM can be used to achieve higher fit accuracy in implant-supported FDPs.

**Barucca G , Santecchia E, Majni G, Girardin E, Bassoli E, Denti L et al (2015)**[24] studied microstructural characterization and hardness of biomedical Co-Cr-Mo alloys produced by direct metal laser sintering .For checking these properties, they did X-ray diffraction (XRD), electron microscopy (SEM and TEM) and energy dispersive microanalysis (EDX). The result of study was homogeneous microstructure comprised of an intricate network of thin ε (hcp)-lamellae distributed inside a γ (fcc) phase was observed. The ε-lamellae grown on the {111}γ planes limit the dislocation slip inside the γ (fcc) phase, causing the measured hardness increase. The results suggests possible innovative applications of the DMLS technique for production of mechanical parts in the medical and dental fields.

**Jong-Kyoung, Lee WS, Kim HY, Kim CW, Kim HJ (2015)**[25] studied the accuracy of metal copings fabricated by different technique CAD-CAM and DMLS, for their study selected a maxillary right canine from a typodont resin model and tooth was prepared to make a stone replica. Seven mesiodistal and labiolingual positions were then measured, and each of these were divided into the categories; marginal gap (MG), cervical gap (CG), axial wall at internal gap (AG), and incisal edge at internal gap (IG). Evaluation was performed by a silicone replica technique. A digital microscope was used for measurement of silicone layer. The images were measured by the internal stored imaging data software which was equipped to the digital microscope machine and the result of study were the overall mean internal gap was lowest for the coping fabricated by the casting method at (31.3) for CAD–CAM (88.9) for DMLS (103.3) demonstrating significant difference in values for internal gap.

**Wagner C, Stock V, Merk S, Schmidlin PR, Roos M , Eichbeger (2015)**[4] studied the retention forces of different fabrication methods of Co-Cr crowns: Pre-sintered and Milled, Cast and Electroforming Secondary Crowns with Different Taper Angles. Cobalt-chromium primary crowns with 0°, 1° and 2° taper angles were fabricated. Secondary crowns were made either by i.) a milling and sintering, ii.) casting or iii.) electro-forming process. Pull-off tests were performed and data were analysed concluded that, double crowns, produced with new fabrication methods for Co- Cr materials, *e.g*. milling under dry conditions and later sintering, showed reliable values considering retention forces in comparison to conventional cast secondary crowns and electroforming secondary crowns. The retention force values of the electroformed secondary crowns confirmed their clinical use for conical crowns as well as telescoping crowns.

**Theodoros Koutsoukis, Zineli S , Eliades G , Khalid WA, Rifai MA (2015)**[26] reviewed the effect of selective laser melting (SLM) procedure on the properties of dental structures made of Co-Cr alloys and to evaluate its quality and compare it to those produced by conventional casting and milling fabrication techniques. Given conclusion that SLM provides different microstructure from casting and milling with minimal internal porosity and internal fitting, marginal adaptation, and comparable bond strength to porcelain. Mechanical and electrochemical properties of SLM structures are enhanced compared to cast. Clinical significance*:* The current SLM devices provide metallic restorations made of Co-Cr alloys for removable and fixed partial dentures without compromising the alloy or restoration properties at a fraction of the time and cost, showing great potential to replace the aforementioned fabrication techniques in the long term; however, further clinical studies are essential to increase the acceptance of this technology by the worldwide dental community.

**Prabhu R, Prabhu G, Bhaskaran E, Arumugam EM (2016)**[27] in prospective study of clinical acceptability of metal-ceramic fixed partial dental prosthesis fabricated with direct metal laser sintering technique, using modified Ryge criteria for the period of 60 months to assess the clinical longevity of these restorations in this author had selected 45 patients with age group 40 with missing maxillary or mandibular second premolar or first molar . They observed survival rate was 95.5% with very few complications.

**Kim HR , Jang SH , Kim YK, Son JS, Min BK, Kim KH et al (2016)**[12] in their extensive research on microstructure and mechanical properties of Co-Cr alloys fabricated with three different CAD-CAM based techniques, they prepared four dumbbell to check mechanical properties and disc to check microstructural properties. The microstructures of the specimens were evaluated via X-ray diffractometry, optical and scanning electron microscopy with energy-dispersive X-ray spectroscopy, and electron backscattered diffraction pattern analysis. The mechanical properties were evaluated using a tensile test. They evaluated that microstructures and mechanical properties of Co-Cr alloys were greatly dependent on the manufacturing technique as well as the chemical composition .selective laser melting, milling and post sintering may be considered promising alternative to conventional casting.

**Vojdani M, Torabi K, Atashkar B, Heidari H, Torabi AM (2016)**[6] in their study of comparison of the marginal and internal fit of cobalt chromium copings fabricated by two different CAD/CAM systems they prepared one master model of size 7 mm and 5 mm diameter. On this die they fabricated 10 copings from hard pre-sintered Co-Cr blocks according to CAD/CAM technique and ten copings from soft non pre-sintered Co-Cr blocks according to CAD/Ceramill sintron technique. In their study both internal as well as marginal in accuracies was observed at ten different points by replica method. These replicas were made of two light bodied and heavy bodied silicone. The inaccuracies were examined under digital microscope. They concluded that the marginal and internal discrepancy of the CAD/ Milling system was lower compared to CAD/ Ceramill Sintron. CAD/ Ceramill Sintron, as a new technology in the CAD/ CAM system, is easy to use due to the wax like texture of blocks and minimal tool wears. Marginal discrepancy, occlusal discrepancy and axial discrepancy of both systems are clinically acceptable.

**Rathika Rai, Arun Kumar S, R Prabhu, Govindandan R, Tanveer FM (2017)**[28] evaluated marginal and internal gaps of metal ceramic crowns obtained from conventional impressions and casting techniques with those obtained from digital techniques. For their research a custom made master model of stainless steel was made by using a computer numerical control milling machine resembling maxillary first molar teeth and concluded that internal fit for directly scanned and digitally printed crowns is good.

**Barazanchi, Li KC, Al-Amleh B, Lyons K, Waddell JN (2017)**[29] reviewed additive technology how it is evolving as substitution to subtractive manufacturing and also given update on current materials used in additive manufacturing in dentistry such as polymers, ceramics and metals like Co-Cr metal. Various properties of Co-Cr metals manufactured by additive technology. advantages of additive technology in them they mentioned the accuracy of this technology is great as compared to subtractive technology flexibility of machines to print multiple materials at the same time without having to replace structure halfway through build also low percentage of wasted raw material.

**Guven M, Tuna M, Bozdag E, Ozturk G, Bayraktar G (2017)**[11] evaluated Comparison of retention forces with various fabrication methods and materials in double crowns in his study ten groups each containing six sample were evaluated. They made design of dies such that it resemble tooth or implant abutment in CNC machine. The dimension of dies was 6 mm in height and 4.5 mm in base diameter. Groups were as follows casting gold alloy primary crown - casting gold alloy secondary crown (AA), laser sintering primary crown - laser sintering secondary crown (LL), casting Cr alloy primary crown - casting Cr alloy secondary crown, (CC) zirconia primary crown - electroformed secondary crown (ZA), and CAD/CAM titanium alloy primary crown - CAD/CAM titanium alloy secondary crown (TT) groups were evaluated at cone angles of 4° and 6° The samples were subjected to 5,000 insertion-separation cycles in artificial saliva, and the retention forces were measured every 500 cycles. The wear levels were analysed via SEM. In all samples, the retention forces increased when the conus angle decreased. The highest initial and final retention force values were found in the LL-4° group (32.89 N-32.65 N), and the lowest retention force values were found in the ZA6° group (5.41 N-6.27 N). The ZA groups' samples showed the least change in the retention force, and no wear was observed. In the other groups, wear was observed mostly in the primary crowns.

**Tsanka Dikova, Vasilev T, Dzhendov D, Ivanova E (2017)[30]** investigated the fitting accuracy of Co-Cr dental bridges, manufactured by three technologies, with the newly developed method using CAD software and concluded that, the fitting accuracy of the bridges, cast with 3D printed patterns, is the highest, followed by the SLM and conventionally cast bridges.

**Lucia D (2017)[31]** evaluated and compared the investment casting and DMLS technique focusing on dental applications for prosthesis production. It was found that Co-Cr prosthesis fabricated by DMLS has excellent strength and without any defects. It was concluded that DMLS is very reliable and repeatable technique. The SEM analysis showed that the particles were strongly joined together; not only with each layer but also between different layers and the isotropy in build direction is rarity. From mechanical point of view, it was concluded that DMLS technique has higher performance with respect to the investment casting.

**Sujana Ullattuthodi , Cherian KP, Anandkumar R, Nambiar MS (2017)**[32] in their vitro study of marginal and internal fit of cobalt-chromium copings fabricated using the conventional and the direct metal laser sintering techniques stated that, there was a significant difference of the internal fit in the copings prepared by two methods and the mean internal fit of copings showed that the conventional copings had better fit.

**Moris I**, **Monteiro S, Martins R, Ribeira R, Gomes G (2017)**[33] evaluated the influence of different manufacturing methods of single implant-supported metallic crowns on the internal and external marginal fit through computed micro tomography. The groups were according to the manufacturing method: GC, conventional casting; GI, induction casting; GP, plasma casting; and GCAD, CAD/CAM machining. The marginal fit was evaluated at sagittal and coronal planes using 3 slices for each sample. For internal fit, both vertical and horizontal internal fit were measured. The evaluation of internal fit at both planes (sagittal and coronal) was done in the same slices selected for external marginal fit. In each slice, a total of 12 measures (6 vertical measures and 6 horizontal measures) were done, resulting in 108 measures per sample assuming analysis in 3 slices per plane and concluded that the manufacturing method of the crowns influenced the accuracy of marginal fit between the prosthesis and implant. The best results were found for the crowns fabricated through CAD/CAM machining.

**Yakout M, Elbestawi M, Veldhuis S (2018)**[34] reviewed metal additive manufacturing technologies. Additive manufacturing is a layer based manufacturing process aimed at producing parts directly from a 3D model. This article provides a review of key technologies for metal additive manufacturing. They focused on the effect of important process parameters on the microstructure and mechanical properties of the resulting part. Several materials were also considered in this article.

**Liu Y, Ye H, Wang Y, Zhao Y, Sun Y, Zhou Y (2018)**[35] in their study a full-crown abutment made of zirconia was digitized using an intraoral scanner, and the design of the crown was finished on the digital model. Resin patterns were fabricated using a fused deposition modelling (FDM) 3D printer (LT group), a digital light projection (DLP) 3D printer (EV group) or a five-axis milling machine (ZT group). All patterns were cast in cobalt-chromium alloy crowns. Crowns made from traditional handmade wax patterns (HM group) were used as controls. Each group contained 10 samples. The internal gaps of the patterns were analysed using a 3D replica method and optical digitization. The results were compared using Kruskal-Wallis analysis of variance (ANOVA), a one-sample *t* test, and signed rank test casting crowns using casting patterns made from all three CAD/CAM systems could not produce the prescribed parameters, but the crowns showed clinically acceptable internal adaptations.

**Zuskova L, Mortadi NAA, Williams RJ, Alzoubi KH, Khabour OF (2019)**[7] studied overall fit of CAD restoration fabricated by two different methods milling and DMLS technique. For that they made full veneer crown preparation of maxillary right first molar and poured in die stone. The die was digitalized by an Identica Blue Light Scanner, and the coping substructure was designed using CAD software. after that ten copings were milled and ten copings were laser sintered based on scanned data**.** All twenty copings were digitized by the Identica scanner, and the data were superimposed with the original pre-manufacturing data file of the prepared full crown. Using the Geometric Modelling Library (GML) package, the fit discrepancies were displayed as colour maps showing discrepancies in three dimensions. So, after using the GML result of study was, the milled group displayed a mean of fit discrepancies of 42.20 $\mu$m (SD 3.04 $\mu$m), while the laser-sintered group showed a mean of 42.24 $\mu$m fit discrepancies (SD 2.94 $\mu$m), a small difference of 0.04 $\mu$m between the two groups was detected. So both manufacturing systems can be used in dental practice as a small and insignificant discrepancy of fit between the two manufacturing methods was detected.

**Schweiger J, Guth J, Erdelt K, Edelhoff D, Schubert O (2019)**[36] studied internal porosities, retentive force, and survival of cobalt–chromium alloy clasps fabricated by selective laser-sintering. For that 32 embrasure clasps were digitally designed on tooth number 35 36 out of them 16 were made by DMLS technique and for another 16 clasps firstly clasps were additively manufactured in wax and then conventionally casted. Internal porosities were examined using micro-focus X-ray (micro-CT) and retentive force values were checked on universal testing machine .So, results were. Laser-sintered (DMLS) clasps displayed a smaller volume and a more homogeneous distribution of internal porosities compared to the cast specimens. The retentive force values of the DMLS clasps showed superior consistency over time.

**Ghodsi S , Fayyazi A, Ghiasi M, Rohanian A, Alikhasi M (2020)**[37] checked retention and seating of implant supported hard and soft metal copings in their study twenty four solid implant abutment were taken and scanned by scanner. Then they were divided in two groups 12 each received metal copings fabricated by either soft or hard Co-Cr alloy. Soft Co-Cr alloy were dry milled first which is relatively newer technology and then sintered this is done under an argon protective gas atmosphere at approximately 1300˚C. Hard Co-Cr blocks were milled in a milling machine. These twenty four copings were air abraded polished and finished. After these surface treatment these copings were cemented by Zinc phosphate cement and then subjected to universal testing machine for checking tensile strength of copings. The conclusion of this study was although hard metal copings required more adjustments, retention of soft and hard Co-Cr copings was not significantly different.

**Subrahmanyam A.P, Siva Prasad K, P.Srinivasa Rao (2020)**[38] given critical review on characterization of DMLS materials in there review they studied 150 papers published for various DMLS materials, for Co-Cr alloys they mentioned that as DMLS fabricated restorations are superior in mechanical properties and biocompatibility DMLS is appropriate method for fabrication of implants and dental restorations

# MATERIALS AND METHOD

***Subjectivism is not an absolute principle; it is a necessary but not sufficient condition for sound methodology***

**- Murray Rothbard**

This study was carried out in the department of prosthodontics. All attempts were made to standardize the procedures throughout the study to minimize the effects of variable factors on the observations and the final results.

**The materials and method are divided under following headings: -**

## A. Materials and Armamentarium

1. Materials/Instruments used for mounting and preparation of typodont ivorine right mandibular first molar tooth

2. Materials/Instruments used for preparation of metal dies and crown fabrication.

3. Materials/Instruments used to lute samples.

4.Materials/Equipments used for testing samples

## B. Methodology

1. Mounting and preparation of typoodont ivorine right mandibular first molar

2. Preparation of metal dies

3. Copings fabrication by Conventional technique

4. Copings fabrication by CAD-CAM technique

5. Copings fabrication by DMLS technique

6. Cementation procedure

7. Retention checking procedure.

# A. MATERIALS

**1. Materials / Instruments used for mounting and preparation of typodont ivorine tooth: (Colour plate -1 fig.1,2,3,4,5)**

| Sr. No. | Type of Material | Manufacturer | Batch Number |
|---|---|---|---|
| 1. | Typodont ivorine mandibular first molar | -- | -- |
| 2. | Cold-cure polymethyl methacrylate monomer | Dental products of India Ltd ( DPI) | 41815 |
| 3. | Cold-cure polymethyl methacrylate polymer | Dental products of India Ltd( DPI) | 41814 |
| 4. | Dental surveyor (William's) | MARATHON-103,<br>Saeyang company,<br>Korea | ----- |
| 5 | Air-rotor hand-piece | Kavo Kerr, India | ---- |
| 6 | i) Dumbbell shaped diamond point (EX-11)<br>ii)Tapered round ended diamond point (TR-26)<br>iii) Extra Fine Tapered round ended diamond point (TR-26EF) | Mani Inc. Japan | 18A135600<br>D16E133500<br>D181087400 |

**2 Materials / Instruments/equipments used for preparation of metal dies and copings fabrication (Colour Plate-1and Colour Plate- 2 figs 6-20)**

| Sr No. | Type of Material/Instrument | Manufacturer | Batch Number |
|---|---|---|---|
| 1. | Polyvinyl siloxane putty and light body consistency impression material | Kerr, Germany | 34070 792638 |
| 2. | Blue Inlay wax | Dheeraj industries | 492098 |
| 3. | Vacuum mixer (Speedymix) | Sirio, Italy | 6603 |
| 4. | Investment material (Wirovest) | Bego Corp., Germany | 0209584 51090 |
| 5. | Burnout Furnace | Unident dental products Ltd. | --- |
| 6. | Induction casting machine (LCcast) | Confident, India | |
| 7. | Metal polishing kit | Shofu dental corporation, Japan | |
| 8. | Scanner | Sirona inEos X5 | |
| 9. | CAD/CAM | ARUM 5X-200 | |
| 10. | DMLS MACHINE | EOS M 100 | |
| 11. | Cobalt-Chromium alloy pellets for conventional casting (Wironit) | Bego, Germany | 50030/12635 |
| 12. | Blocks of Co-Cr alloy for CAD – CAM milling | ARUM Premium Co-Cr | 138110 |
| 13. | EOS Cobalt-chromium alloy | EOSINT M | 291201 |

**3 Material to lute metal copings used are as follows- (Colour Plate- 2 fig.21)**

| Sr No. | Type of Material | Manufacturer | Batch Number |
|---|---|---|---|
| 1. | Zinc phosphate cement | Harvard | 7002300 |
| 2. | Glass slab | -- | -- |
| 3. | Metal spatula | -- | -- |

**4 materials/Instruments for testing of samples (Colour Plate -2 fig.22)**

| Sr. No. | instruments | Manufacturer |
|---|---|---|
| 1. | Universal Testing Machine | INSTRON |

## B. Methodology

For preparation of tooth, tooth was first embedded in acrylic block and following six step were carried out.

**1 Mounting and preparation of typodont ivorine right mandibular first molar: (Colour plate-3)**

Acrylic block was made using plastic box. The root of ivorine tooth were grooved to resist dislodgement from the auto-polymerising acrylic resin block. The auto-polymerising acrylic resin was packed in the dough stage. The ivorine tooth was centered in the block maintaining cementoenamel junction of the tooth 2 mm above the resin surface embedding the root completely.

## Tooth preparation

For standardization protocol, during tooth preparation, an air rotor hand piece was mounted on the dental surveyor using test tube holder. In this assembly the diamond point was parallel to the long axis of the sample. Constant taper of 6° for the preparations was obtained as a negative image of a long round ended tapered diamond instrument. This was to ensure uniform taper, height and mesio-distal diameter of the prepared tooth. The tooth preparations were done under copious water irrigation as follows: **Occlusal reduction** :- Using tapered diamond point guiding grooves were placed for occlusal reduction. Following the anatomic configuration, occlusal reduction was done with round ended diamond bur, 1.5 mm on the functional cusp and 1 mm on the non-functional cusp. **Axial reduction** :- After occlusal reduction, 3 alignment grooves were placed in each buccal and lingual wall with a tapered round end diamond point. One was placed in the centre of the wall and one on each mesial and distal transitional line angle. **Finish line** :- 1 mm reduction was achieved using tapered round end diamond point to create a uniform chamfer finish line. **Placement of functional bevel and finishing:**- A bevel of 45° was given at the axio-occlusal line angle by the tapered round diamond point on buccal cusp. Care was taken to keep the width of the bevel relatively constant at 0.5 mm**. Finishing the preparation:-** The preparation was finished using extra fine grit tapered round ended diamond point.

In this way, the completion of uniform preparation was done.

## 2. Metal dies preparation: (Colour plate -3)

For preparation of metal dies prepared ivorine tooth was removed from mounted acrylic block. Now, after removing metal dies were made by duplicating the prepared ivorine tooth in inlay wax; for which two piece mould was made using polyvinyl siloxane putty and light body impression material. After making two piece mould inlay wax was flowed in two piece mould for 30 times to make 30 wax pattern for making 30 metal dies(fig.25,26). The wax patterns were sprued using 2 mm sprue inlay wax.(fig.27) After this, powder and liquid (water) of high strength phosphate bonded investment material was mixed in vacuum mixer and the patterns were invested.(fig.28). Wax burnout was done at 800°C in burnout furnace, followed by casting using cobalt-chromium alloy, in induction casting machine. External surface of all castings were evaluated under magnification for any casting defects.(fig.29) Metal dies were finished and polished using metal polishing kit. These were sandblasted using sandblasting unit with the 110 μ aluminium oxide particles and after this all the samples were submerged into acrylic block for ease of scanning and fabrication. Total 30 duplicate Co-Cr alloy (metal) dies were fabricated by using casting method.(fig.30)

These dies were randomly divided into 3 Groups (10 samples each):

1. For 1$^{st}$ group, copings fabricated by conventional casting procedure.
2. For 2$^{nd}$ group, copings milled by 3D milling (CAD-CAM) technique.
3. For 3$^{rd}$ group, copings milled by DMLS technique.

These copings were cemented with zinc phosphate cement on their respective metal dies and stored in distilled water at room temperature.

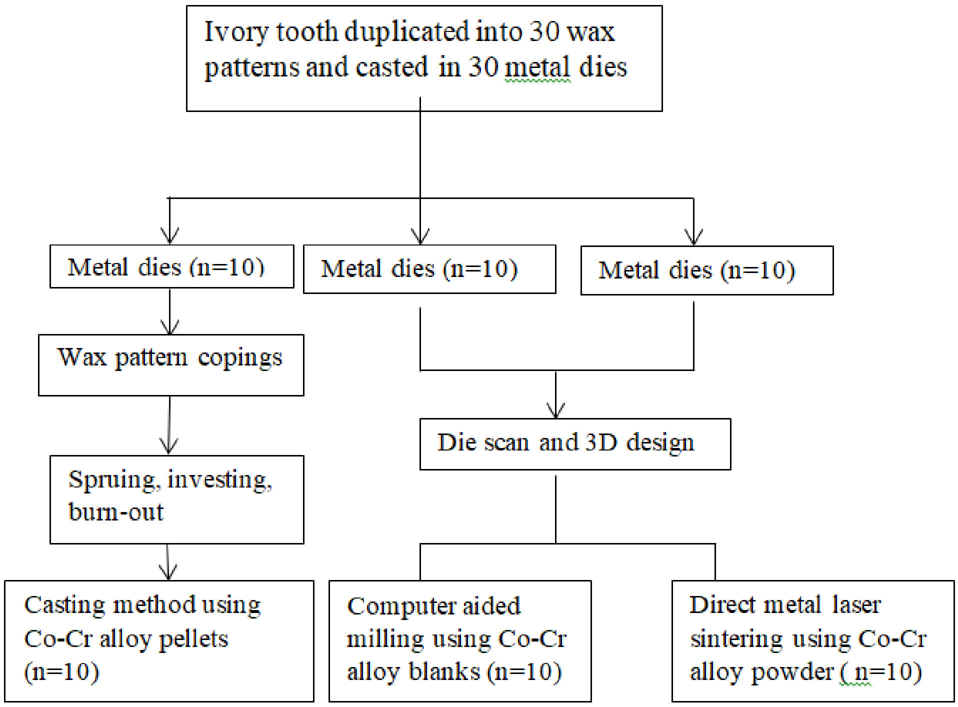



Fig. 1: Flow chart of study procedure

## 3. For the 1st group, copings fabricated by conventional casting procedure:-

Inlay wax pattern was made along with the loop of 3 mm on each of metal die after applying die spacer of 50 um thickness 0.5 mm short of margin. These 10 wax patterns were sprued using sprue wax.(fig.31)[17] Coping were coated with surface tension reducing agent and dried. After this, powder and liquid of high strength phosphate bonded investment material was mixed in vacuum mixer and the patterns were invested at the center of casting ring to reduce casting defects. Wax burnout was done at 800°C in burnout furnace, followed by casting using cobalt-chromium alloy, in induction casting machine. After fabrication of 10 copings (fig.32), copings were inspected for porosity and any gross casting defects and in this way 10 Co-Cr copings were fabricated by conventional casting method.(colour plate 5-fig.39)

### 4. For 2nd group, copings milled by 3D milling (CAD-CAM milling) technique (Colour plate -4):-

All ten metal dies of group 2 were scanned with digital lab scanner sirona inEosX5 from all surfaces to get the appropriate digital image of the die. (fig.33).Which was then send to CAD software named EXOCAD to design the full veneer crown coping along with loop above it of internal diameter 3mm which was used to hold the assembly on universal testing machine during pull out test (fig.34.) The cement film thickness was set to 50um.[17]After designing, a data has sent to milling center for computerised milling ( a programme was set for milling the copings. The milling machine ARUM 5X-200 started the process of carving the copings from the Co-Cr blanks as per the scanned image.(fig.35) In this way 10 coping were milled by CAD –CAM milling process and were checked for fit on respective metal die.(Colour plate 5-fig.39)

### 5. For 3rd group, crown fabrication by DMLS technique (Colour plate - 5):-

All the 10 metal dies of group 3 were scanned with the same scanner sirona inEosX5 lab scanner from all the surfaces to get the appropriate digital image of the die, which was used to design the cobalt-chromium full veneer coping. The copings were designed on the image of the metal dies over which a loop was designed with the internal diameter of 3 mm, to get engage on the universal testing machine during pull-out test.(fig.34)

After designing, the data was transferred to the Cambridge software for the slice file i.e. in SLI file format which is accepted by DMLS machine (fig.36). This slice file was then sent to the DMLS machine's computer program RP tools. At this stage, the geometry of 3D model was properly oriented for part building. Once this "build file" was completed, for fabrication of crowns, DMLS machine began the build-up process.

In the build chamber area, there is a platform for dispensing of the material and a build platform alongside a recoater blade which is used to move new powder over the build platform.(fig.37) It fuses metal powder into a solid part by sintering it locally using the centred light beam (200 watt Yb-fiber optic laser). Parts were built up additively layer by layer, typically using layers 20 μm thick (fig.38). This sintering continued until final dimension of the samples were obtained. After fabrication of copings they were allowed to cool at room temperature. In this way 10 copings were sintered by DMLS technique.

In this ways 30 Co-Cr copings were fabricated by three different techniques and sent to metallurgical laboratory for pull out test. (fig.39**)**

## 6. For Cementation:- (Colour Plate-5)

Zinc phosphate cement was used for cementation of crowns of all three groups. In order to achieve a maximum physical property of the cement used for luting the crowns, the cement was mixed according to the manufacturer's instructions. For mixing of cement cool and dried glass slab was taken 1.4 gm. of powder and 0.5 ml. liquid was dispensed on glass slab. Powder was divided into six portion and powder and liquid was mixed in increments. Each increment was mixed for 20 seconds over large area of glass slab as cement sets by exothermic reaction. Mixing over large surface area also neutralise the acid and retards setting time of cement.[16] (fig.40)The mixed cement was then applied on the axial surface of the internal surface of the coping. The coping was then seated over the tooth sample. This sample was kept on digital weighing machine and tare button was pressed for zeroing of the weight. Then finger pressure of 1 kg was applied and the weight was seen on the digital screen to monitor the exact weight (fig.41).Excess cement was removed from all sides with a clean instrument.

The same procedure was done for cementation of all 30 copings to respective prepared metal dies.(fig.42)

## 7. Retention Checking Procedure: (Colour Plate-6 fig.43)

After luting procedure, samples were stored in distilled water at room temperature. All the samples were carried to metallurgy laboratory for the retention testing procedure. The retention test was carried out with the universal testing machine (Instron, U.S.A). The specimens were loaded axially in the universal testing machine. The hook was engaged in the loop of the coping to apply force opposite to the path of insertion. The samples were subjected to tensile stress and removed along the path of insertion using universal testing machine at a cross head speed of 0.5 mm / min and separation force was recorded.[16] The maximum load at the de-bonding was measured, which was determined on the computer. The tensile bond strength was calculated in Newton. (fig.43)

## Statistical Analysis:-

Statistical analysis was done with STATA statistical software vs.13. Data comparison was done by applying specific statistical tests to find out the statistical significance of the results. Since the data was of continuous type and normally distributed, parametric tests were used for analysis. Mean and Standard Deviation (SD) were calculated. Statistical tests employed for the obtained data in this study were One-way Analysis of Variance (ANOVA) test followed by Pair-wise comparison of three study groups by Bonferroni Multiple Comparison test.

# COLOUR PLATE – 1

**Fig. 1: Typodont invorine right mandibular first molar**

**Fig. 2: Auto polymerising acrylic resin**

**Fig.3: Dental surveyor**

**Fig. 4 : Airotor handpiece**


**Fig.5 : Diamond burs ( EX-11, TR-26, TR-26EF)**

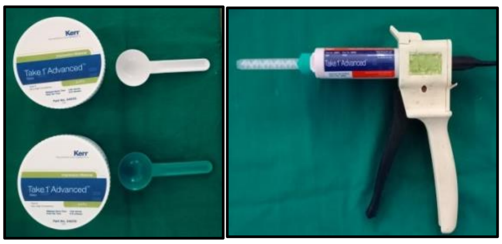


**Fig. 6 : Addition silicone putty and light body impression material**

**Fig. 7: Blue inlay wax**

**Fig. 8:Vaccum mixer**

**Fig. 9: Investment material**

**Fig. 10: Burnout furnace**

**Fig. 11: Induction casting machine**

# COLOUR PLATE 2

Fig. 12: Metal Polishing kit

Fig. 13: Aluminium oxide particles

Fig. 14: Sand blaster

Fig. 15: scanner


Fig. 16: CAD-CAM milling machine

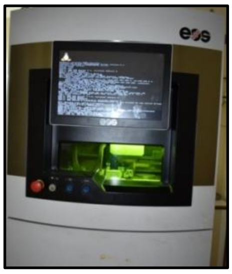


Fig. 17: EOS 100 DMLS machine

Fig. 18: CO-CR alloy pellets


Fig. 19: Blocks of Co-Cr alloy for CAD –CAM milling

Fig. 20: Co-Cr powder for sintering

Fig. 21.zinc Phosphate cement


Fig. 22: Universal testing machine

# COLOUR PLATE -3

**Fig. 23: Typodont tooth molar**

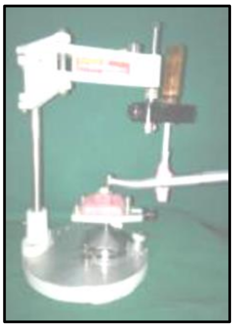


**Fig. 24: Tooth preparation**

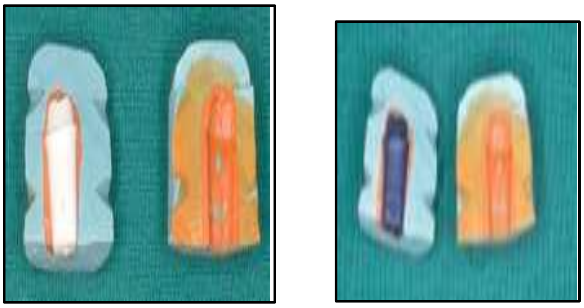


**Fig. 25: Two-piece mould & Inlay Wax filled**

**Fig. 26: Wax pattern of Prepared tooth**

**Fig. 27: Spruing**

**Fig.28: Investing**

**Fig. 29: Casted metal dies**

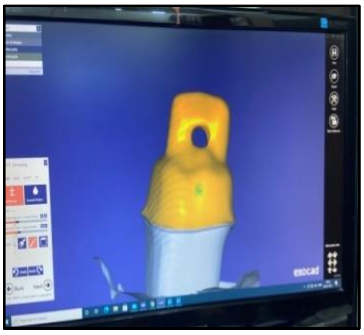
# COLOUR PLATE – 4


**Fig. 30: 30 Metal dies submerged in acrylic block**

**Fig.31.Spruing of 10 conventional group wax pattern of coping**

**Fig.32.Finally casted Co-Cr copings with loop**

**Fig. 33: Scanner**



**34: Design of metal _ ing with loop in process**


**Fig. 35: Milling of Co-Cr coping in process**

# COLOUR PLATE – 5

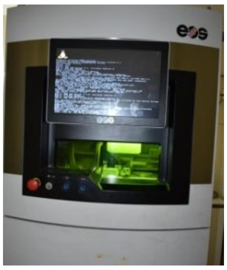


**Fig. 36: DMLS machine**

**Fig. 37: Laser sintering platform**

**Fig. 38: Sintering of Co-Cr coping in process**

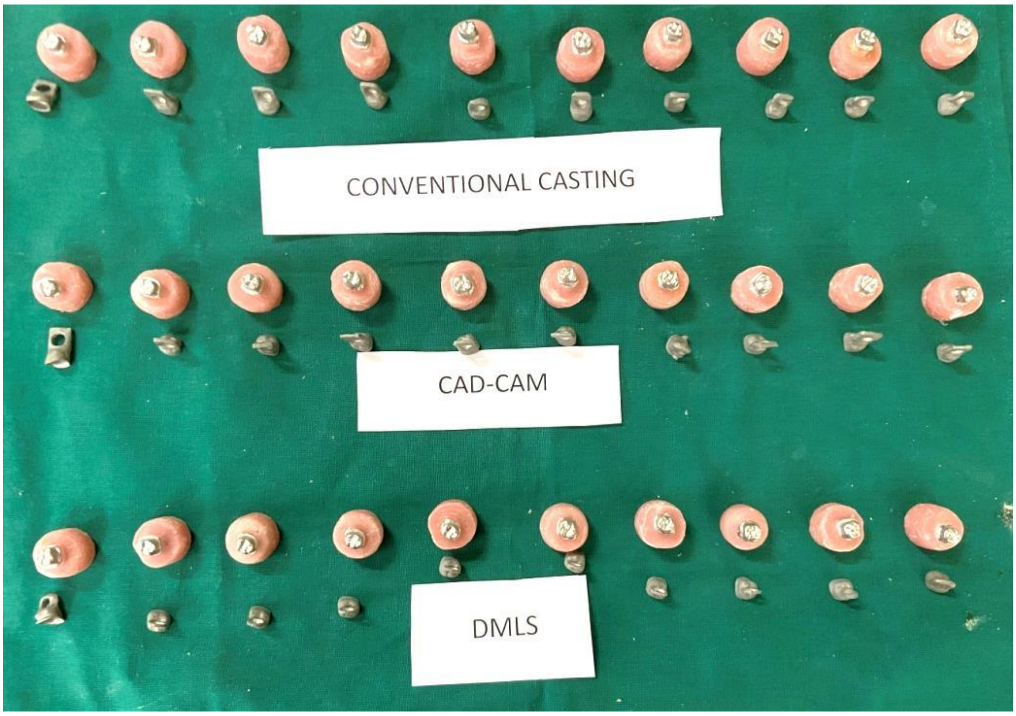



**Fig. 39: Finally prepared all three groups METAL crowns with METALLIC loop**

**Fig. 40: Mixing of cement**

**Fig. 41: Pressure of 1kg**

# COLOUR PLATE – 6


**Fig. 42: Total 30 Co-Cr metal crowns cemented on metal dies**


**Fig. 43: Retention testing of samples on universal testing machine**

# RESULTS

***The result you achieve will be in direct proportion to the effort you apply.***

- **Denis Waitley.**

In this study, we compared the effect of three different techniques of fabrication of Co-Cr alloys; conventional casting, 3D milling and Direct Metal Laser Sintering on retention of single unit metal copings.

Standardize tooth preparation was done on typodont ivorine right mandibular first molar. After taking the impression and duplicating it into inlay wax; casting procedure was performed. 30 metal dies were fabricated using conventional casting technique. After that 30 Co-Cr copings were fabricated on those 30 metal dies by different fabrication techniques. These copings were divided into three groups according to their method of fabrication as follows:-

| Sr. No. | Groups | Description | Samples |
|---|---|---|---|
| 1. | Group 1 | Conventional casting technique | 10 |
| 2. | Group 2 | CAD-CAM milling technique | 10 |
| 3. | Group 3 | DMLS technique | 10 |
| | Total | | 30 |

In all these three groups, 10 copings of each group were cemented by using zinc phosphate cement on respective metal dies. After this, all 30 samples were subjected to retention testing on Universal Testing Machine at 0.5 mm/min cross-head speed (primarily based on computerized software system). A vertical tensile force was applied on the crowns consistently. Retentive force values at the point, where cemented crowns were dislodged from the prepared teeth were calculated in Newton on Universal Testing Machine attached with computerized software (Master chart and Graph 1).

Statistical Analysis:- Statistical analysis was done with STATA statistical software vs.13. Data comparison was done by applying specific statistical tests to find out the statistical significance of the results. Since the data was of continuous type and normally distributed, parametric tests were used for analysis. Mean and Standard Deviation (SD) were calculated.

Statistical tests employed for the obtained data in this study were One-way Analysis of Variance (ANOVA) test followed by Pair-wise comparison of three study groups by Bonferroni Multiple Comparison test.

**The hypothesis of no difference (Null Hypothesis)** was:

**$H_0$**: There is statistically no significant difference on retention of single unit metal copings fabricated by three different techniques - conventional casting, 3D milling and Direct Metal Laser Sintering

**Alternate hypothesis** was:

**$H_1$**: There is statistically significant difference on retention of single unit metal copings fabricated by three different techniques - conventional casting, 3D milling and Direct Metal Laser Sintering

The formulations and method used in this study are briefly described below:

**Mean and Standard deviation**

These statistical measures of central tendency and dispersion were obtained for the continuous variables included in the study showed in the Graph. The expressions for the two are given as below:

a) Sample mean for the set of observations was given by

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

Where $x_i$ = observation on each object, $n$ = number of objects

b) Sample standard deviation was given by

$$s = \sqrt{\frac{1}{(n-1)}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

ONE WAY ANALYSIS OF VARIANCE: (one way ANOVA)

Analysis of Variance (ANOVA) is a statistical method used to test differences between two or more means. It may seem odd that the technique is called "Analysis of Variance" rather than "Analysis of Means" because inferences about means are made by analysing variance. ANOVA is used to test general rather than specific differences among means.

$$\text{Variance Ratio (F)} = \frac{\text{Mean square between samples}}{\text{Mean square within samples}}$$

**Mean square between samples** = sum of squares for variance between the Samples / (k-1)

Sum of squares for variance between the samples = $\Sigma\, n_1(X_1 - X)$

k- 1 represents degree of freedom

**Mean square within samples** = sum of squares for variance within the Samples / (n - k)

Sum of squares for variance within the samples

$$= \sum(x_{1i} - \overline{x_1})^2 + \sum(x_{2i} - \overline{x_2})^2 + \cdots\cdots + \sum(x_{ki} - \overline{x_k})^2$$

n – k = degree of freedom

n = number of items in all samples.

$\overline{x_1}$ , $\overline{x_2}$ …………………………$\overline{x_{k.}}$ = mean of each sample, when there are k samples.

$\bar{x}$ = mean of the sample means.

i = 1, 2, 3, 4…….

ANOVA is performed as there were more than 2 comparison groups in the study. ANOVA results indicated that overall, there is a significant between-the-group difference in mean tensile bond strength across the three comparison groups.

Which one of the mean differences out of three-pair-wise comparisons (Group I vs II, or I vs III or II vs III) contributed to the above significant result was established by Bonferroni Multiple Comparison test.

**Bonferroni Multiple Comparison test:**

A Bonferroni test is a type of multiple comparison test used in statistical analysis. When an experimenter performs enough hypothesis tests, he or she will eventually end up with a result that shows statistical significance of the dependent variable, even if there is none. If a particular test yields correct results 99% of the time, running 100 tests could lead to a false result somewhere in the mix. The Bonferroni test attempts to prevent data from incorrectly appearing to be statistically significant by lowering the alpha value.

The Bonferroni test, also known as the "Bonferroni correction" or "Bonferroni adjustment" suggests that the "p" value for each test must be equal to alpha divided by the number of tests. To perform a Bonferroni correction, divide the critical P value (α) by the number of comparisons being made.

## Descriptive Analysis:-

**Table 1** gives descriptive statistics of mean retention value and standard deviation along with minimum and maximum values of retention force. The results showed that mean retention value for **conventional** was 209.1 N, for **CAD-CAM group** was 273.2 N and for **DMLS** group was 304.8 N. DMLS group had highest mean retention force (304.8 N).

Here **conventional group** showed significantly less mean retentive force value than **CAD-CAM Group** and **DMLS Group** respectively. There was statistically significant difference between mean retention force between the three groups (p-value = 0.0001).**(Table 2**)

The results also showed that retention of metal coping depends on method of fabrication. There was statistically significant difference between retention forces when metal copings were fabricated by two methods other than conventional method.

As ANOVA test was significant (p-value: <0.05), we applied Bonferroni multiple comparison test to compare the mean difference within groups. From the statistical data of table 3, mean difference was found the highest in the pair of **conventional groups versus DMLS group** i.e. 95.8 and *p*-value was highly significant (p-value= < 0.0001). The mean difference between conventional group and CAD-CAM group was 64.1 and p-value was statistically different (0.006). There was no statistical difference between mean values of DMLS versus CAD-CAM group.**(Table 3)**

The results of the study showed that the mean retention value for **conventional group** (Control) was 209.1 N, for CAD-CAM **Group 273.2** N, and 304.8 N for DMLS **Group which** were assessed statistically using ANOVA test (Table 1 and 2). Since p-value for the ANOVA was seen less than 0.05 ($p < 0.05$); indicates significant difference between the means of 3 groups. Metallic copings fabricated by conventional method (Group 1) showed considerably less mean retentive force value than the metallic copings fabricated with CAD-CAM and DMLS i.e. Group 2 and Group 3 respectively. Whereas there was no statistically significant difference ($p > 0.05$) between the mean retentive force values of Group 2 (CAD-CAM) and Group 3 (DMLS) (Table 3). The results stated that fabrication of metallic copings by DMLS method considerably increased the retention of metal copings. Hence, from the statistical data the null hypothesis ($H_0$ )is rejected and the alternate hypothesis $H_1$ is accepted. The mean retention value after fabrication using DMLS method (Group 3) was seen to be higher than CAD-CAM method (Group 2) but the increase in the mean retention value wasn't statistically significant (p-value = 0.31).(Table 3) This reinforced the conception that fabrication by either CAD-CAM or DMLS methods increases the retention. (Graph 1).

# DISCUSSION

***Rational discussion is useful only when there is a significant base of shared assumptions.***

**-Noam Chomsky**

In this advanced world, fixed restorations have become an integral part of restorative dental procedures. A well fabricated fixed prosthesis not only restores oral function, aesthetics & occlusal equilibrium, but also it additionally provides a psychological boost to the patient and their confidence.

The success of any treatment modality is measured in terms of its dependability, durability and same applies to fixed restorations. The prosthesis should be reliable, comfortable and tailor made alternative to the lost teeth. To attain a fruitful outcome of a successful fixed restoration, all the steps concerned within the process should be meticulously followed. In order to realize the same, dentist should direct his or her efforts in diagnosis, treatment planning and execution of the planned treatment. To achieve a positive outcome, the planning, fabrication and placement of fixed restorations should be ruled by basic principles. These principles are often classified into biological, mechanical and aesthetic principles.[39] The success of fixed restorations has been attributed to its retention & resistance form. As dental restoration is subjected to repetitive dynamic loading which is a mixture of compressive and tensile stresses on the restoration throughout mastication and para-function, efforts should be made to take into consideration of these factors. The long-term success of fixed restoration is multifactorial which has numerous factors that are either within the control of the operator or patient related factors. Hence, the prosthodontist should attempt hard to identify maximum number of such factors and control them to the most effective of his skills. Even the smallest and apparently insignificant factor will form a chain of inappropriate decisions which can ultimately result in failure of fixed prosthesis. For a restoration to accomplish its purpose, it has to stay in its desired position on the tooth. So, retention form is one of the most important factor.[40]

To fabricate fixed restorations earlier gold alloys were used because of their higher biocompatibility but soon gold prizes raised and researchers focused on some lesser expensive option. They developed some noble alloys made up of gold –silver-palladium and palladium-silver alloys to decrease expenses for production of fixed dental prosthesis and even after that researcher found best option for fabrication of

FPD and that was use of base metal alloys. These were made up of either Ni-Cr or Co-Cr alloys.[3]

Base metal alloys have demonstrated better performance and less intraoral deformation in most cases. Resistant to corrosion by Co-Cr alloys showed by many electrochemical studies and also these alloys shows no allergic reaction.[21] So, Co-Cr alloys were selected for this study.

Fixed partial dentures can be made by various techniques. The most ancient and widely used technique of fabrication is introduced by Taggart in 1927 which is "lost wax technique". To make castings by this conventional techniques dentist as well as technician need to perform many steps. Such as making an impressions poring cast, removing cast from poured impression, fabrication of wax pattern, investing, casting and divesting etc.[31]

So, to eliminate this time consuming and tedious process newer techniques are introduced. The CAD-CAM is introduced in dentistry before 20 years for various uses and many favourable reports were also given by researchers for use of CAD-CAM in making fixed prosthesis.[3] When the word CAD-CAM is used it is mostly associated with milling, however there are two types of computer assisted milling (CAM) and those are subtractive technique; computer aided milling (CAD-CAM) and additive technique; direct metal laser sintering (DMLS) namely. Various preparation burs are used in milling machines with multi-axial preparations to make prosthesis from single block of material. Milling processes vary according to the number of milling axes from simple to more complicated. A greater number of milling axes facilitate milling of more complex geometries.[7] Whereas, additive manufacturing is defined by the

American Society for Testing and Materials (ASTM) as “the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies”. Direct metal laser sintering is actually process of making dental prosthesis by a high-powered laser beam focusing onto a bed of the Co-Cr alloy powder and welding it together into subsequent, thin solid layers on cooling.[28]

In both of these techniques based on CAD data prosthesis is design in software and this data is sent to CAM processor to fabricate prosthesis by subtractive method or additive method.[32]

So in this study, three groups were taken conventional casting, CAD-CAM milling, DMLS group. Typodont ivorine first molar was taken and it was prepared to receive full veneer metal crown coping to it. It was duplicated into 30 teeth in inlay wax pattern to make three groups containing 10 samples in each. After duplicating in inlay wax these teeth were invested in phosphate bonded investment material. Sprued and then casted by induction casting machine. After casting of 30 dies they were then cleaned, sprues were cut and finally finishing polishing was carried out. These 30 dies then embedded in cold cure block till cervical margin of tooth such that margin of tooth preparation should be completely visible. All 30 embedded teeth were divided into three groups:- Conventional casting, CAD-CAM and DMLS group.

For preparation of conventional group copings wax pattern were made manually for metal coping and loop of 3 mm. internal diameter was also made to get engaged in hook of universal testing machine for retention checking procedure and then these 10 wax pattern were invested, casted and after that finishing and polishing was done.

For making of CAD-CAM milled copings 10 dies were scanned using software (Sirona inEosX5) and copings were designed by EXOCAD software with loop of internal diameter 3 mm and this CAD data was sent to a communicating multi axis milling machine for the fabrication of CAD-CAM milled specimens from the Co-Cr alloy blanks according to the manufacturer's recommendations.

For fabrication of DMLS copings same scanner was used to scan another 10 metal dies and this data was sent to laser sintering to be performed direct metal laser sintering. (EOS M 100)The samples were fabricated under a laser power of 200 W and scan spacing from 0.02 mm. The laser scan speed and layer thickness were fixed at 7.0 m/sec and 30 ㎛, respectively. Finally 30 copings obtained from all three methods were luted with zinc phosphate cement.

Zinc phosphate is the oldest of the luting cements, has the longest clinical "track record" and serves as a gold standard with which newer systems can be compared. It consists of powder and liquid in two separate bottles which can be mixed on cool glass slab for better physical and mechanical properties. Zinc phosphate cement mechanically bond to tooth structure.[41] **Chandra Shekhar (2010)[16]** mentioned that use of adhesive cement does not significantly increased retention of crowns. Also, as in our study both die and copings were fabricated in Co-Cr metal, adhesive bonding was not needed hence use of zinc phosphate cement was done. Luting agent was mixed according to manufacturer’s instructions and a constant seating force of 1 kg was maintained during cementation to standardize the pressure for cementing all copings.

On Universal Testing Machine, the loop of metal copings was engaged to upper holding assembly and the lower part of holding assembly grasped the acrylic block having cemented samples. The maximum load required to dislodge the crown was recorded in Newton on Universal Testing Machine attached with computerized software. Generally, removing of cemented crowns by pulling them along the long axis of preparation with an increasing statically loaded model is the measure of the retentive strength.

The results of this study showed that mean retention value for conventional group was 209.1 N with standard deviation 25.45; for CAD-CAM group was 273.2 N with standard deviation 49.80; and for DMLS group was 304.8 N with standard deviation 47.04. DMLS group had highest mean retention force 304.8 N. There was statistically significant difference between mean retention force between the three groups (p-value=0.0001) since p-value for the ANOVA was found out to be less than 0.05 ($p < 0.05$).

We applied Bonferroni multiple comparison test to compare the mean difference within groups. From the statistical data, mean difference was found the highest in the pair of conventional group versus DMLS group i.e. 95.8 N. The mean difference between conventional group and CAD-CAM group was 64.1 N and there was no statistical difference between mean values of DMLS versus CAD-CAM group. It was observed that retention of metal coping depends on methods of fabrication. The findings of our study i.e. superior quality of DMLS group are similar to study conducted by **Ortrop et al (2011)**[17] where he compared marginal and internal fit of

Co-Cr alloys fabricated with four different techniques and DMLS group shows best marginal and internal fit.This finding was again supported by a study done by **Bhaskaran et al (2013)**[22] where they compared marginal gap of metal copings fabricated by three different methods. Such findings were seen as microstructures and mechanical properties of Co-Cr alloys were greatly dependent on the manufacturing technique as well as the chemical composition.[12]

In another study done by **Takaichi et al(2013)**[9] they evaluated microstructural and mechanical properties of additively manufactured Co-Cr alloy where he observed higher 0.2% Yield strength, and the ultimate tensile strength than conventional casting procedures.

There was statistically significant difference between retention forces when metal copings were fabricated by two methods other than conventional method. In result, the mean difference between conventional group and CAD-CAM group was 64.1 and p-value was statistically different (0.006). Mean difference between the conventional groups versus DMLS group was highest i.e. 95.8. The lower retention of conventional casting group might be justified by distortion of wax pattern like shrinkage due to relaxation of internal stress contributes to detrimental effects on cast restorations. The possibility of casting defects, porosity, other microstructural defects and also the regions around micro-pores of the completed casting might have localized stress concentrations.[22] These findings were also supported by **Al jabbari et al (2014)**[10] where they did x- ray diffraction and mentioned presence of gross porosity was seen at the centre of conventionally casted crowns, affecting their microstructure and hardness.

In CAD-CAM milling technique, the precision fit of milled crowns depends upon the use of smallest diameter tool. If the cutting tool is larger in diameter and geometry of preparation is smaller than smallest size bur of milling machine then some parts of restoration preparation in that CAD system will face problem during cutting or not cutting the corresponding part. So this might result in milling of crown that doesn't has good adaptation to the die, subsequently hampering the internal fit precision or marginal fit, mechanical properties and retention of crowns.[6]

The mean difference between conventional group and DMLS group was 95.8 and *p*-value was highly significant (p-value= < 0.0001). similar kind of results that is higher retentive forces were found in study done by **Josef Schweiger et al(2013)[36]** and they stated that Co-Cr clasp made from DMLS technique contain less porosity as that of conventional casting and they can sustain better retentive forces.

The highest values in DMLS group can be because of its finer microstructural characteristics and those are may be due to finer grain size 3-14um, resulting in higher density of around 99.9%, which is resulting in tougher coping with no voids. The cellular dendrite and elongated precipitates in DMLS prosthesis while retention checking can work as obstacles for dislocation motion.[9,24,27,38]

## Clinical Implications:-

1. Use of newer technologies CAD-CAM and DMLS for fabrication of fixed partial restorations increases its retention significantly if all other parameters are standardised.

2. Use of CAD-CAM and DMLS technologies also reduces time of fabrication of fixed partial dentures.

3. It decreases all casting defect that are mostly seen in conventional castings.

4. The role of the clinician and laboratory personnel is equally important in retention and longevity of the prosthesis in-service; owing to its technique sensitivity, one must be thorough with the knowledge of the materials in concern as well as newer digital technologies.

## Limitations of this Study

This being an in-vitro study could not replicate the conditions present in the oral environment. Also, most prepared molars in the oral cavity are not uniform in the height circumferentially. The dislodging forces to that fixed restoration, subjected in the oral cavity are multidirectional might it be vertical, lateral or oblique forces however on the other hand the dislodging force exerted by the universal testing machine is uni-directional. So, the direct comparison between dislodging forces encountered in the oral cavity and those exerted by the universal testing machine is ambiguous.

## Further Scope

There arises a desire for future clinical research following a similar technique with different parameters, like that simulate oral environment, artificial saliva, thermo-cycling etc. Also studies on multi-unit fixed partial dentures can be carried out

# SUMMARY

***Egotism is the source and summary of all faults and miseries***

**-Thomas Carlyle**

The present study was done with an aim to evaluate and compare the retention of Co-Cr crowns using three different techniques. For achieving the longevity of the prosthesis, many modifications have been already done on the tooth surface. In this, retention plays very important role. It is not always possible to alter the tooth surface or crown surface to increase the mechanical property like retention depending on various clinical situations. In order to overcome this problem, with this background, an in-vitro study was taken for comparative evaluation of retention of single unit Co-

Cr copings fabricated using three different techniques conventional, CAD-CAM , DMLS.

In study, typodont ivorine first molar was taken and it was prepared to receive full veneer metal crown to it. It was duplicated in 30 inlay wax to make three groups containing 10 samples in each. After duplicating in inlay wax these teeth were sprued, invested in phosphate bonded investment material and then casted by induction casting machine. After casting of thirty teeth this teeth were then cleaned sprues were cut off followed by finishing and polishing. These teeth then embedded in cold cure block till cervical margin of tooth such that margin of tooth preparation should be completely visible. After embedding teeth into cold cure mould these teeth were divided into three groups: Conventional casting, CAD-CAM, DMLS.

For preparation of conventional group, wax pattern was made manually for metal coping and loop of 3 mm. internal diameter was also made they were invested, casted, followed by finishing and polishing.

For making of CAD-CAM Copings, die was scanned using software (Sirona inEosX5) and coping was designed by EXOCAD software with loop of diameter 3mm. and this CAD data was sent to a communicating multi axis milling machine for the fabrication of CAD-CAM milled specimens from the Co-Cr alloy disc according to the manufacturer's recommendation.

For fabrication of DMLS copings same software was used to scan another 10 metal dies and this data was sent to laser sintering to perform direct metal laser sintering. (EOS M 100) The samples were fabricated under a laser power of 200 W and scan spacing from 0.02 mm. The laser scan speed and layer thickness were fixed at 7.0 m/sec and 30 ㎛, respectively. Finally 30 copings fabricated from all three methods were luted with zinc phosphate cement according to manufacturer's instructions. These cemented samples were tested for their retention in universal Testing Machine at 0.5 mm/min cross-head speed. A vertical tensile force was applied on the crowns consistently. Retentive force values at the point, where cemented crowns were dislodged from the prepared teeth were calculated in Newton.

Statistical analysis was done for the calculation of mean and standard deviation. Data comparison was done by applying specific statistical tests to find out the statistical significance of the results. The results of the study showed that the mean retention value for conventional was 209.1 N, for CAD-CAM group was 273.2 N and for DMLS group was 304.8 N. DMLS group had highest mean retention force (304.8 N). Here conventional group showed significantly less mean retentive force value than CAD-CAM Group and DMLS Group respectively. There was statistically significant difference between mean retention force between three group (p-value=0.0001). Since p-value for the ANOVA was found out to be less than 0.05 ($p < 0.05$).

The results also showed that retention of metal coping depends on the method of fabrication. There was statistically significant difference between retention forces when metal copings were fabricated by two methods other than conventional method. Whereas there was no statistically significant difference ($p > 0.05$) between the mean retentive force values of Group 2 (CAD-CAM) and Group 3 (DMLS).

Retention of metal copings fabricated by Direct Metal Laser Sintering (DMLS) is higher than conventional and CAD-CAM technique and the retention of metal coping depends on the method of fabrication.

# CONCLUSION

***A conclusion is simply the place where you got tired of thinking.***

**— Dan Chaon**

The aim of this study was to evaluate and compare the effect of three different casting procedures; conventional casting, 3D milling and Direct Metal Laser Sintering on retention of single unit metal copings.

Within the limitations of the study, the following conclusions were drawn: -

1) In these three different manufacturing techniques; conventional casting, 3D(CAD-CAM) milling and Direct Metal Laser Sintering, retention of metal copings fabricated by Direct Metal Laser Sintering (DMLS) is higher than

conventional and CAD-CAM milling technique and the retention of metal coping depends on the method of fabrication.

2) There was statistically significant difference between retention forces when metal copings were fabricated by two methods (CAD-CAM and DMLS) other than conventional method.

3) Although the retention was found to vary with fabrication methods, both CAD-CAM milling and DMLS techniques produces prosthesis with higher retention than conventional group as these automated methods overlooks wax-up, investing and burn out thus simplifying the fabrication in favour of reduced material consumption and greater time efficiency. In clinical practice, either of these methods can be used as per clinician's choice.

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# TABLES AND GRAPHS

**Table 1: Mean retention in three study groups along with different measures of variation**

| Groups | Observations | Mean | Standard Deviation | Minimum | Maximum |
|---|---|---|---|---|---|
| Conventional | 10 | 209.1 | 25.45 | 170.5 | 247.6 |
| CAD-CAM | 10 | 273.2 | 49.80 | 178.7 | 346.1 |
| DMLS | 10 | 304.8 | 47.04 | 238.5 | 382.7 |

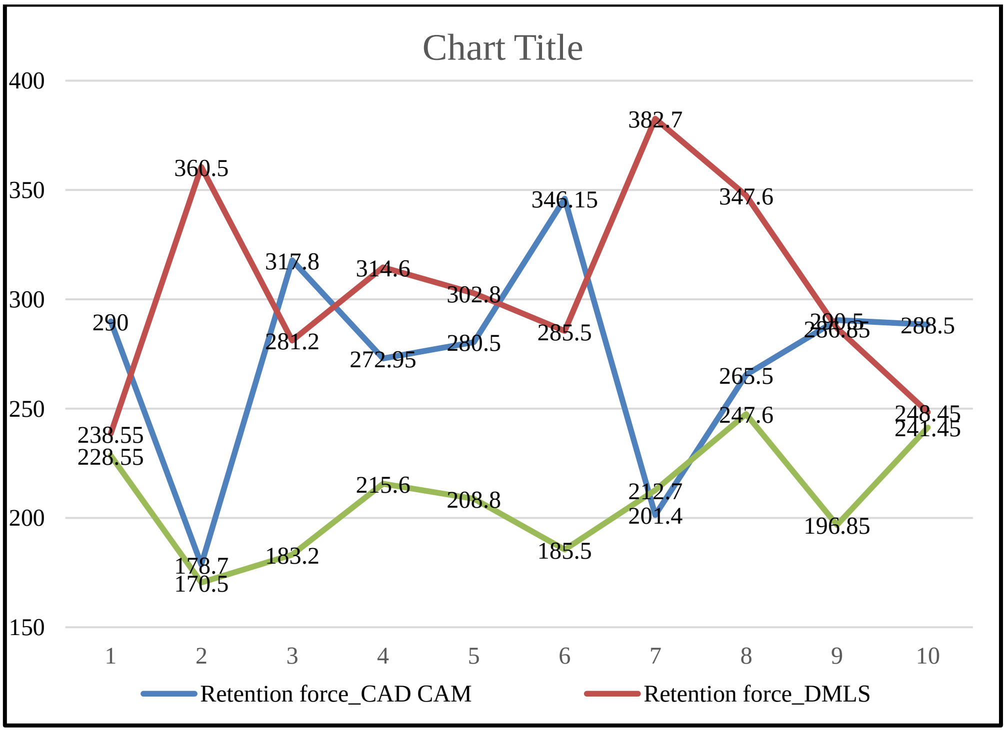
**Table 2: - Comparison of mean retention across three study groups by one-way ANOVA (Analysis of Variance)**

| Source | SS (sum of samples) | df (degree of freedom) | MS (mean sum of squares) | F (statistics) | Prob > F (P value) |
|---|---|---|---|---|---|
| Between groups | 47643.20 | 2 | 23821.60 | 13.38 | 0.0001 |
| Within groups | 48073.53 | 27 | 1780.50 | | |

**Table 3: Pair-wise comparison of Mean retention force of three study groups by Bonferroni Multiple Comparison test**

| Group-wise pairs | Mean of two comparison groups | Mean difference | P-value |
|---|---|---|---|
| Conventional Versus CAD-CAM | 209.1 versus 273.2 | 64.1 | 0.006 |
| Conventional Versus DMLS | 209.1 versus 304.9 | 95.8 | < 0.0001 |
| CAD-CAM Versus DMLS | 273.2 versus 304.9 | 31.7 | 0.31 |

## Graph 1: Comparison of retention force in three groups



# ANNEXURE

## MASTER CHART

| Maximum load in Newton | | | |
|---|---|---|---|
| **Sr.No.** | **Group 1** | **Group 2** | **Group 3** |
| 1 | 228.55 | 290.00 | 238.55 |
| 2 | 170.50 | 178.70 | 360.50 |
| 3 | 183.20 | 317.80 | 281.20 |
| 4 | 215.60 | 272.95 | 314.60 |
| 5 | 208.80 | 280.50 | 302.80 |
| 6 | 185.50 | 346.15 | 285.50 |
| 7 | 212.70 | 201.40 | 382.70 |
| 8 | 247.60 | 265.50 | 347.60 |
| 9 | 196.85 | 290.50 | 286.85 |
| 10 | 241.45 | 288.50 | 248.45 |
| **Average** | **209.07** | **273.20** | **304.87** |