COMPARATIVE EVALUATION OF THE MARGINAL GAP AND INTERNAL GAP OF Co-Cr COPINGS FABRICATED BY DIFFERENT TECHNIQUES - AN IN VITRO STUDY

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In partial fulfillment for the Degree of

MASTER OF DENTAL SURGERY

BRANCH I
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CERTIFICATE

This is to certify that the dissertation titled "**COMPARATIVE EVALUATION OF THE MARGINAL GAP AND INTERNAL GAP OF Co-Cr COPINGS FABRICATED BY DIFFERENT TECHNIQUES - AN IN VITRO STUDY**" is a bonafide record work done by **Dr. ESWARAN. B** under our guidance and to our satisfaction during his post graduate study period between 2009 – 2012.

This Dissertation is submitted to **THE TAMILNADU DR. M.G.R. MEDICAL UNIVERSITY**, in partial fulfillment for the Degree of **MASTER OF DENTAL SURGERY – PROSTHODONTICS AND CROWN & BRIDGE, BRANCH I.** It has not been submitted (partial or full) for the award of any other degree or diploma.

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INTRODUCTION

The restoration of missing tooth structure with the casting alloys has been an important part of restorative dental treatment for more than a century. Accuracy of the fit of cast metal restoration has always remained as one of the primary factors in determining success of the restoration. A well fitting restoration needs to be accurate both along its margins as well as with regard to its internal surface.[15, 43, 49]

The long term success of restorations is significantly influenced by marginal and internal fit. Precise marginal adaptation is necessary to achieve better mechanical, biological and esthetic prognosis of the restorations. Inaccurate marginal fit is responsible for plaque retention, micro leakage and cement breakdown.Studies in the literature have revealed that gingival tissue adjacent to the margin of an artificial crown contained chronic inflammatory infiltrate and believed it occurred due to accumulation of bacterial plaque at microscopic opening of margins of the restoration.[41] The authors also demonstrated that periodontal tissues surrounding teeth restored with artificial crowns were not as healthy as contra-lateral teeth[41.] Poor internal fit of a coping can increase the thickness of the cement and thus influence the mechanical stability of dental restorations.[19,23] The minimization of crown marginal gap and internal gap is an important goal in prosthodontics.[47] Based on literature review the acceptable vertical marginal gap ranges between 10-160 µm[13,22,43,47]and internal gap ranges between 81to 136 µm[49].

The accuracy of fit of cast restoration is essential for its longevity. Generally marginal gap and internal gap of restorations are very much influenced by clinical and laboratory factors. Clinical factors are geometry of tooth preparation, including type of finish line and degree of taper, impression materials, and finally cement used to lute the restoration in dental office.[43, 50] Laboratory factors that affect marginal gap and internal gap are incompatibility of dental materials such as wax, die stone and casting investments, die spacer and the casting techniques.[7, 36, 37, 38, 56]

Conventional casting techniques require patterns for casting procedure. The fabrication of acceptable patterns is an important variable that can affect the marginal and internal fit of cast restoration. The techniques for pattern formation employ materials like inlay casting wax, autopolymerizing resins, light cured resins.[28] Wax is popular because of its desirable properties like adequate strength, rigidity, ease of manipulation and absence of residue on burnout. But distortion of wax pattern like shrinkage due to relaxation of internal stress contributes to detrimental effects on cast restoration.

Resins were recommended to overcome the shortcomings of wax as pattern forming material. Autopolymerising resins offer strength, rigidity, and dimensional stability if immediate investment is not possible. It provides easy manipulation with rotary instruments without any fear of distortion. However the disadvantage of this material is its polymerization shrinkage. Thus to overcome this, newer light polymerized dimethacrylate modeling resins were used which can be manipulated with increased precision and stability after light polymerization.The advantage of these resins include low polymerization shrinkage, good dimensional stability, ease of use and absence of residue on burnout.

Computer–aided design/computer aided manufacturing (CAD/CAM) technology was introduced to dental community in the early 1980's. These systems fabricate the restoration by additive or subtractive methods. Additive rapid prototyping has been used in dentistry to generate copings and frameworks for bridges. An additive prototyping technique is being used to design and then print a wax pattern of a restoration. It operates like inkjet printer,the machine builds up wax patterns of frameworks and full crowns. The wax pattern is subsequently cast or pressed in the same manner as manually waxed restorations would be. Advanced printing unit that prints a resin type material instead of wax are also in use. The other similar technologies reported in literature are Stereo lithography (SL), Selective Laser Sintering (SLS) and Polyjet. Recently an additive prototyping technique and 3D printing is being used to design and then print a wax pattern or a resin pattern in a layer by layer manner to result in three dimensional objects which has good dimensional stability. The patterns obtained from this technique are subjected to casting procedures.

Historically, precious alloys have been used more frequently for casting, but the popularity of base metal alloys has increased since 1970's.

Base metal alloys have demonstrated good clinical performance and resistance to permanent intraoral deformation in most clinical situations.The high elastic modulus and hardness of base metal alloys are adequate for long span metal- ceramic restorations and removable partial dentures. The mechanical properties of base metal alloys and low cost of these alloys make them attractive to be used for fixed and removable partial dentures frame works.Titanium and its alloys are also being used as material of choice for restorative frameworks and copings especially when margins are placed sub gingival, due to its biocompatibility.[7] Previously Co-Cr alloys were primarily used for RPD frameworks. Currently they are also used more commonly than Ni-Cr alloys for fixed prosthesis.[52] Electrochemical studies show that Co-Cr alloys are more resistant to corrosion than Ni-Cr alloys. Nickel based alloys also have a greater sensitization potential than cobalt chromium alloys, whereas Co-Cr alloy allergies are rare. Furthermore, the casting of Co-Cr alloys has become a routine procedure in dental laboratories. The absence of allergic response and its rigidity made Co-Cr to be selected as material of choice for this study.[31, 34, 48, 52, 53, 57]

The fabrication of dental cast restorations with the base metal alloys by lost wax technique involves impression procedure, preparation of the die, fabrication of pattern, investing and casting. Difficulties encountered during casting of base metal dental alloys limit their use. Application of these alloys might be enhanced if casting procedure is completely eliminated and new techniques are used.One of the new techniques for fabrication of alloy copings reported in the literature is Direct Metal Laser Sintering (DMLS).

Direct Metal Laser Sintering (DMLS) is a new technique that replaces conventional metal casting procedures.[27, 29, 42, 49] DMLS is a CAD/CAM based technique in which frame works and metal copings can be designed and fabricated using cobalt chromium.[49] Cobalt chromium powdered alloy used in this technique has slight variations in composition. The molybdenum content in the alloy powder used in DMLS is comparatively less than the alloy which is used for conventional casting. This hi-tech process is sometimes described as 3D printing because it builds up each frame work in a series of successive thin layers (0.020 mm). A high power laser beam is focused on to a bed of powdered metal (Co-Cr) and these areas fuse into thin solid layer and another layer of powder is then laid down over this and the next slice of frame work is produced and fused with the first until framework or coping is finished.[24, 27]

The CAD/CAM process of producing copings by DMLS technique using automated scanning process and powerful CAD software offers many advantages such as complete control over the framework and coping designing, margin placement, cement space maintenance, coping thickness and pontic designs as well as elimination of casting procedures.[48] First a structure light optical scanner is used to scan the model for which we need a coping or a framework. The registration and triangulation algorithms are used to reconstruct the scanned data into STL file (Standard Template

Library-virtual model consisting in mesh of triangles) after which we obtain a virtual triangular solid model. In the coping design process, the first part is to find the margin lines of the prepared abutment teeth followed by programming the desired spacer thickness. Then the non uniform offsetting and shelling algorithms is proposed to create the coping shell model with variable thickness. The completed STL data of the restoration are fed to the CAM bridge software from where the data are forwarded to the building chamber of the DMLS machine which produces the final copings and frameworks.

Many of the previous studies have focused on evaluation of marginal and internal fit of cast restorations fabricated by different preparation designs, impression techniques, die preparation, spacer thickness, pattern fabrication, investment material and conventional casting techniques. However very few studies have been reported on the evaluation of marginal and internal fit of cast restorations by comparing the conventional casting techniques and the newly introduced DMLS technique.

In view of the above the present in-vitro study was conducted to comparatively evaluate the marginal gap and the internal gap of Co-Cr copings fabricated by conventional casting procedures and with Direct Metal Laser Sintering (DMLS) technique. In the conventional casting procedures, two different pattern forming techniques, namely, conventional inlay casting wax pattern fabrication and 3D printed resin pattern fabrication were employed.

The objective of the study included:

1. To evaluate vertical marginal gap of Co-Cr cast copings obtained from inlay casting wax pattern.
2. To evaluate vertical marginal gap of Co-Cr cast copings obtained from 3D printed resin pattern.
3. To evaluate vertical marginal gap of Co-Cr copings obtained from Direct Metal Laser Sintering (DMLS) technique.
4. To evaluate internal gap of Co-Cr cast copings obtained from inlay casting wax pattern.
5. To evaluate internal gap of Co-Cr cast copings obtained from 3D printed resin pattern.
6. To evaluate internal gap of Co-Cr copings obtained from DMLS technique.
7. To comparatively evaluate the vertical marginal gap of Co-Cr cast copings obtained from inlay casting wax pattern, 3D printed resin pattern and copings from DMLS technique.
8. To comparatively evaluate the internal gap of Co-Cr cast copings obtained from inlay casting wax pattern, 3D printed resin pattern and copings from DMLS technique.

REVIEW OF LITERATURE

Fusayama T (1959)[15] Dimensional accuracy is particularly critical for external restorations, such as cast crowns which grip the tooth from outside. He also stated that contraction of wax pattern during solidification and cooling and elastic recovery after removal are also as important factor as cooling shrinkage of wax patterns after removal from the preparation. Difference in setting expansion of the investment and wax pattern will distort the wax pattern or mould and restrict investment expansion. Casting shrinkage of metal varies according to form and size of the moulds. The cement space and the surface roughness should also be considered in measuring dimensional change of casting.

Fusayama T (1959)[16] reported in his studies that a base plate paraffin wax of a softening point slightly above the room temperature produced more accurate patterns than did inlay wax. The press molding of softened wax is superior since the molten wax results in greater strain from the resisted solidifying shrinkage. The strain made by plastic manipulation seems insignificant if the pattern is invested within 30 minutes after the removal and not subjected to temperature change during this time. In the same year in another study he stated the ideal total expansion of the investment for universal use is 2%, in which ideal thermal expansion is 1.95% and the ideal setting expansion is 0.05%. He also described clinical procedure for making precision casting.

M.Kamal EL-Ebrashi et al (1967)[14] Article on “Experimental stress analysis of dental restoration-part-III. The concept of geometry of proximal margins” reported that the chamfer and round type marginal preparation showed low stress concentration when loaded vertically. Rounding the axiogingival line angle in shoulder geometry experiments reduced stress concentration factor upto 50 %. The gingival area of proximal shoulders was critical location for stress concentration, and extra retentive features (pins or grooves) should not be placed in this area.

Cooney et al (1979)[11] did a study to evaluate the surface smoothness and fit of casting obtained by two phosphate bonded investments and one calcium sulfate investment. Also a modified technique was tested where the sol was used undiluted which gave longer working time and more fluid mix, which allowed easier investing with patterns. Results revealed that all phosphate bonded methods were comparable to each other and superior to that obtained with calcium sulfate investment.

Ogura et al (1981)[38] Inner surface roughness of complete cast crowns made by centrifugal casting machines was studied. Six variables that could affect the surface roughness of a casting were investigated-1.Type of alloy, 2. Mold temperature, 3. Metal casting temperature, 4. Casting Machine, 5. Sandblasting, 6. Location of each section. The summary of the study was that trailing portion of complete casting had rougher surface than the leading portion, higher mold and casting temperature produced rougher casting more in base metal alloy, sandblasting reduced rough surface but produced scratches, the morphology and roughness profile of the original cast surface differed considerably with the type of alloy used.

Lacy et al (1983)[32] The purpose of this study was to investigate the plated effects of (1) mixing rate, (2) ring liner position and (3) storage conditions on the setting expansion of both gypsum-bonded and phosphate-bonded investment molds; and subsequently to correlate casting size with measured data. Results reveal that the position and extent of ring liners, rates of mixing, and conditions of storage may be even more significant in determining ultimate casting size than classically accepted factors such as liquid/powder ratios or numbers of ring liners. The dynamic nature of setting expansion within the first 60 minutes after mixing suggests that consistent results demand waiting at least that long prior to burnout. If molds are to be stored overnight, maximum dimensional stability is probably ensured by keeping them in 100% relative humidity.

Plekavich et al (1983)[41] The study compared the adaptation of the margins of gold crowns produced from three impression-die combinations. Gold crowns were fabricated and cemented to prepared human teeth. After sectioning, the degree of margin opening was measured and the groups were compared. Crowns produced on silver dies from polysulfide impressions had smaller margin opening than crowns made on dies of improved stone.

Webb et al (1983)[55] Effects of preparation relief and flow channels on seating full coverage castings during cementation. Axial channels can significantly reduce marginal discrepancy during cementation of full coverage castings. Occlusal surface relief and occlusal channels do not result in significantly reduced marginal discrepancy during cementation. Occlusal modifications in conjunction with axial channels do not result in further significant reductions in marginal discrepancy when compared with the use of axial channels alone. The die modification technique used in this study has potential for clinical use in reducing marginal discrepancies during cementation procedures.

Blanco-Dalmau et al (1984)[34] published a study on Nickel allergy. He stated that Nickel is potentially allergenic material cause's contact dermatitis more common in women. Contact dermatitis is a prototype of hypersensitivity reaction mostly cellular one. It has two phase induction and elicitation phase. The induction phase is a period from initial contact with the chemical until the lymphocytes recognize andrespond to the chemical after initial contact. The elicitation phase is a period from re-exposure to the chemical until dermatitis appears. Nickel compounds stimulate this type immune response by their entrance through the connective tissue of the host on direct contact with skin or mucosa. He had strongly recommended a patch test to be performed on every patient who is treated with prosthesis that contains nickel to detect nickel sensitivity.

Marsaw et al (1984)[36] explained in his study on internal volumetric expansion of casting investments that a common problem with base metal alloy is undersized castings, a result of greater thermal contraction from higher solidification temperatures than with Nobel alloys. In casting alloys the setting and thermal expansion of the investment compensate for shrinkage of the metal during solidification and cooling. The linear expansion required for these alloys varies between 1.4% for gold alloys and 2.5% for base metal alloys

H.W.Dedmon et al (1985)[13] The purpose of the present study was to correlate the marginal fit of full cast crowns made by commercial dental laboratories with the design of the margin. Based on Christian's study, 39 µm was used as the maximum acceptable width of margin opening when the fit was evaluated on the dies.

Brune D et al (**1986)**[9] Levels of corrosion products released from dental alloys in natural or synthetic saliva, i.e. from amalgams, cobalt, gold, nickel, iron, or titanium based alloys have been surveyed. The amounts of Ag, Au, Cd, Co, Cr, Cu, Hg, Mo, Ti, or Ni released from such alloys, either in vitro or in vivo during animal tests or during clinical usage have been compiled. The quantities released have been adapted to a 'standard restored man' with a specified number of restorations or a specified construction with a defined surface area, and compared to man's food and drink intake or similar elements. This was done as one approach to a security analysis of wearing dental alloys. In view of the assessment of extensive corrosion testing using electrochemical methods, rather scarce information seems presently available pertinent to release kinetics of specific elements in various biological environments like saliva or saliva substitutes. From a base metal alloy with high nickel content the nickel could be released in vitro at the same level as from food and drink intake. However, from cobalt based alloys the nickel release seems insignificant.

Ivy Schwartz (1986)[43] had published a journal article in which he had suggested many methods to evaluate and improve the marginal adaptation of restorations 1. Overwaxing the margins of wax pattern by 0.25mm to 0.5mm with soft red utility wax so that the margins could be refined on the die before seating on the tooth, 2. Removing wax from internal surface of wax pattern, 3. Internal relief of cast restoration by sandblasting, mechanical milling with burs with and without disclosing wax, acid etching (aquaregia) electrochemical milling, 4. Occlusal venting for escape of excess cement, 5. Devices to apply seating forces, 6. Vibration during cementation, 7.die spacer application.

Holmes et al (1989)[23] described in his article that best way to visualize the marginal and internal discrepancy is by embedded and sectioned specimens or by direct visualization of the specimens or their replicas. The fit of a casting can be defined best in terms of the “misfit” measured at various points between the castings surface and the tooth. Measurements between the castings and the tooth can be made from points along the surface, at the margin, on the external surface of the casting.

Grajower et al (1989)[18] studied the dependence of seating crowns on the thickness of layers of spacers applied to dies. Extracted molars were prepared to designated taper angles. Polyether impressions were made and stone dies prepared and covered with one to five layers of new or old spacer materials in a predetermined manner. Wax pattern made and casted crown luted to the teeth invested in acrylic resin and sectioned and inspected. The application of spaces upto the shoulder margins of dies decreased the elevation of the casting above the margin of the tooth preparation until an average minimum elevation above the shoulder of the preparation was obtained. Further increase in spacer thickness increased cement thickness at axial walls but did not affect the elevation of the crowns at the margin. The optimum thickness of the spacer results in minimum elevation at the margin. Leaving the cervical part of the axial walls near the axial margin uncovered with spacer negates the effect of a thick spacer on remaining die surface, so it is contraindicated.

Hung et al (1990)[25] The marginal fit of Dicor, Cerestore and porcelain-fused -to- metal crowns was evaluated. Ten premolars free of caries were prepared for each type of restoration and crowns were made. Their studies showed the marginal openings significantly increased after cementation and thermo cycling. PFM crowns had better marginal fit than Dicor and Cerestore crowns.

A.J. Hunter et al (1990)[26] Thin finish lines have been advocated in the belief that they allow marginal closure through intraoral finishing and contribute to the maintenance of pulpal vitality. If maintaining a normal emergence profile is important, then wider margins allow easier fabrication of appropriately contoured crowns a while also improving rigidity and esthetics. While conservation of tooth structure is desirable, this principle is not an absolute contraindication to increasing marginal width beyond the minimum to accommodate the materials being used. Experience with shoulder preparations suggests that margin widths exceeding 0.3 mm are not usually incompatible with pulpal vitality. If the advantages of increased preparation were stressed, rather than the conservation of tooth tissue, dentists might be encouraged to increase marginal widths where possible.

Wiltshire et al (1996)[57] Allergies related to dentistry generally constitute delayed hypersensitivity reactions to specific dental materials. The dentist forms a vital link in team approach to the differential diagnosis of allergenic biomaterials that elicit symptoms in a patient, not only intra-orally, but also on unrelated parts of the body.

Groton et al (2000)[20] in his study had stated that a minimum of 50 measurements are required for clinically relevant information about gap size regardless of whether the measurement sites are selected or random manner.

It was of minor importance whether 50 measurements along the margin were randomly selected or recorded in distance of about 500 microns.

Ushiwata et al (2000)[50] used an accessory device for toolmakers microscope an innovative method for the marginal measurements of restorations. This study describes the fabrication of a device that allowed fixation of specimens on a tool maker’s microscope with identical conditions according to tri-dimensional positioning of specimens, measuring location, and seating force also the marginal measurement can be done throughout the periphery.

Bayramoglu G et al (2000)[3] The aim of this study is to determine the effects of the oral environment’s pH on the corrosion of dental metals and alloys that have different compositions, using electrochemical methods. The effect of pH on the corrosion of dental metals and alloys was dependent on their composition. Dissolution of the icons occurred in all of the tested pH states. The dissolution was moderately low for samples containing titanium because its surface was covered with a protective layer, whereas the dissolution was maximal for the samples containing tin and copper. Addition of cobalt and molybdenum to the alloys improved their corrosion resistance; these cobalt and molybdenum alloys were not affected by changes in the pH. Dissolution of the precious metal alloys increased as the percentage of noble metals increased. The corrosion characteristics of dental metals and alloys are important because the corrosion tendencies of dental alloys in the mouth may cause health hazards, weakening and the aesthetic loss of dental restorations.

Luthardt RG et al (2004)[35] Tested internal fit of using a innovative procedure of 3-D analysis. He directly digitized the master metal die using CEREC camera and dies that where duplicated from the master metal die were digitized using CEREC-3 scan and 24 all ceramic single crowns out of two glass ceramics were fabricated. The space between the duplicate die and the internal surface of the respective crown was filled with low viscosity addition silicone. These silicone films with corresponding dies were digitized in the same measuring position. Results stated that internal fit evaluation indirectly from impression (CEREC 3-scan) showed improved internal fit than direct digitizing (CEREC-camera) but the difference was small compared to their absolute values.

Machado Millan et al (2004)[37] did a study on influence of casting methods on marginal and internal discrepancy of complete cast crowns .The relationship between the application of die spacer prior to wax pattern fabrication and metal removal from the inner surface of the casting on marginal and internal discrepancies of complete cast crowns was evaluated. The best marginal fit were obtained with gas oxygen torch source. The 45 –degree chamfered shoulder showed the best marginal and inner fit, and better internal relief was obtained in the crowns abraded with 50 µm AL_2O_3 particles·

Person A et al (2006)[40] A study was done to determine the repeatability and relative accuracy of 2 dental surface digitization devices (laser scanner and touch probe scanner). The repeatability and accuracy of the experimental optical digitizer was comparable with touch probe surface digitization device. The results show that a non touching system has good potential to serve as input in manufacturing system for fixed dental prostheses.

Viennot et al (2006)[52] in his clinical report on combination of fixed and removable prosthesis using a Co-Cr alloys had stated that Co-Cr alloys were primarily used for RPD frameworks, currently they are also used more commonly than Ni-Cr alloys for fixed prostheses. Co-Cr alloys contain predominantly cobalt, and sometimes tungsten in small amounts and possess high rigidity and hardness. Electrochemical studies show that Co-Cr alloys are more resistant to corrosion than Ni-Cr alloys.

Bottino et al (2007)[8] studied the influence of cervical finish line ,internal relief ,cement type on the cervical adaptation of metal crowns stated that best cervical adaptation was achieved with chamfer type of finish line,the internal relief improved marginal adaptation significantly and glass ionomer cement led to best cervical adaptation followed by zinc phosphate and resin cement.

Wazzan et al (2007)[54] in vitro study was to investigate the marginal accuracy and internal fit of complete cast crowns after sectioning and reorienting the casted single crowns and fixed partial dentures casted with pure titanium and titanium alloy. In his study he reported that titanium alloy (Ti-6AL-4V) demonstrated less fit discrepancy than commercially pure Ti castings and single crown offered better fit than FPD and mid occlusal internal fit demonstrated greater gap discrepancy than axial internal fit.

Siadat et al (2008)[44] in his journal article on scanning electron microscope evaluation of marginal discrepancy of gold and base metal implant supported prostheses with three fabrication methods had mentioned that framework fabricated using noble alloys had more vertical and horizontal discrepancy than base metal alloys.

Hong-Tzong Yau, Chien-Yu Hsu (2008)[24] in his article on computer–aided "Framework Design For Digital Dentistry" which aimed in proposing a customizing dental framework design system to improve artificial teeth production .In his paper he had explained about scanning, and how the registration and triangulation algorithms are used to reconstruct the scanned data to triangular solid model,the non uniform offsetting and shelling algorithm is proposed to create the coping shell model with variable thickness.

Quante et al (2008)[42] In vivo investigation evaluate the marginal and internal fit of metal-ceramic crowns fabricated with a laser melting technology and to investigate the influence of ceramic firing on the marginal accuracy of these crowns .Results show that mean marginal discrepancy ranged from 74 -99 microns and the internal gap ranged from 250-350 microns and ceramic firing increased the marginal gap and the internal gaps decreased especially at occlusal surface.

Tan et al (2008)[47] In vitro comparison of vertical marginal openings of cast restorations, computer aided design, and computer aided machine restoration concluded that there was no difference between the vertical marginal gaps of the CAD/CAM and WAX /CAM. His study results show that the WAX/CAST technique resulted in smaller vertical marginal gaps than either CAD/CAM or WAX/CAM.

Gordon j et al (2008)[10] did a observation where he mentioned that CAD/CAM restorations serve no better or worse than do their conventional counterparts, and that their clinical longevity is highly operator dependent.

Akova et al (2008)[1] Compared the shear bond strengths of cast Ni-Cr and Co-Cr alloys and the laser sintered Co-Cr alloy to dental porcelain. They concluded their study saying that new laser-sintering technique for Co-Cr alloy appears promising for dental applications but additional study of properties of this technique is needed before application.

Bedi et al (2008)[4] did a study on the effect of different investment techniques on the surface roughness and irregularities of gold palladium alloy castings. Phosphate bonded investment was used half the specimen were invested using vacuum mixer, while the reminder was invested using vacuum mixer and investor again each half of the group were divided into two groups half of them left to set under atmospheric pressure and half under compression chamber under a pressure of 3 bars for 24 minutes then allowed to bench set for 36 minutes. Profilometer was used to evaluate the roughness of the castings. The results suggested that the specimens set under positive pressure are much more likely to present surface irregularities than specimens under positive pressure.

Beur et al (2009)[5] Conducted a study to find the influence of the preparation angle on marginal and internal fit of CAD/CAM fabricated zirconia crown copings and concluded that highest marginal gap were found in 4 and 8 degree groups. In the groups with 12 degree preparation angle, additional adaptation did not improve the fit.

Gonzalo et al (2009)[17] The purpose of this in vitro study was to compare changes in marginal fit of posterior fixed dental prostheses of 3 zirconia systems manufactured using CAD/CAM technology and metal ceramic posterior fixed dental prostheses fabricated with the conventional lost-wax technique, before and after cementation. The results of this study showed that cementation did not cause a significant increase in the vertical marginal discrepancies of the FDPs and that an internal space of 50 µm provided a high precision of fit of the restorations.

Ibrahimet al (2009)[27] Compared dimensional error of selective laser sintering ,three-dimensional printing and Polyjet models in the reproduction of mandibular anatomy The results revealed that SLS model had dimensional error of 1.79% and was more accurate than Polyjet 2.14% and 3DP models 3.14%.

Yurdanur Ucar et al (2009)[49] Compared the internal fit of laser sintered Co-Cr alloy crowns with conventionally casted copings fabricated using Co-Cr and Ni-Cr copings. The internal fit was examined 3 dimensionally using weighing of the light body silicone which were used to cement the copings and 2 dimensionally after embedding and sectioning of copings.The light body silicone weight used to provide relative comparison for the fit of castings was relatively high for laser sintered Co-Cr alloys,however sectioned crown specimens showed no much difference among the three groups.

Holden et al (2009)[22] did study to compare the marginal adaptation of a pressed ceramic material used with a metal and without metal substructure to traditional feldspathic porcelain fused a metal restoration with a porcelain butt margin. The pressed to metal restoration reported with a smaller mean marginal opening than metal ceramic restoration and all ceramic restoration but all were within acceptable range.

Tara et al (2011)[48] did a study to evaluate the clinical outcome of metal –ceramic crowns fabricated with laser sintering technology.47 months of clinical observation revealed promising results and the outcomes were comparable to that of conventionally fabricated metal ceramic crown.

MATERIALS AND METHODS

An in vitro study was conducted to comparatively evaluate the marginal gap and internal gap of Co-Cr copings fabricated by conventional casting procedures and with Direct Metal Laser Sintering (DMLS) technique. In the conventional casting procedures, two different pattern forming techniques namely conventional inlay casting wax pattern fabrication and 3D printed resin pattern fabrication were employed.

Materials used for the study:

1. Stainless steel master model with former assembly (Custom-made). (Fig.1a,1b)
2. Polyvinyl siloxane putty and light body (Aquasil Densply Germany). (Fig.6a)
3. Die stone (Type IV , Ultrarock, Kalabhai, Mumbai) (Fig.6b)
4. Die spacer (YETI, Germany).(Fig.8a)
5. Die lubricant (YETI, Germany).(Fig.8b)
6. Inlay casting wax (GC Corporation, Tokyo,Japan).(Fig.9a)
7. Sprue wax (Bego, Germany). (Fig.9c)
8. Surfactant spray (Aurofilm, Bego, Germany).(Fig.8c)
9. Siliring (Delta labs Chennai, India).(Fig.9b)
10. Phosphate bonded investment (Bellasun, Bego, Germany).(Fig.9d)
11. Colloidal silica (Begosol, Bego, Germany).(Fig.9d)

12. Base metal Co-Cr alloy (Denchrome-C, CE Germany).(Fig.9e)
13. Separating discs (Fig.20b)
14. Aluminum oxide powder (110µm). (Delta labs,Chennai, India). (Fig.19b)
15. Tungsten carbide burs. (Edenta, Switzer land) (fig.20c)
16. PKT instruments (Fig.9f)
17. Pressure indicating paste.(Fit checker II GC Corporation, Tokyo, Japan) (Fig.23)

Equipments used for study

- ❖ Vacuum powder mixer (Whipmix, Kentucky USA). (Fig.17)
- ❖ Burnout furnace (Technico, ind products, Chennai). (Fig.18a)
- ❖ Induction casting machine (Fornax Bego, Germany). (Fig.18b)
- ❖ Sandblaster (Delta labs.Chennai,India).(Fig.19a)
- ❖ Alloy grinder (Demco, California, U.S.A).(Fig.20a)
- ❖ D 700 3D scanners (3 Shape Dental System, Copenhagen K, Denmark).(Fig.12 a)
- ❖ Lava –ST Scanner (3M ESPE US).(Fig.15a)
- ❖ Project HD 3000 3D printer (3D Systems Corporation, Three D Systems Circle, Rock Hill, Germany).(Fig.12b)
- ❖ Direct Metal Laser Sintering Machine - (EOSINT M 270).(Fig.15b)
- ❖ Video Measuring System (VMS2010F, CIP Corporation-Korea).(Fig.25)
- ❖ Dental surveyor. (Paraflex, Bego Germany) along with custom made platform and a 2kg weight.(Fig.24)

Description of custom made stainless steel master model.

A custom – made stainless steel master model (Fig.1a) was prepared simulating the shape and dimension of tooth preparation resembling a first molar using a CNC Milling Machine.

The stainless steel master model and stainless steel former, (Fig.1b) employed in this study were custom made, based on the model employed by Ushiwata O, de Moraes JV et al[50] for their studies with a little modifications.

Stainless steel master model comprises of the following four sections.

1. Tooth preparation section.**(P)** (Fig.3a)
2. Cylindrical section.**(C1)** (Fig.3a)
3. Trough around the cylindrical section.**(T)** (Fig.3a)
4. Octagonal base.**(C2)** (Fig.3a)

1. **Tooth preparation section (P)**

(The shape and dimension of tooth preparation section resembled a maxillary first molar.)

a. 8mm in cervical diameter
b. 7mm in height.
c. Axial reduction of 1.2mm.
d. Rounded axial line angles.
e. 10 degree occlusal surface inclination.

f. 135 degree chamfer finish line.

g. Occlusal bevel resembling functional cusp bevel at 45°

2. **Cylindrical section (C1)**

   The first cylindrical section (C1) of the metal die was contiguous to tooth preparation finish line with 10mm height and 8mm diameter.

3. **Trough around the cylindrical section.(T)**

   A trough of 4mm width around the cylindrical section for collection of over flowing wax during wax pattern fabrication with inlay casting wax was designed. When the counterpart (master model assembly) is being mounted by the master die (Fig.7), the excess melted inlay casting wax will over flow through these slits and gets collected in this trough (Fig.10d) which in turn ensures complete seating of the master die to the counterpart. Also this complete seating ensures wax patterns to be obtained of even thickness.

4. **Octagonal base (C2)**

   The octagonal section (C2) was 35mm in height and 25mm in diameter. External surface of (C2) cylindrical section was equally divided into 8 parts Fig.(5a) which helps in placement of master model on the platform of the video measuring system device such that light rays falling on the specified area of the die along with coping is perpendicular, while measuring the marginal and internal discrepancy of copings.

A custom made stainless steel former was fabricated, such that the former could be accurately positioned over the stainless steel die. The stainless steel former was larger than the die in all dimensions by 0.5mm uniformly (Fig.4). This was done to maintain a space of 0.5mm throughout between the die and the former. This space helped to obtain the pattern copings with uniform thickness. The counterpart also had three vertical slits (Fig.2b) which acts as escape hole for the excess molten inlay casting wax that comes out during assembling of master die to the metal counterpart (Fig.10c). These slits are channels to dissipate inbuilt pressure and ensures in complete seating of master die assembly to the metal counterpart.

METHODOLOGY

In this study 20 test samples of cast Co-Cr copings were fabricated by conventional casting procedures. Two different pattern forming techniques namely inlay casting wax pattern and 3D printed resin pattern were employed for casting procedure.10 test samples of Co-Cr copings were fabricated from DMLS technique. A total of 30 test samples were fabricated and grouped as follows:

Group 1: Cast Co-Cr test samples obtained by using inlay casting wax pattern (10 samples) (G1)

Group 2: Cast Co-Cr test samples obtained by 3D printed resin pattern. (10 samples) (G2)

Group 3:Co-Cr test samples obtained using Direct Metal Laser Sintering (DMLS) (10 samples) (G3)

I. Preparation of master die.

II. Fabrication of cast Co-Cr copings with inlay casting wax patterns-(G1).

  - Preparation of inlay casting wax pattern
  - Sprue former attachment
  - Investing procedure
  - Burn out procedure
  - Casting procedure
  - Divesting and finishing of cast copings

III. Fabrication of cast Co-Cr copings with 3D printed resin patterns-(G2)

  - Preparation of 3D printed resin pattern
  - Sprue former attachment
  - Investing procedure
  - Burn out procedure
  - Casting procedure
  - Divesting and finishing of cast copings

IV. Fabrication of Co-Cr copings with DMLS technique (G3)

V. Cementation of the test samples (Co-Cr copings) on the master model
    a. Cementation procedure of the test samples before vertical marginal gap evaluation.
    b. Cementation procedure of the test samples before internal gap evaluation.

VI. Measurement of vertical marginal gap and internal gap in microns using Video Measuring System (VMS2010F)
    a. Vertical marginal gap of the test samples (G1, G2, G3)
    b. Internal gap of the test samples (G1,G2,G3)

This study evaluated the vertical marginal gap and internal gap of all 30 test samples and results were tabulated for statistical analysis.

I. Preparation of master die (Fig.6,7)

An elastomeric impression of the custom-made stainless steel model was made using addition silicone (Fig.6a) using single stage technique. Type IV dental stone (Fig.6b) was mixed in w/p ratio recommended by the manufacturer. The mixed die stone material was poured into the mold. After setting a single master die (Fig.7) was obtained which was used for fabrication of all the test samples in the study.

II. Fabrication of cast Co-Cr copings with inlay casting wax patterns- (G1) (Fig. 10,11)

- **Preparation of patterns from inlay casting wax. (Fig.10)**

The master die was treated with die hardner and 3 coats of die spacer (Fig.8a) (YETI, Germany). 10 microns per coat was applied on the die to create 30 microns space, simulating the luting cement space, 1mm short of the margin (Fig.10a). A fine coat of die lubricant (Fig8b) (YETI, Germany) was applied onto the die and the fitting surface of the stainless steel former using a small paint brush. It allows easy removal of the wax pattern from the die and prevents the pattern from adhering to the stainless steel former. The inlay casting wax (Fig.9a) (GC Corporation, Tokyo, Japan) was melted and filled in the stainless steel former and was pressed on with the type IV die stone master die (Fig.10c). The master die and stainless steel die former assembly was held together for 1 minute with finger pressure. The die was then separated from the former (Fig.10d) and wax pattern margins were readapted (Fig.10e). The excess wax below the margin was trimmed using a PKT carver (Fig.10f). A pattern of uniform thickness of 0.5mm was obtained (Fig.10g). The pattern was checked for uniform thickness of wax using a wax caliper.

- **Sprue former attachment for the inlay casting wax patterns (Fig.11a)**

Wax Patterns were connected to a manifold sprue (Bego, Germany) of 2.5mm thick at their thickest portion which is the bevel region, in turn were connected to horizontal runner bar of 3.5mm preformed round wax sprue. The horizontal runner bar was connected to feeder sprue of 5mm diameter which was bent to semicircle in shape. The open arms connected to the runner bar and the bent portion to the base of the crucible former.

- **Investing procedure for inlay casting wax patterns. (Fig.11c,d,e,f)**

All the inlay wax patterns were invested using graphite free, phosphate bonded investment material (Fig.9d) (Bellosun, Bego, Germany). A 6mm distance was provided between the margin of coping and top of the ring (Siliring, Delta, India). As per the manufacturer's recommendation, 160gm of phosphate bonded investment requires 30ml of colloidal silica (Fig.9d) mixed with 8ml of distilled water in the ratio of 75:25 respectively. The patterns along with the sprue is treated with surfactant spray prior to investment (Fig.11b). The investment material powder and liquid were first hand mixed (Fig.11c) until the entire material was wetted thoroughly followed by vacuum mixing for 30 seconds (Fig.17). Siliring was positioned on the crucible former and patterns were painted with a thin layer of investment using a small paint brush (Fig.11d). Remainder of investment was vibrated slowly into the ring (Fig.11e). The invested patterns were allowed to bench set for 20 minutes.

- **Burn out procedures for inlay casting wax patterns (Fig.11g)**

After a 20 minutes bench time, the set investment mold was placed in the burnout furnace (Fig.11g) (Technico Laboratory Pvt. Ltd, Chennai, India). Burn out of the wax patterns was done using a programmed preheating technique. The investment was kept in a furnace at room temperature and was heated continuously till 950°C at the rate of 8°C/min. The investment mold was initially placed in the furnace such that the crucible end was in contact with the floor of the furnace for the escape of melting wax. The investment mold was reversed later near the end of the burn out cycle with the space hole facing upward to enable the escape of the entrapped gases and allow oxygen contact to ensure complete burnout of the wax patterns and allow mold expansion.

- **Casting procedure for inlay casing wax patterns (Fig.11h)**

Casting (Fig.11h) was accomplished with a Co-Cr alloy (Fig.9e) (Denchrome-C, CE, Germany) melted in an induction casting machine (Fig.18b) (FornaxGeu, Germany). The casting procedure was performed quickly to prevent heat loss resulting in the thermal contraction of the mould. The Co-Cr alloy was heated sufficiently till the alloy ingot turned to molten state, and the crucible was released and centrifugal force ensured the completion of the casting procedure. This procedure is repeated for all 10 patterns from inlay casting wax.

- **Divesting and finishing of cast copings obtained from inlay casting wax patterns (Fig.11i, j & k)**

Following casting the hot casting ring was bench cooled to room temperature. Divesting was done to retrieve the cast coping from the investment (Fig.11i). Care was employed to prevent damage to the margins. Adherent investment was removed from the casting by sandblasting (Fig.11j) with 110µm alumina (Fig.19b) at 80 psi pressure. The sprue was cut with the help of thin carborundum disc (Fig.20b) and the area of its attachment was recontoured. The internal surface of the copings were inspected under magnification and relieved of all nodules with a round carbide bur (Fig.20c) and steam cleaned for. This procedure was repeated for all the 10 Co-Cr cast copings obtained from inlay casting wax pattern. After completion of these procedures the 10 cast copings obtained were labeled as group 1 (G1) test samples.

III. Fabrication of cast Co-Cr copings with 3D printed resin patterns- (G2) (Fig.13,14)

- **Preparation of 3D printed resin pattern (Fig.13)**

In this study the resin patterns were prepared with 3 Dimensional Printing technology using 3shape D700 scanner (Fig.12a) for scanning the die and a project HD 3000 printer (Fig.12b) was used for fabricating patterns and the material used is epoxy resin containing reacting diluents. This system is CAD/CAM based and works on additive mechanism that forms patterns layer by layer.The type IV die stone master die is scanned using a 3 shape D 700 scanner which guarantees superior scan results. (The scanning of the master die for fabricating 3D printed resin pattern was done before the master die was used for fabricating inlay casting wax pattern).The scanner employs a unique 2 cameras and 3 axis motion system, which results in accuracy of the object geometry acquisition. The 3 axis motion system facilitates easy object placement, full undercut scanning and impression scanning. The 3-axis allows the object to be tilted, rotated and translated so as to be scanned from any viewpoint, making 3-axis the optimal number of axis for a scanning volume corresponding to a dental model. The system's powerful algorithms automatically detect the margin line (Fig.13b). The system is also flexible, allowing the user to modify the preset line with built-in-design tools; such as the "fast edit"and the "red pencil", which in effect replicates the red pencil used on models in the lab. The desired spacer thickness of 30µm is programmed 1mm short of the margin (Fig.13c). Designing of the coping is done using the default set parameters for a coping thickness of 0.5mm, (Fig.13f) and anatomical form on the CAM software. The design thus created is transferred to the 3D printer (rapid prototyping machines). In the three dimensional printing (3DP) technique, the printer has a reservoir of polymeric powder, a build tray moves down, a roller to distribute and evenly spread the layer of powder, and a print head that distributes a binding material. First, the reservoir along with roller moves over the build tray and evenly spreads a uniform layer of powder; the print head moves in the X and Y axis and releases a jet of binder onto the powder; and the binder fuses the powder. After that, the platform moves down; another layer of powder is deposited and receives the jet of binder. This second layer fuses and adheres to the previous layer, and the process is repeated to result in the 3 dimensional pattern (Fig.13f). In this manner a total of 10 resin patterns were obtained with 3 Dimensional Printing (3DP) technology. The resin pattern was checked for the uniform thickness for 0.5mm with the wax caliper.

- **Sprue former attachment for 3D printed resin patterns (Fig.14a)**

3D printed resin patterns were connected to a manifold sprue (Bego, Germany) of 2.5mm thick at their thickest portion which is the bevel region, in turn were connected to horizontal runner bar of 3.5mm preformed round wax sprue. The horizontal runner bar was connected to feeder sprue of 5mm diameter which was bend to semicircle in shape, The open arms connected to the runner bar and the bend portion to the base of the crucible former (Fig.14a).

➢ Investing procedures for 3D printed resin patterns (Fig.14c,d,e,f)

All the 3D printed resin patterns were invested using graphite free, phosphate bonded investment material (fig.9d) (Bellosun, Bego, Germany). A 6mm distance was provided between the margin of coping and top of the ring (Siliring, Delta, India). As per the manufacturer’s recommendation, 160gm of phosphate bonded investment requires 30ml of colloidal silica (Fig.9d) mixed with 8ml of distilled water in the ratio of 75:25 respectively. The patterns along with the sprue is treated with surfactant spray prior to investment (Fig.14b). The investment material powder and liquid were first hand mixed (Fig.14c) until the entire material was wetted thoroughly followed by vacuum mixing for 30 seconds (Fig.17). Siliring was positioned on the crucible former and patterns were painted with a thin layer of investment using a small paint brush (Fig.14d). Remainder of investment was vibrated slowly in to the ring (Fig.14e). The invested patterns were allowed to bench set for 20 minutes.

➢ Burn out procedurefor 3D printed resin patterns (Fig.14g)

Casting rings were heat treated (Fig.14g) for 3 hours in a burnout furnace. During the first hour, the temperature was raised from room temperature to 380^{o} C; for the second hour, the temperature was raised to 900^{o}C to accomplish complete burnout of the patterns with no residues remaining. The investment mold was initially placed in the furnace such that the crucible end was in contact with the floor of the furnace for the escape of resin material. The investment mold was reversed later near the end of the burnout cycle with the sprue hole facing upward to enable the escape of the entrapped gases and allow oxygen contact to ensure complete burnout of the patterns and allow mold expansion.

- **Casting procedure for 3D printed resin patterns (Fig.14h)**

Casting (Fig.14h) was accomplished with a Co-Cr alloy (Fig.9e) (Denchrome C, CE, Germany) melted in an induction casting machine (Fig.18b) (Fornax Geu, Germany). The casting procedure was performed quickly to prevent heat loss resulting in the thermal contraction of the mould. The Co-Cr alloy was heated sufficiently till the alloy ingot turned to molten state and the crucible was released and centrifugal force ensured the completion of the casting procedure. This procedure is repeated for all 10 patterns from 3D printed resin.

- **Divesting and finishing procedure for cast copings obtained from 3D printed resin patterns. (Fig.14i, j & k)**

Following casting, the hot casting ring was bench cooled to room temperature. Divesting was done to retrieve the cast coping from the investment (Fig.14i). Care was employed to prevent damage to the margins. Adherent investment was removed from the casting by sandblasting (Fig.14j) with 110 alumina (Fig.19b) at 80 psi pressure. The sprue was cut with the help of thin carborundum disc (Fig.22a) and the area of its attachment was recontoured. The internal surface of the copings were inspected under magnification and relieved of all nodules with a round carbide bur (Fig.20c) and steam cleaned for. This procedure was repeated for all the 10 Co-Cr cast copings obtained from patterns formed using 3D printed resin pattern. After completion of these procedures the 10 cast copings obtained from 3D printed resin pattern were labeled as group 2 (G2) test samples

IV. Fabrication Co-Cr copings with Direct Metal Laser Sintering- (G3) (Fig.16)

The same type IV die stone master die was scanned using Lava-ST Scanner (Fig.15a) and the registration and algorithms are used to reconstruct the scanned data to a triangular solid model. (The scanning of the master die for fabricating Co-Cr copings with DMLS was done before the master die was used for fabricating inlay casting wax pattern). The margin location and the spacer thickness adaptation techniques are similar to the 3 shape D 700 Scanner which was used for 3D resin pattern. Then the non uniform offsetting and shelling algorithm is proposed to create the coping shell model with uniform thickness of 0.5mm. The STL data (Fig.16e) thus obtained forwarded to CAM bridge (Fig.15b) which is a professional software for automatic part placement, orientation and identification if in case multiple scanned STL data are fed to the CAM bridge. From here the data are forwarded to building chamber (Fig.15b) where infrared laser beam is used to fuse the (Co-Cr) powder, layer by layer to produce the solid object. Production begins once a layer of powder is spread across the build platform, which then is evenly spread with a powder leveling roller. The laser beam (Fig.16f) scans the powder surface heats the particles and fuses them. After the first layer solidifies the built platform moves another layer of powder, which is again sintered by the laser beam. The process is repeated until the coping is completed (Fig.16g). After completion of these procedures 10 copings were obtained which were sandblasted with 110µm aluminum oxide powder and steam cleaned and labeled as group 3(G3) test samples.

V. Cementation procedure of the Co-Cr copings test samples on the master model using pressure indicating paste. (Fig.21, 22)

a) Cementation procedure before evaluation of vertical marginal gap (Fig.21)

All 30 test samples were applied with a thin layer of pressure indicating paste (Fig.21a) and cemented on the stainless steel die and a load of 2kg is applied for 2 minute, with coping tang against the vertical axis of the tooth preparation section using a surveyor (Fig.24). The 2 kg load was placed over a custom made metal platform. The platform had a slot in the center, half the depth of its thickness which stabilizes it when placed over the vertical arm of the surveyor and this same procedure was followed for applying load for all the 30 test samples. This was done to simulate a coping cemented in the oral condition. Pressure indicating paste (Fig.23) was used for cementing purpose as it was easy for retrieval of the copings from the model without any damage to the coping and the master model. The vertical marginal discrepancy was determined as the maximum distance between the tooth preparation margin and the most apical part of the casting margin in a plane parallel to the long axis of the tooth preparation.[20]

b) Cementation procedure before evaluation of internal gap. (Fig.22)

After the evaluation of vertical marginal gap the copings were removed from the master model .All the 30 copings were partially sectioned with carborundum discs in such a way that, a band of the coping, 3mm from the margin remains even after sectioning which helps in reorienting sectioned coping on the stainless steel master model (Fig.22). Previously applied pressure indicating paste were removed from the internal surface of copings and coated with a new thin layer of pressure indicating paste and they were reoriented on the metal model under the same load of 2kg, for 2 minutes and they were evaluated for internal gap. The 2 kg load was placed over a custom made metal platform (Fig.24). The platform had a slot in the center half the depth of its thickness which stabilizes it when placed over the vertical arm of the surveyor and this same procedure was followed for applying load for all the 30 test samples.

V. Measurement of vertical marginal gap and internal gap using Video Measuring System (VMS2010F)

All the 30 test samples of groups G1, G2and G3 were evaluated for vertical marginal gap employing Video Measuring System (VMS2010F) (Fig.25) in microns. The same copings from the groups G1, G2 and G3 were partially sectioned (Fig.21b) and the copings were evaluated for internal gap employing Video Measuring System.

Description of Video Measuring System (VMS2010F) (Fig.25)

Video measuring system is a photoelectric measuring system of high precision and efficiency. It is composed of a series of components, such as a camera (SONY 1/2" Color CCD Camera) of high resolution & continuous zoom lens (NAVITAR: 0.7 ~ 4.5X), Color monitor (17”), video crosshairs generator, precision linear scale, multi-functional digital readout (DRO), 2D measuring software and high precision worktable. It has a resolution of 0.001mm.

It is supplied with RS-232 interface which can communicate between measuring software and computer. The user can manage and output the graph by connecting with PC and running the M2D program. The sample to be measured is placed on the glass table platform of size 260×160 mm which can be moved adjusting the knobs on the platform. The samples on the glass table can be moved in four directions to view different areas of the samples. The magnified images of the samples are projected on the computer screen, which is facilitated by the software. Using the software, both linear and angular measurements are possible and the magnified images on the screen can also be captured and saved for later reference.

a) **Measurement of vertical marginal gap for (G1,G2,G3) (Fig.26,27 & 28)**

The vertical marginal gap at the margin of the casting and the die was measured using VMS2010F which has a sensitivity of 1 micron. Marginal gaps were measured to the nearest micron on each cast coping at the 8 predetermined reference areas on the stainless steel master model separated by 45 degrees (Fig.5a). The same procedure was followed to record the vertical marginal gap for all samples of each of the three test groups. The measurements thus obtained were tabulated. For each samples the mean vertical marginal gap was obtained and the overall mean vertical marginal gap for that test group was obtained from these means. The results thus obtained were statistically analyzed.

Measurement of internal gap for groups (G1, G2, G3) (Fig.29, 30, 31)

The internal gap was evaluated after cementation of the partially sectioned copings with pressure indicating paste, at four predetermined reference areas. The four areas were (Fig.5b)

(A) Axial wall on the non beveled side

(B) Occlusal

(C) Over the beveled region.

(D) Axial wall on the beveled side

The internal gap between the inner surface of the copings and the external surface of the stainless steel master model in these regions were measured, using **(VMS2010F)** to the nearest microns. The measurements thus obtained were tabulated. For each samples the mean internal gap was obtained and the overall mean internal gap for that test group was obtained from these means. The results thus obtained were statistically analyzed.

All statistical calculations were performed using Microsoft Excel (Microsoft, USA). The SPSS (SPSS for Windows 10.05, SPSS Software Corp. Munich, Germany) software package was used for statistical analysis. ‘T’-test was used to compare the mean values of each test groups and a P value < 0.05 was considered statistically significant.

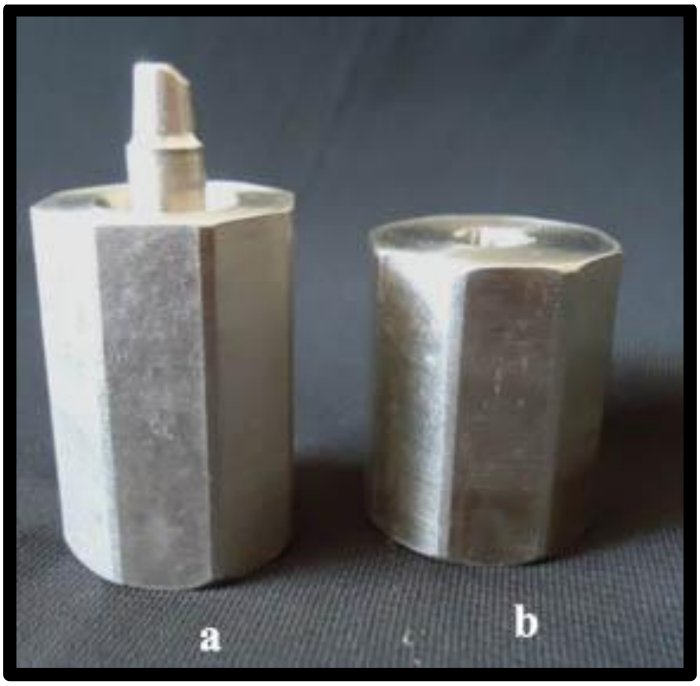


Fig.1a: Axial view of custom-made stainless steel model
b: Stainless steel former assembly

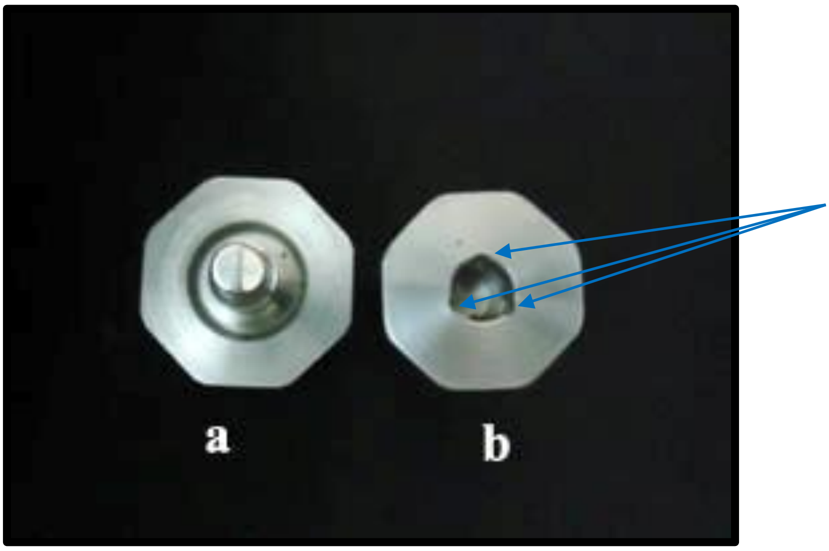
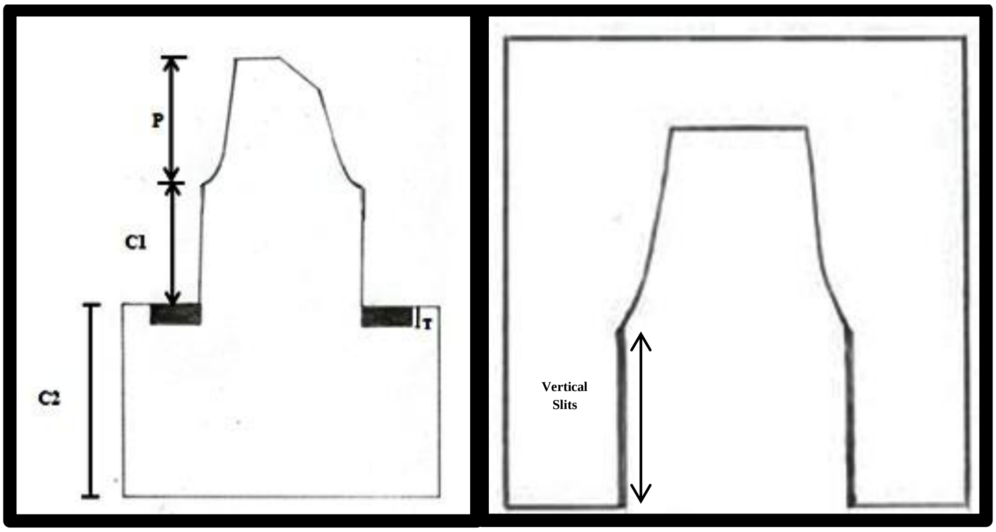


Fig.2a: Occlusal view of custom- made stainless steel model
b: Stainless steel former assembly showing 3 vertical slits



a b

Fig.3a: Line diagram of custom- made stainless steel model

1)Tooth preparation section-**(P)**,2) Cylindrical section-**(C1)**,

3) Trough around the cylindrical section-**(T)**, 4)Octagonal base-**(C2)**

b: Stainless Steel Former assembly

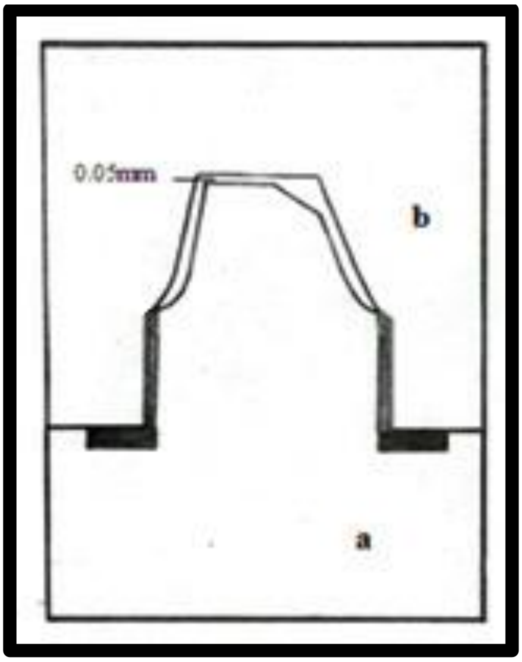
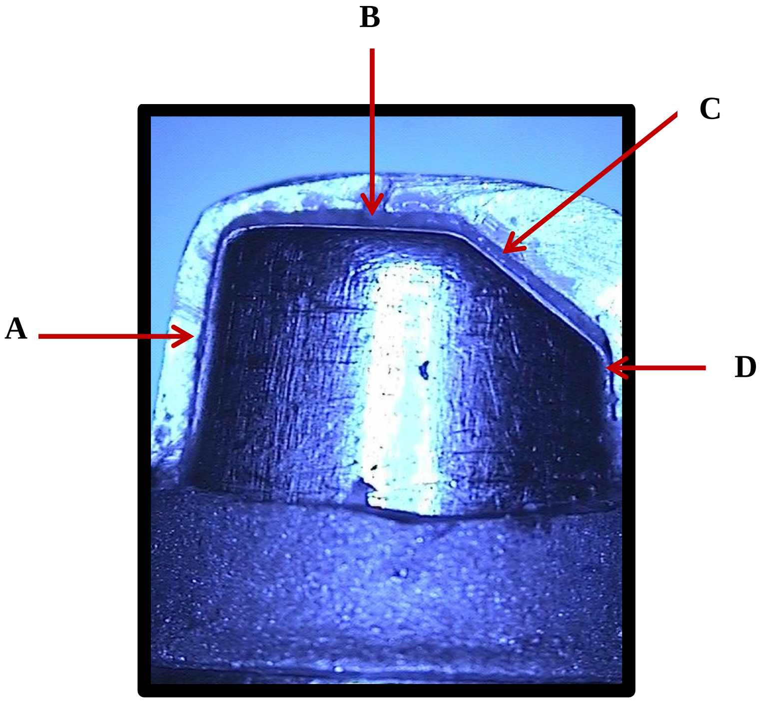


Fig.4a: Line Diagram of Custom made Stainless Steel Model

b: Stainless steel former assembly in apposition

Fig.5a:Schematic representation of 8 predetermined reference areas to be measured for vertical marginal gap



b

Fig.5b: Schematic representation of 4 predetermined reference areas to be measured for internal gap

A-Axial wall on the non beveled side, B-Occlusal

C-Over the beveled region, D-Axial wall on the beveled side

Preparation of Master Die

Materials used for Impression Making and Master Die Preparation

Fig.6a: Polyvinyl Siloxane Putty and Light Body Impression Material

b: Type IV die stone

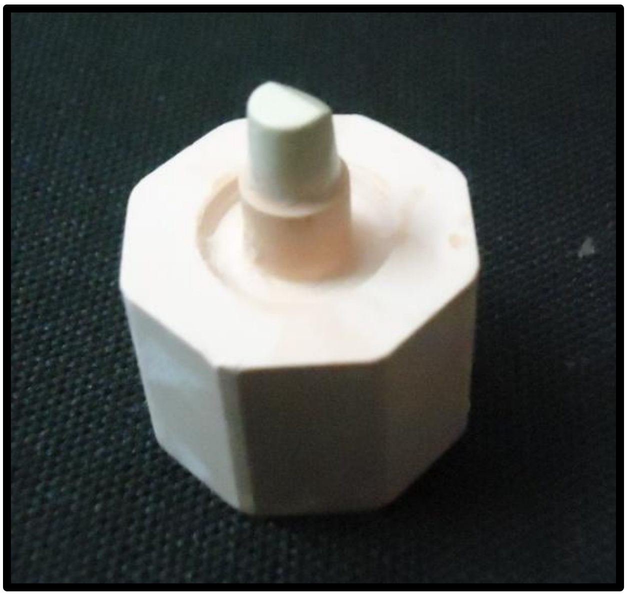


Fig.7: Master die (Type IV die stone)

Fig.8a: Die spacer b: Die Lubricant c: Surfactant Spray

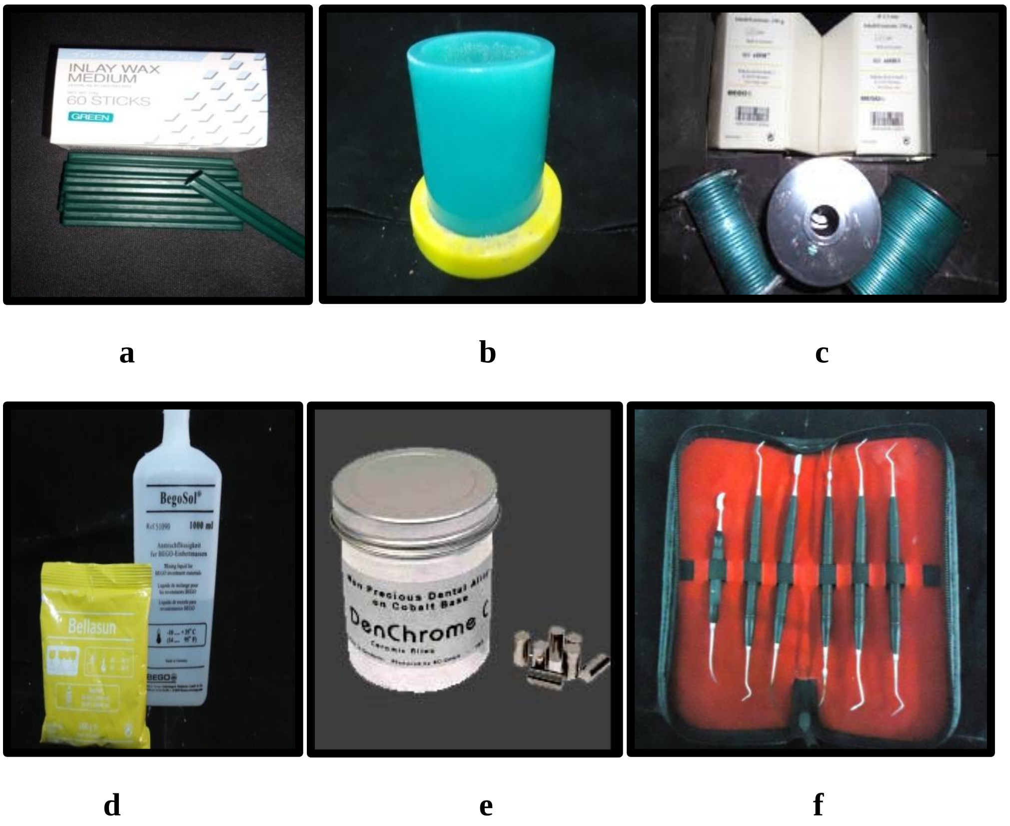


Fig.9a) Inlay Casting Wax, b) Siliring, c) Sprue Wax, d) Phosphate Bonded Investment, e) Denchrome-C Alloy (Co-Cr Alloy Pellets), f) PKT Instruments

Fig. 10: Preparation of Inlay Casting Wax Patterns

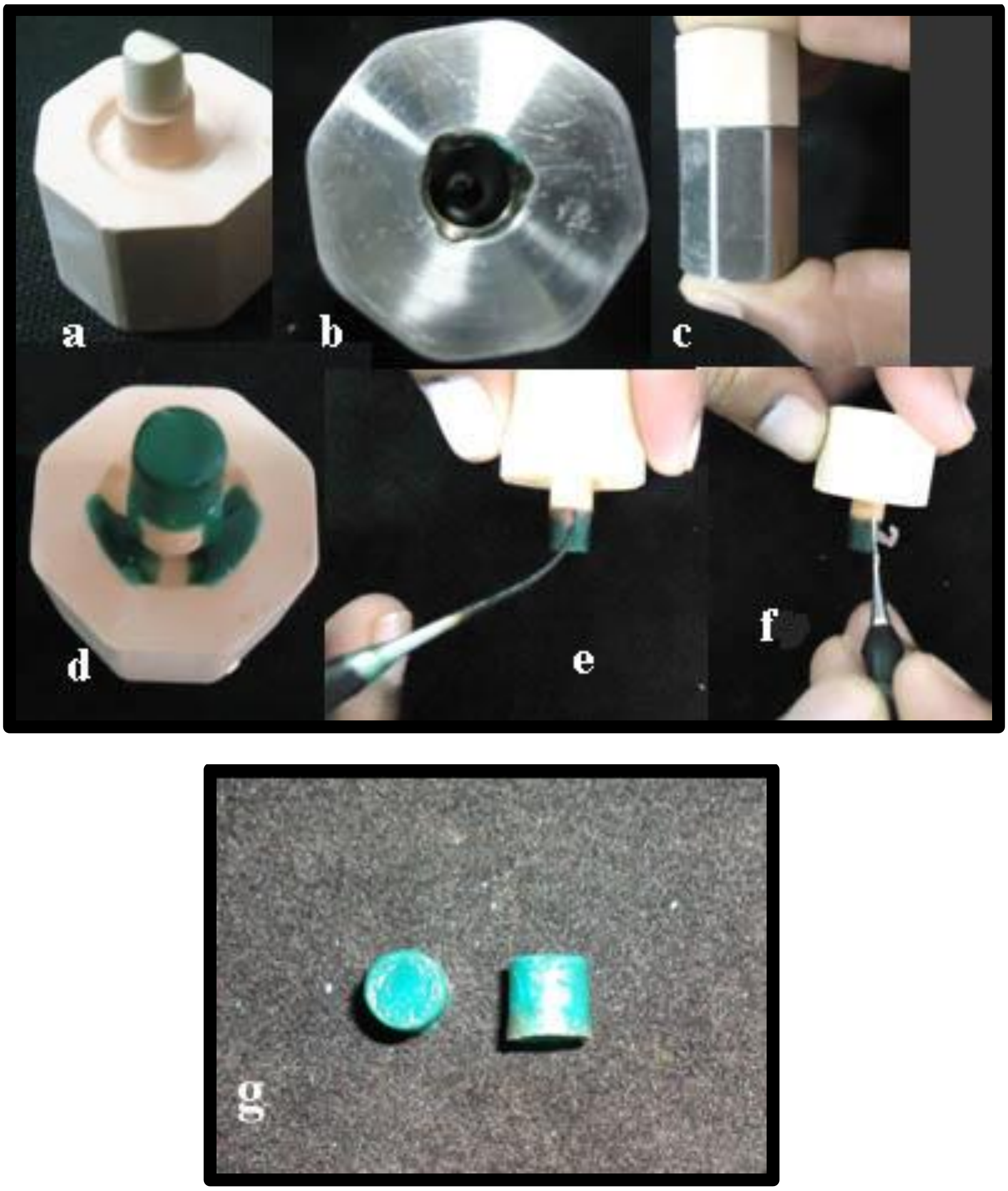
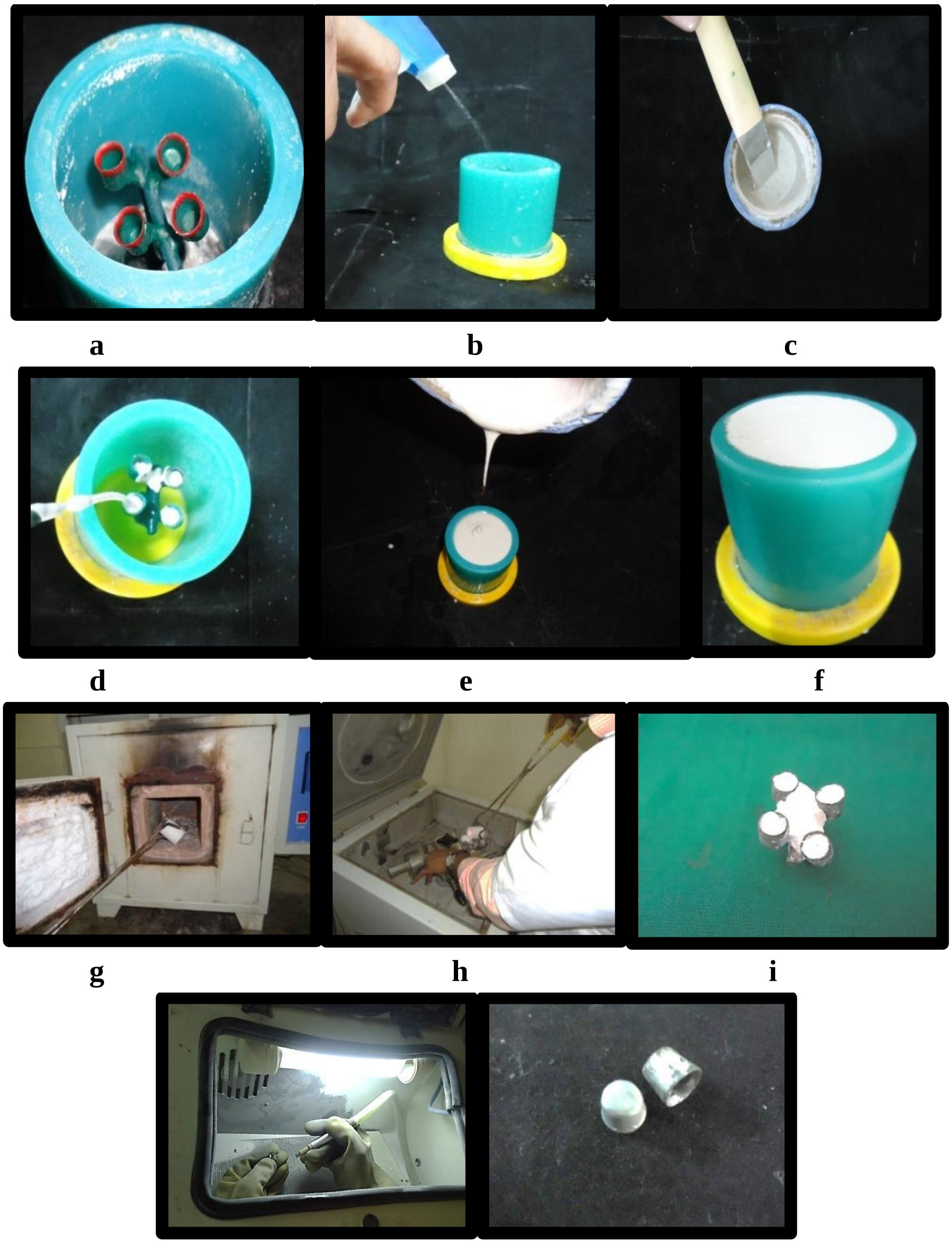


Fig.10a) Master die with spacer, b) Model former filled with molten wax, c) Master die and metal model former assembled, d) Wax Pattern after model former removal, e) Margins readapted, f) Trimming of the excess margin wax, g) Completed wax patterns

Fig.11: Fabrication of Co- Cr Cast Copings with inlay casting wax patterns-(G1)



a b c

d e f

g h i

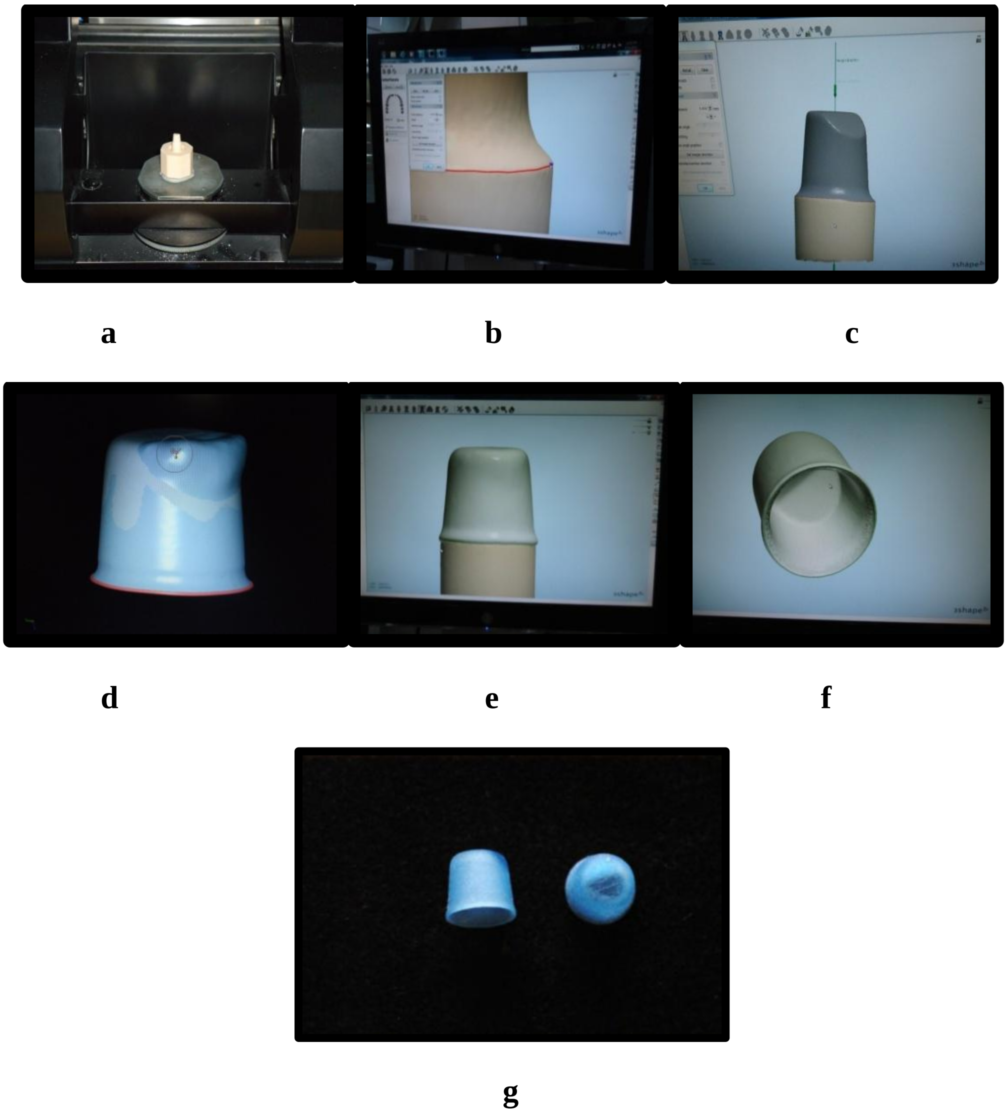
j k

Fig.11a) Sprue attachment for inlay casting wax pattern, b) Surfactant spray, c) Mixing of the phosphate bonded investment, d) Painting of the investment over the patterns, e) Filling of siliring with investment, f) Completed investment, g) Burn out after bench set, h) casting, i) Divested cast coping, j) Sandblasting of the cast coping, k) Completed cast copings

Fig.12: Equipments for Fabrication of 3D Printed Resin Patterns

Fig.12a: D 700 3D scanner
b: Project HD 3000 printer

Fig.13: Preparation of 3D Printed Resin Patterns



a b c

d e f

g

Fig.13a) Scanning of the master die, b) Margin location, c) Die spacer application, d) Virtual addition of wax over the bevel region, e) Virtual coping on the die, f) Completed virtual coping,
g) Completed 3 D printed resin patterns

Fig.14: Fabrication Co-Cr cast copings with 3D Printed Resin Patterns-(G2)

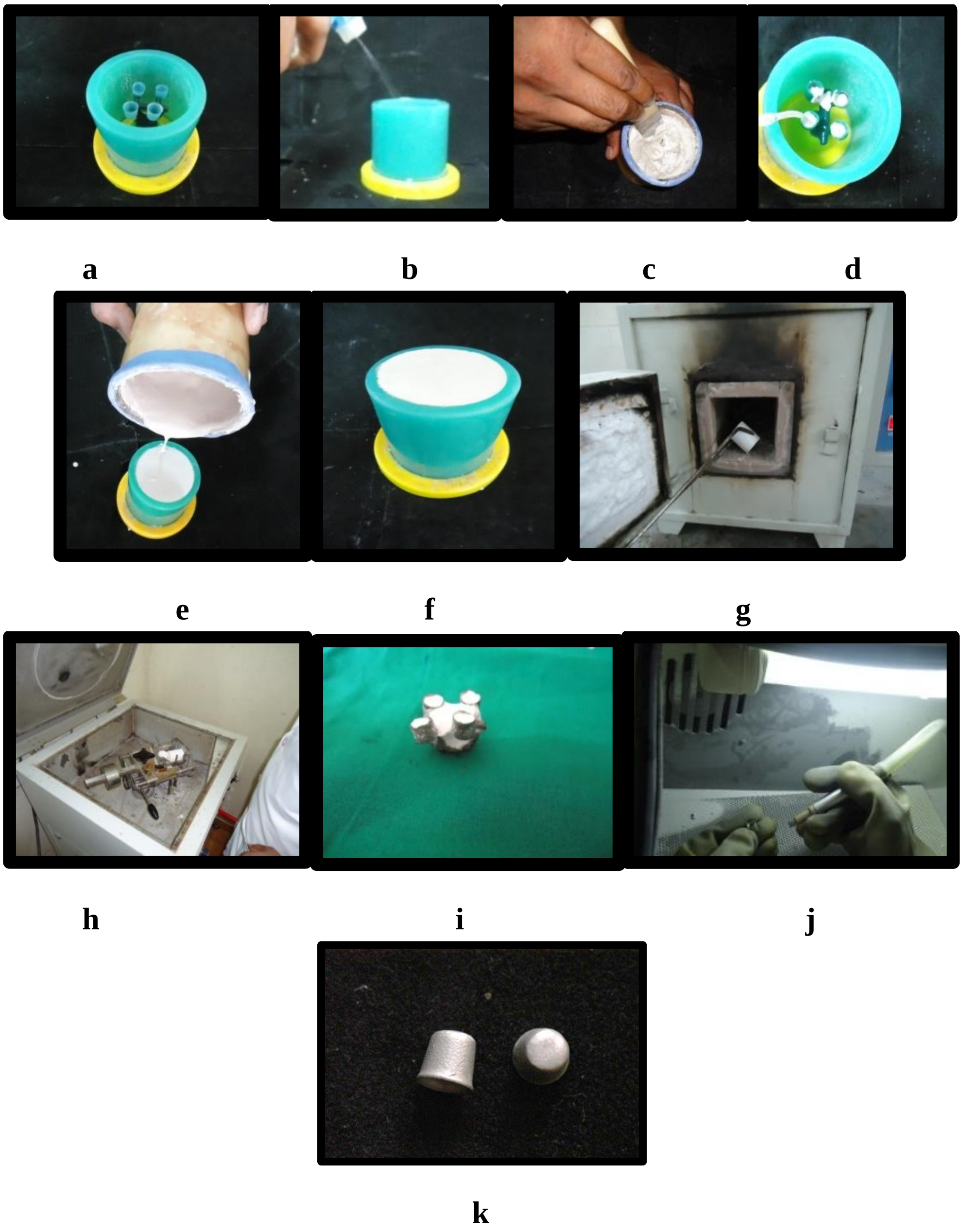


Fig.14a) Sprue attachment for 3D printed resin pattern, b) Surfactant spray, c) Mixing of the phosphate bonded investment, d) Painting of the investment over the patterns, e) Filling of siliring with investment, f) Completed investment, g) Burn out after bench set, h) casting i) Divested cast coping, j) Sandblasting of cast coping k) Completed cast coping

Fig.15: Equipments for the fabrication of Co-Cr copings with Direct Metal Laser Sintering (DMLS) Technique

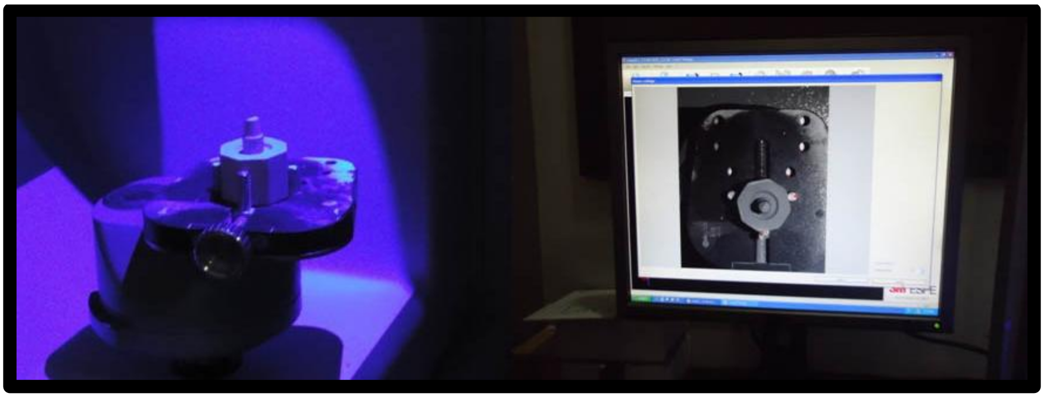


Fig.15a: Lava – ST scanner (3 MESPE US)

Fig.15b: Direct Metal Laser Sintering Machine

Fig.16: Fabrication of Co-Cr copings with DMLS technique-(G3)

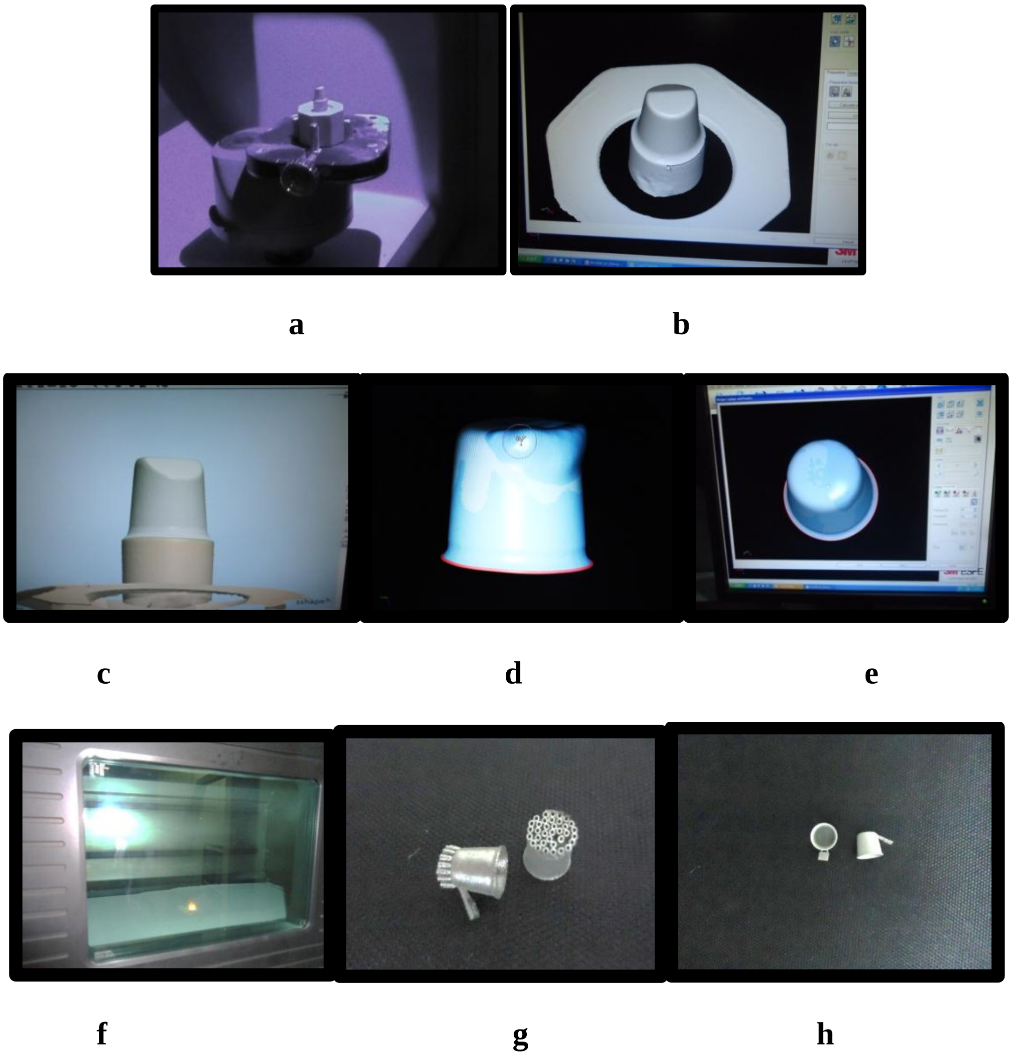


Fig.16a) scanning of master die, b) Margin location, c) Spacer adaptation, d) Virtual addition of wax over the bevel region, e) Virtually completed coping, f) Laser sintering process of Co-Cr alloy powder in the DMLS machine chamber, g) Removed metal copings from the DMLS table after completion of process, h) Completed metal copings

Equipments for Casting Procedures

Fig.17: Vacuum – mixer

Fig.18a: Burnout furnace
b: Induction casting machine

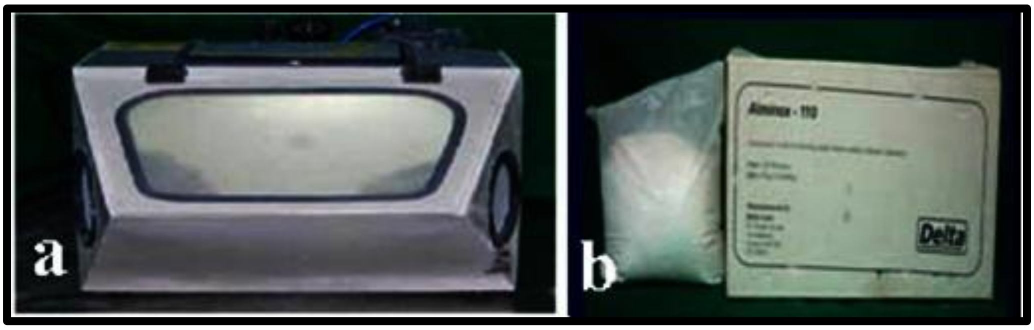
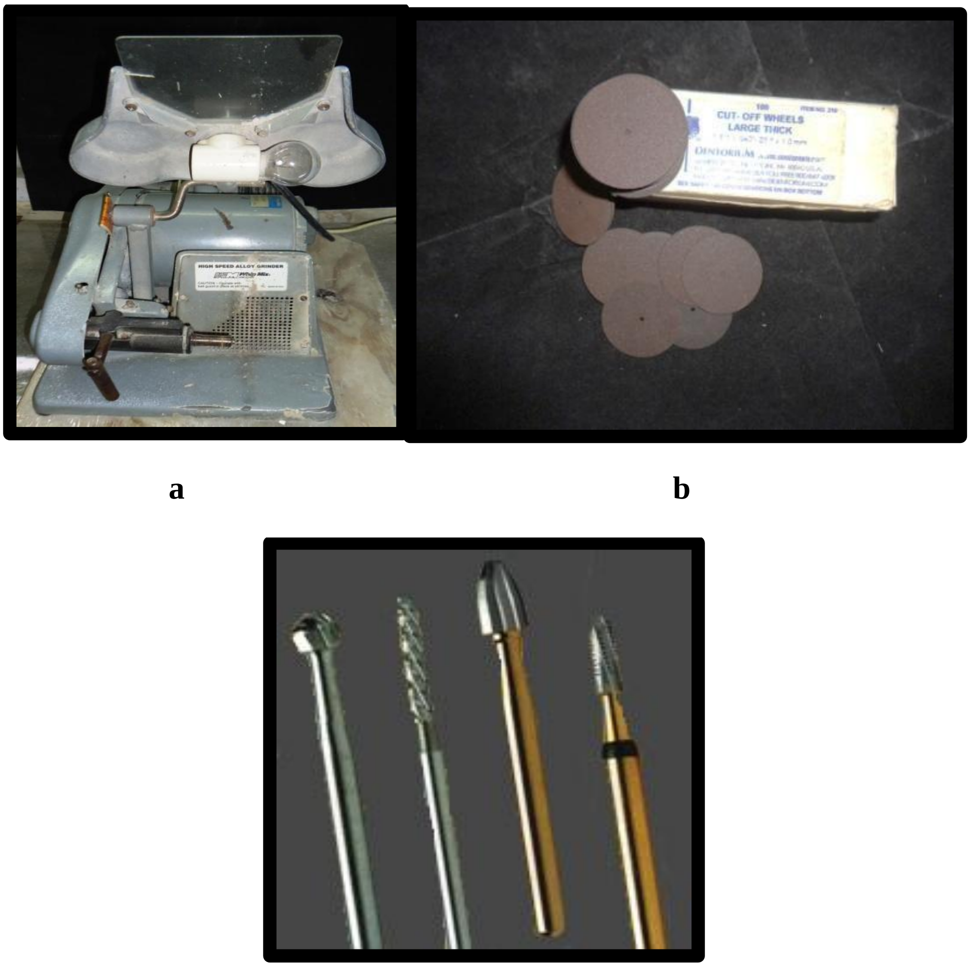


Fig.19a: Sand blaster

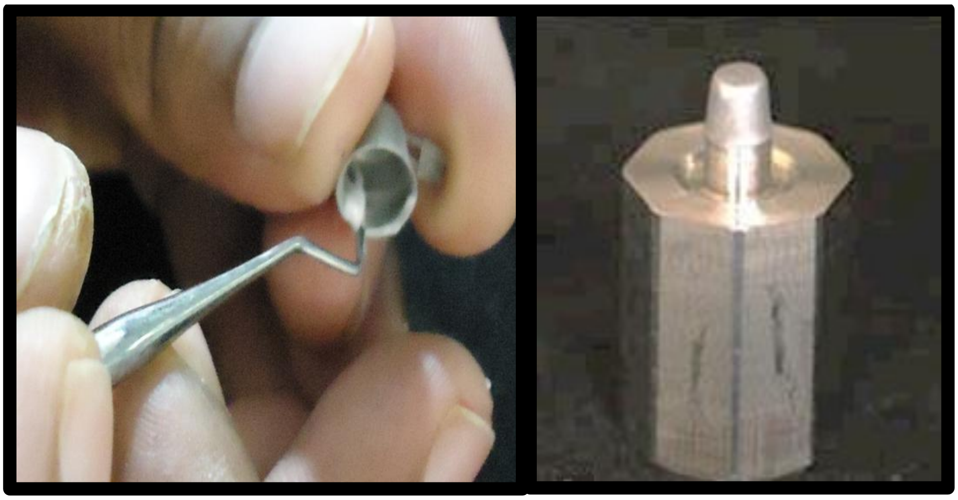
b: Aluminum oxide (110µm)



a **b**

c

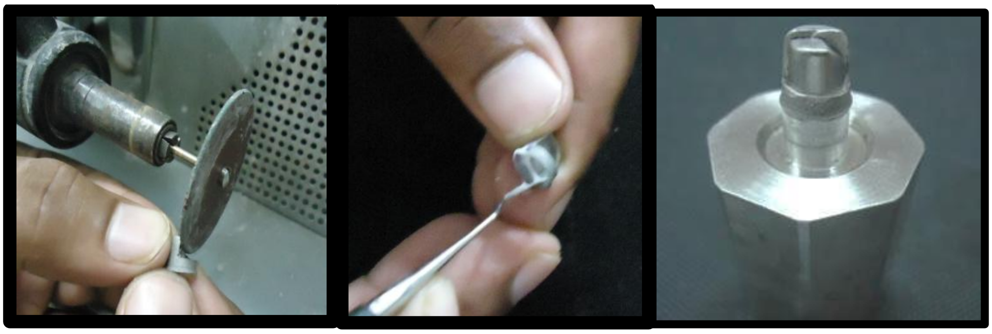
Fig. 20a) Alloy grinder, b) Separating Discs, c) Tungsten Carbide Burs



a b

Fig.21a:Pressure indicating paste applied on the inner aspect of Co-Cr coping

b: Co-Cr coping seated on the SS model



a b c

Fig.22a: Sectioning of Co-Cr coping before internal gap evaluation

b:Pressure indicating paste applied on the inner aspect of Co-Cr coping

c: Co-Cr coping seated on Master model after partial sectioning

Fig.23: Pressure indicating paste (Fit checker II GC corporation, Tokyo, japan)

Fig.24: Dental surveyor, (Para flex, Bego Germany) along with custom made platform and 2 kg weight

Equipment used for Measuring Marginal Gap and Internal Gap for this Study

Fig.25: Video Measuring System (VMS2010F)

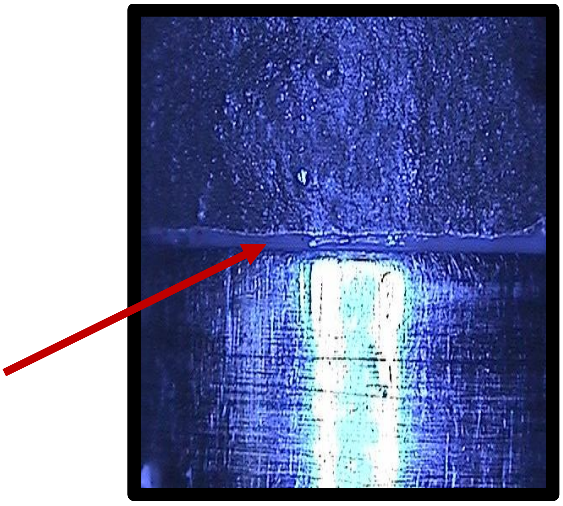


Fig.26: Vertical marginal gap of Co-Cr cast coping obtained from inlay casting wax pattern (G1) as observed under Video Measuring System (VMS2010F)

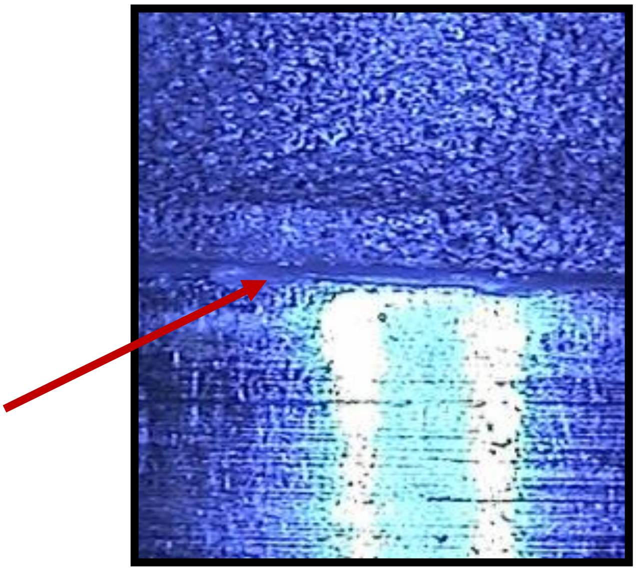


Fig.27: Vertical marginal gap of cast Co-Cr coping obtained from 3D Printed resin pattern (G2) as observed under Video Measuring System (VMS 2010 F)

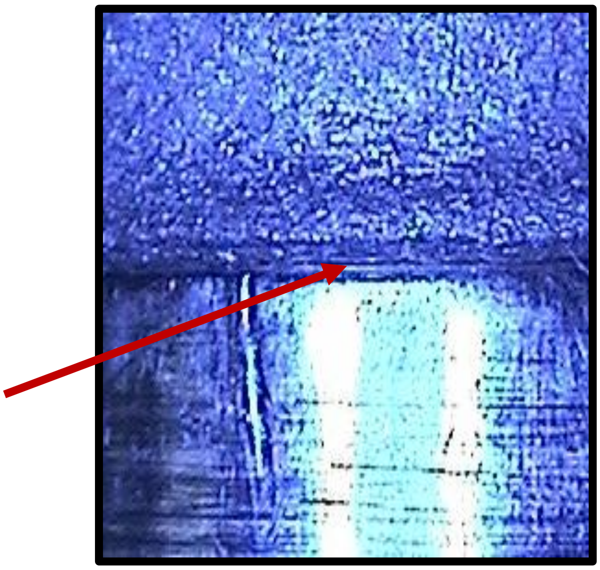


Fig.28: Vertical marginal gap of Co-Cr coping obtained from DMLS technique (G3) as observed under Video Measuring System (VMS 2010 F)

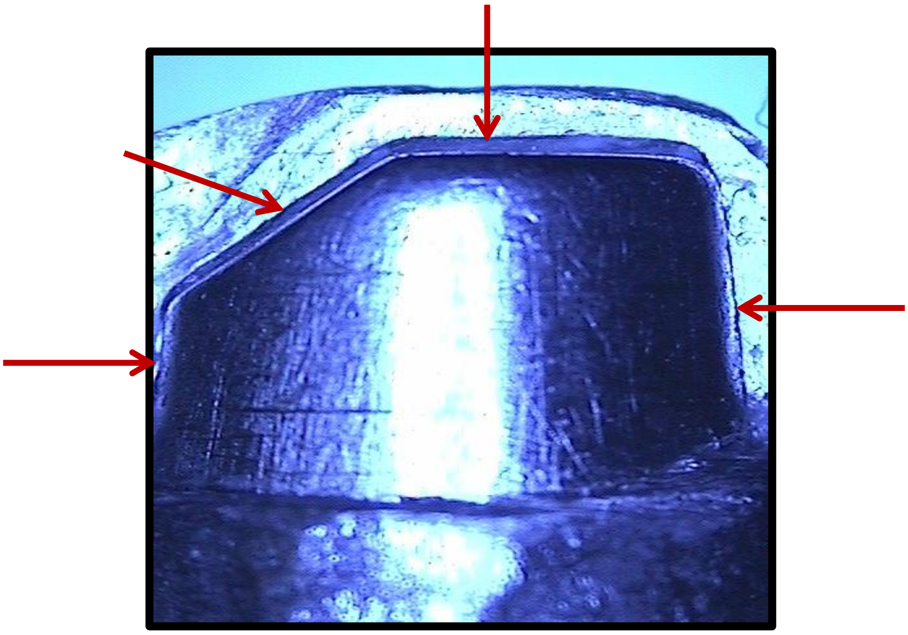


Fig.29: Internal gap of cast Co-Cr coping obtained from inlay casting wax pattern (G1) as observed under Video Measuring System (VMS2010F)

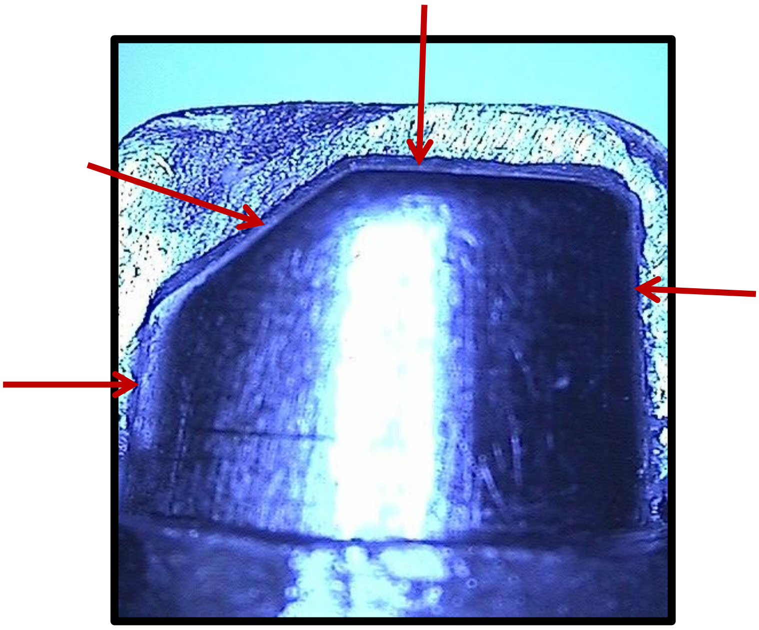


Fig.30: Internal gap of cast Co-Cr coping obtained from 3D printed resin pattern (G2) as observed under Video Measuring System (VMS2010 F)

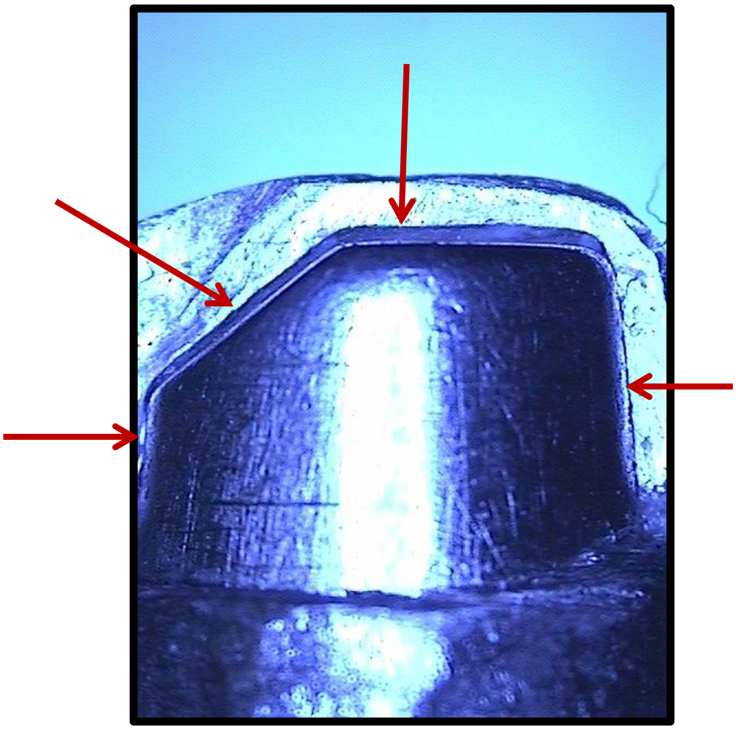
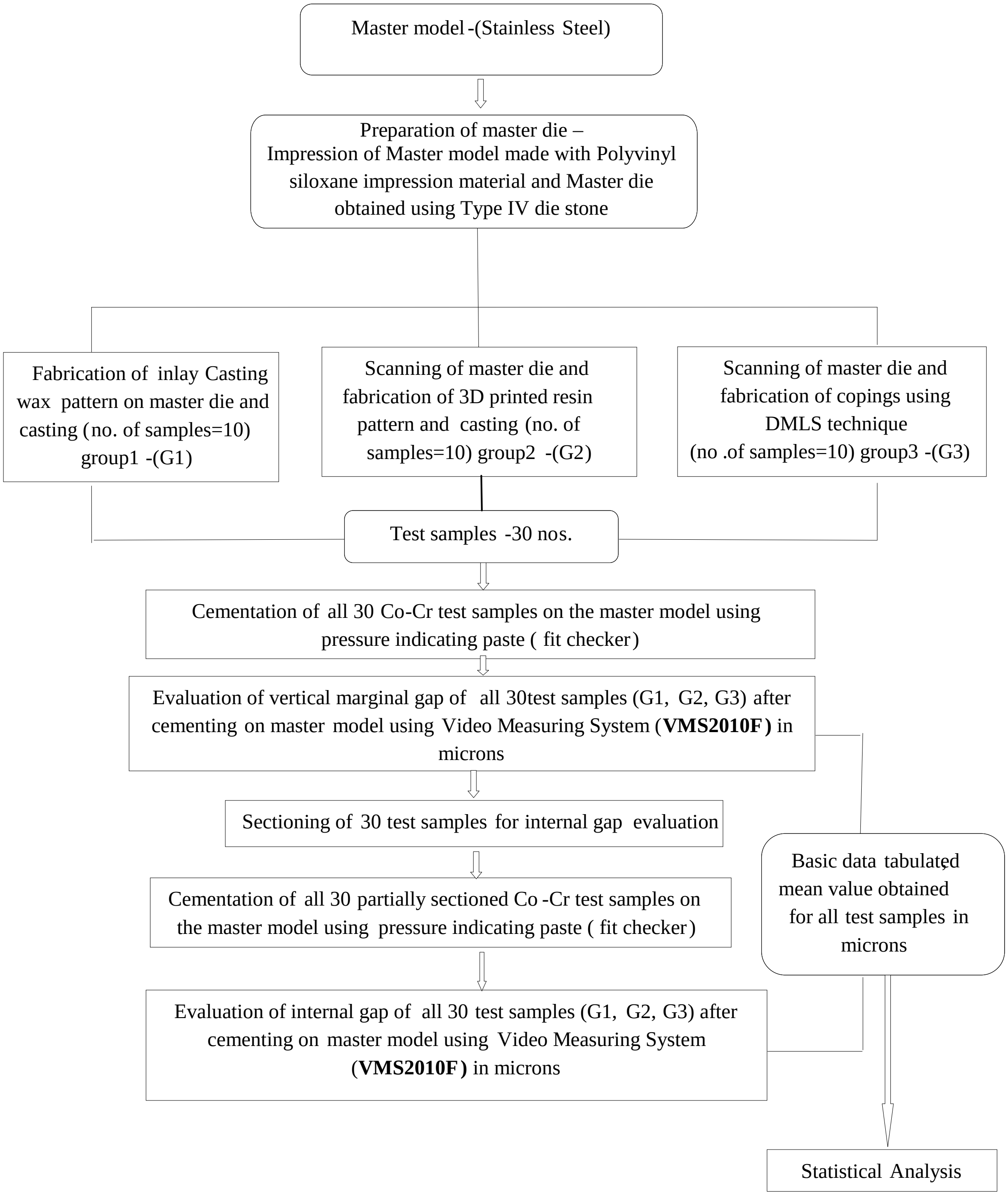


Fig.31: Internal gap of Co-Cr coping obtained from DMLS technique (G3) as observed under Video Measuring System (VMS2010F)

METHODOLOGY - OVERVIEW



G1-Co-Cr- cast copings fabricated using inlay casting wax pattern
G2-Co-Cr- cast copings fabricated using 3D printed resin pattern
G3-Co-Cr-copings fabricated from DMLS technique

RESULTS

An in vitro study was conducted to comparatively evaluate the marginal gap and internal gap of Co-Cr copings fabricated by conventional casting procedures and with Direct Metal Laser Sintering (DMLS) technique. In the conventional casting procedures, two different pattern forming techniques namely conventional inlay casting wax pattern fabrication and 3D printed resin pattern fabrication were employed.

Group 1: Test samples obtained from inlay casting wax pattern (G1)

Group 2: Test samples obtained from 3D printed resin pattern (G2)

Group 3: Test samples obtained from DMLS technique (G3)

Tables 1, 2, 3 shows the basic data of the results obtained in the study for the vertical marginal gap along with the mean determined for each test sample in the group 1, 2 and 3 (G1, G2 and G3) respectively and also mean for individual groups, calculated in microns (µm). The tables 4,5,6 show the basic data of the results obtained in the study for internal gap along with mean determined for each test sample in the group 1,2 and 3 (G1,G2 and G3) respectively and also mean for individual groups, calculated in microns (µm).

The results were subjected to statistical analysis:

Mean and standard deviations were determined for the vertical marginal and internal gap from the samples for each study group. The data were analyzed by the analysis of variance followed by Tukey’s test. In the present study, $p < 0.05$ was considered as the level of significance.

Table 1: Basic data and the mean vertical marginal gap for group 1 (G1) test samples

Vertical marginal gap in microns (µm) with mean for each test sample of group1 (G1) measured at 8 predetermined reference areas and mean value for G1 test samples.

Sample no	**Point a**	**Point b**	**Point c**	**Point d**	**Point e**	**Point f**	**Point g**	**Point h**	**Mean µm**
1	34	40	34	34	42	31	41	39	40.75
2	29	44	34	39	51	74	27	30	41.00
3	39	41	29	48	51	70	24	41	42.87
4	53	38	40	49	48	52	38	39	44.62
5	41	62	32	41	52	29	29	54	42.50
6	38	44	48	48	52	29	74	48	47.62
7	42	34	34	39	42	89	54	54	48.50
8	50	59	42	44	44	47	52	51	48.62
9	47	54	48	55	32	42	52	51	47.62
10	42	54	48	52	47	58	51	44	49.50
Mean vertical marginal gap of the group 1 (G1) test samples ------									**45.36**

Table 2: Basic data and the mean vertical marginal gap for group 2 (G2) test samples

Vertical marginal gap in microns (µm) with mean for each test samples of group 2 (G2) measured at 8 predetermined reference areas and the mean value for (G2) test samples.

Sample no	Point a	Point b	Point c	Point d	Point e	Point f	Point g	Point h	Mean µm
1	25	26	23	24	29	22	17	19	23.12
2	22	29	27	22	22	23	29	21	24.37
3	27	27	20	22	23	21	21	28	23.62
4	28	29	19	21	29	23	24	22	24.37
5	24	29	22	21	24	28	34	29	26.37
6	34	32	21	29	28	27	32	31	29.25
7	34	31	32	28	29	31	25	29	29.87
8	34	33	34	30	33	29	27	34	31.75
9	33	32	29	30	33	34	33	30	31.75
10	29	32	28	27	23	21	32	30	27.75
Mean vertical marginal gap of group 2 (G2)test samples -------------									**27.22**

Table 3: Basic data and the mean vertical marginal gap for group 3 (G3) test samples

Vertical marginal gap in microns (µm) with mean for each test samples of group 3 (G3) measured at 8 predetermined reference areas and the mean value for (G3) test samples.

Sample no	Point a	Point b	Point c	Point d	Point e	Point f	Point g	Point h	Mean (µm)
1	10	10	11	10	9	10	12	10	10.25
2	11	11	10	10	9	10	9	10	10.00
3	12	10	9	9	11	10	11	11	10.37
4	11	12	10	9	9	11	11	11	10.50
5	10	10	9	9	10	12	11	11	10.25
6	12	12	10	11	11	12	11	10	11.12
7	12	11	9	11	12	9	9	10	10.37
8	11	10	9	11	12	12	11	12	11.00
9	11	12	10	11	11	12	12	10	11.12
10	9	10	11	10	10	11	11	10	10.25
Mean vertical marginal gap of group 3 (G3) test samples -------									**10.52**

Table 4: Basic data and the mean internal gap for group 1 (G1) test samples

Internal gap in microns (µm) with mean for each test sample of group 1 (G1) measured at 4 predetermined reference areas and mean value for G1 test samples.

Sample no	Point A	Point B	Point C	Point D	Mean (µm)
1	41	51	44	31	41.75
2	39	49	54	29	42.75
3	34	44	47	22	36.75
4	32	54	45	27	39.50
5	42	57	42	31	43.00
6	49	58	47	34	47.00
7	34	49	47	29	39.75
8	37	42	47	29	38.75
9	30	38	37	24	32.25
10	39	34	41	39	38.25
Mean internal gap of group 1 (G1) test samples ----------------					**39.97**

Table 5: Basic data and the mean internal gap for group 2 (G2) test samples

Internal gap in microns (µm) with mean for each test sample of group 2 (G2) measured at 4 predetermined reference areas and mean value for G2 test samples.

Sample no	Point A	Point B	Point C	Point D	Mean (µm)
1	30	39	41	33	35.75
2	29	44	45	29	36.75
3	31	42	39	34	36.50
4	27	48	41	32	37.00
5	29	49	32	28	34.50
6	31	39	38	34	35.50
7	33	41	37	35	36.50
8	29	49	38	32	37.00
9	35	44	43	31	38.25
10	32	37	39	27	33.75
Mean internal gap of group 2 (G2) test samples ------					**36.15**

Table 6: Basic data and the mean internal gap for group 3 (G3) test samples

Internal gap in microns (μm) with mean for each test sample of group 3 (G3) measured at 4 predetermined reference areas and mean value for G3 test samples.

Sample no	**Point A**	**Point B**	**Point C**	**Point D**	**Mean (μm)**
1	39	45	42	41	41.75
2	42	39	41	41	40.75
3	39	44	39	39	40.25
4	38	41	44	42	41.25
5	39	42	41	40	40.50
6	42	43	44	37	41.50
7	43	41	44	37	41.25
8	39	44	44	43	42.50
9	42	42	41	42	41.75
10	39	44	45	37	41.25
Mean internal gap of group 3 (G3) test samples--------					**41.27**

Table 7: Mean Vertical Marginal Gap Values of Three Groups (G1, G2 and G3)

Group 1	Group 2	Group 3
45.36µm	27.22µm	10.52µm

Graph 7: Comparison of Mean Vertical Marginal Gap Values of Three Groups (G1, G2 and G3)

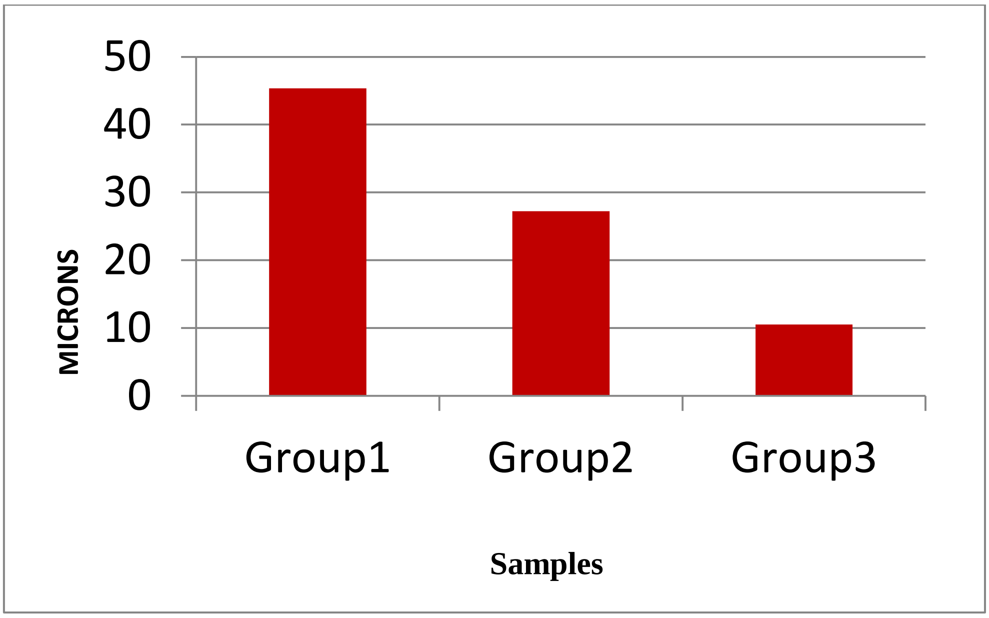


Table 8: Mean Internal Gap Values of Three Groups (G1, G2 and G3)

Group 1	Group 2	Group3
39.97µm	36.15µm	41.27µm

Graph 8: Comparison of Mean Internal Gap Values of Three Groups (G1, G2 and G3)

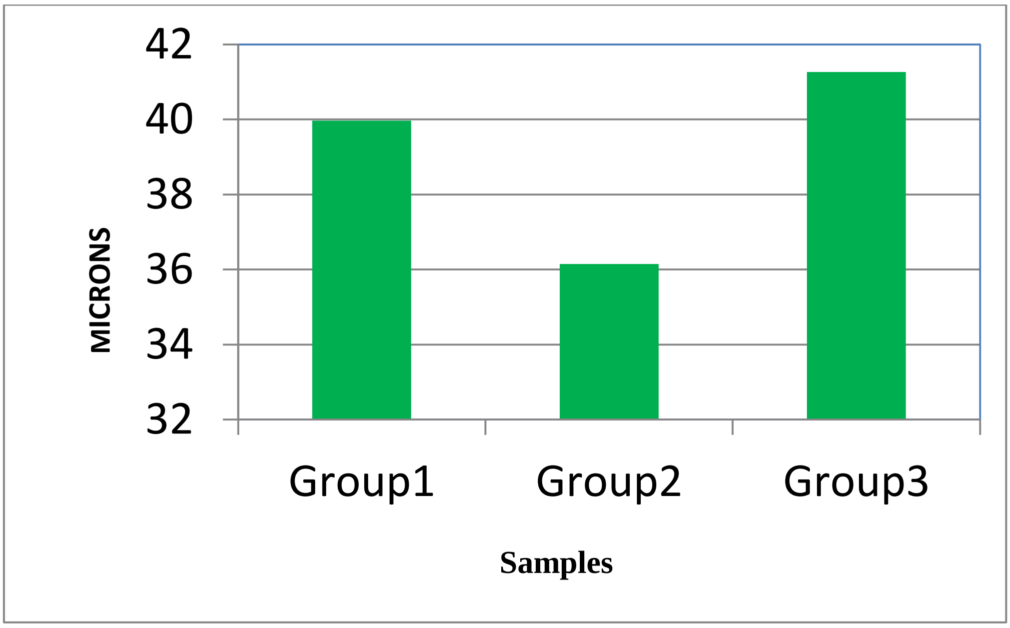


Table 9: Test of Significance for the mean vertical marginal gap obtained from three groups (G1, G2 and G3)

Groups	Mean	S.D	p-value
Group-1	45.36^{c}µm	3.38	0.000*
Group-2	27.22^{b}µm	3.32	
Group-3	10.52^{a}µm	0.4058	

Note: *denotes significance at 5% level

Different superscript letters in mean of vertical marginal gap discrepancy between groups is significant at 5% level.

Inference:

The table 9 shows the comparison of mean value of the vertical marginal gap obtained for each of three groups .One way analysis of variance (ANOVA) was used to calculate the ‘p’ value .Since the ‘p’ value is less than 0.05 there is significant difference between three groups with regard to vertical marginal gap. Multiple range test by Tukey’s test was employed to identify significant groups at 5% level. The mean vertical gap was statistically significant from each other. Group 3 showed least mean vertical marginal gap followed by group 2 and group 1.

Table 10: Test of significance for the mean internal marginal gap from three groups (G1, G2 and G3)

Groups	Mean	S.D	p-value
Group-1	39.97 µm	4.002	0.000*
Group-2	36.15 µm	1.313	
Group-3	41.27 µm	0.6609	

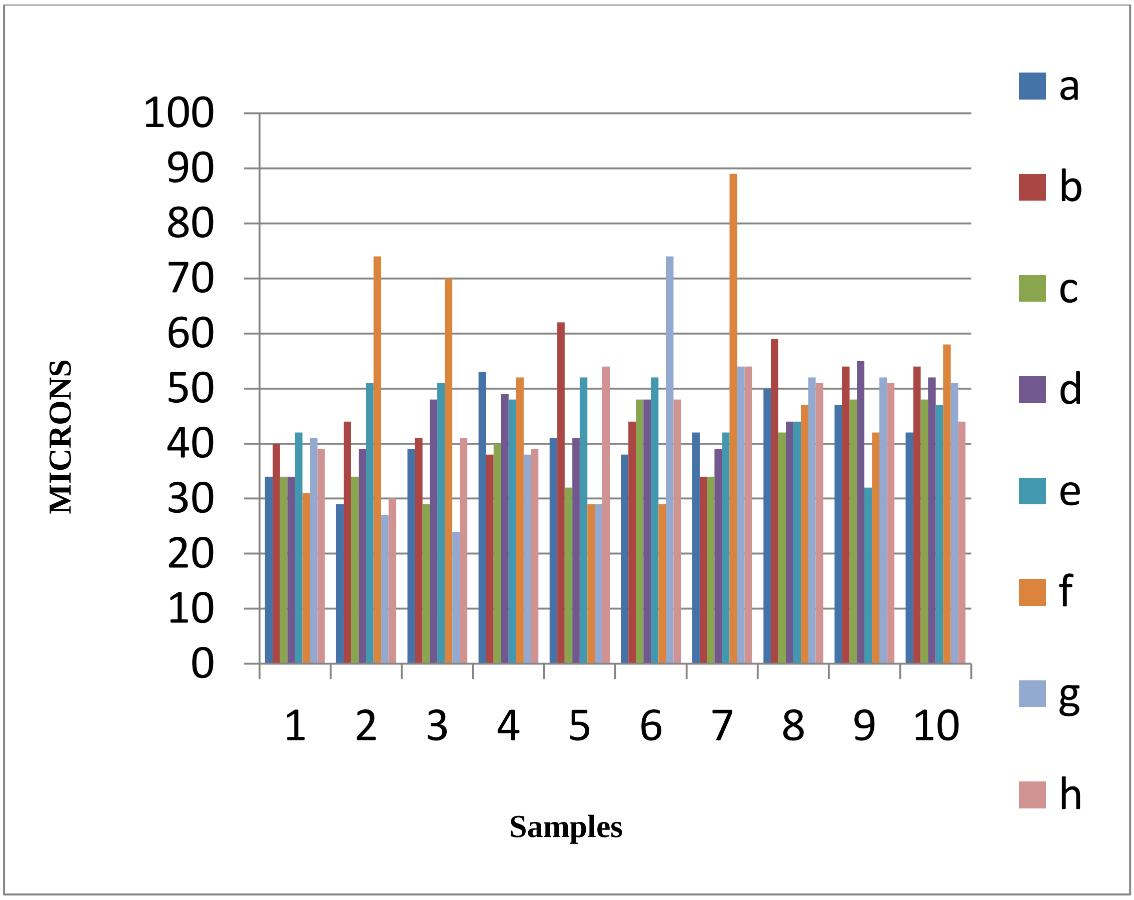
Note:*denotes significance at 5% level

Inference:

The table 10 shows the comparison of mean value of the internal gap obtained for each of three groups .One way analysis of variance (ANOVA) was used to calculate the 'p' value .Since the 'p' value is less than 0.05 there is significant difference between three groups with regard to internal gap. Multiple range test by Tukey's test was employed to identify significant groups at 5% level. . Group 2 showed least mean internal gap. The mean internal gap was statistically significant between group 1 and group 2 & between group 2 and group 3. The mean internal gap was not statistically significant between group 1 and group 3.

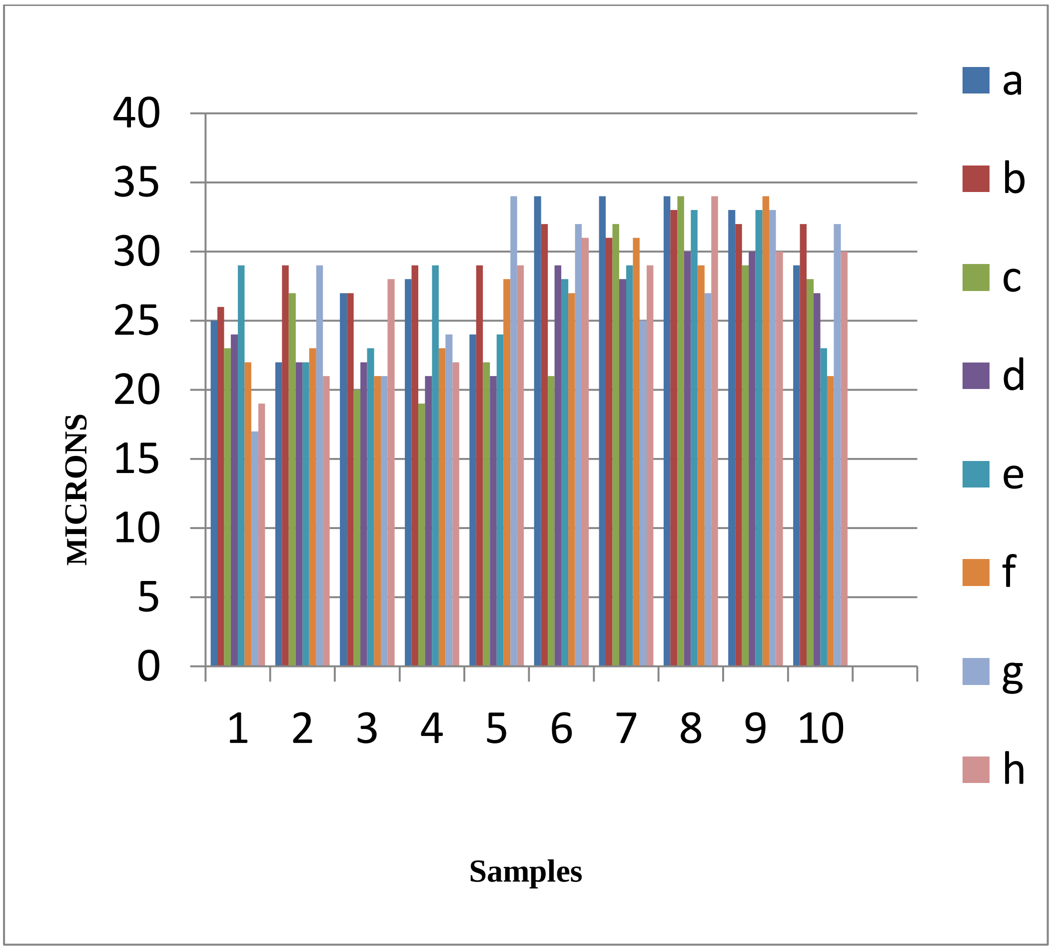
Graphs 1, 2, 3 show the basic data of the results obtained in this study for the vertical marginal gap in group 1 (G1), group 2 (G2) and group 3 (G3) respectively, calculated in the units of microns (μm) and graphs 4, 5, 6 show basic data of the results obtained in this study for the internal gap of group 1 (G1), group 2 (G2) and group 3 (G3) respectively calculated in microns.

Graph 1: Basic Data of Vertical Marginal Gap of Group1 (G1) test samples

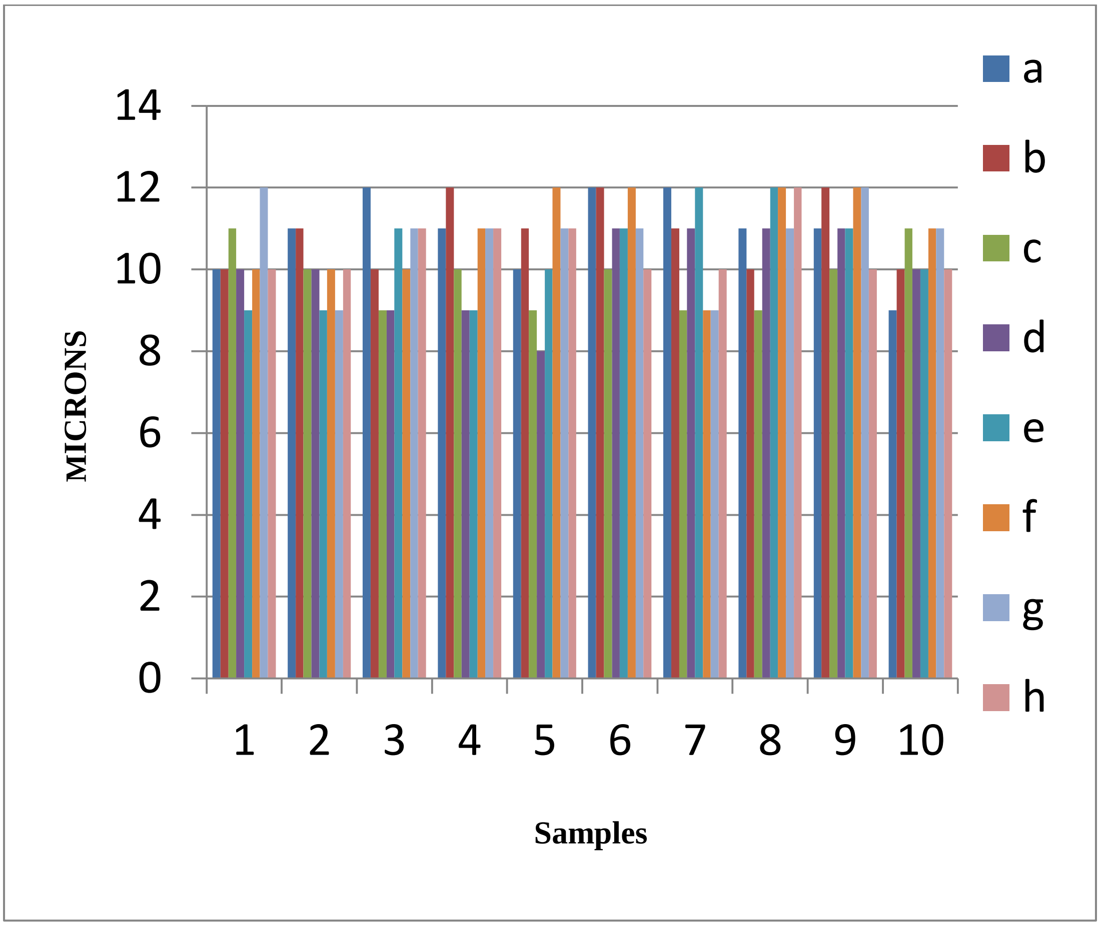


Graph 2: Basic Data of Vertical Marginal Gap of Group 2 (G2)

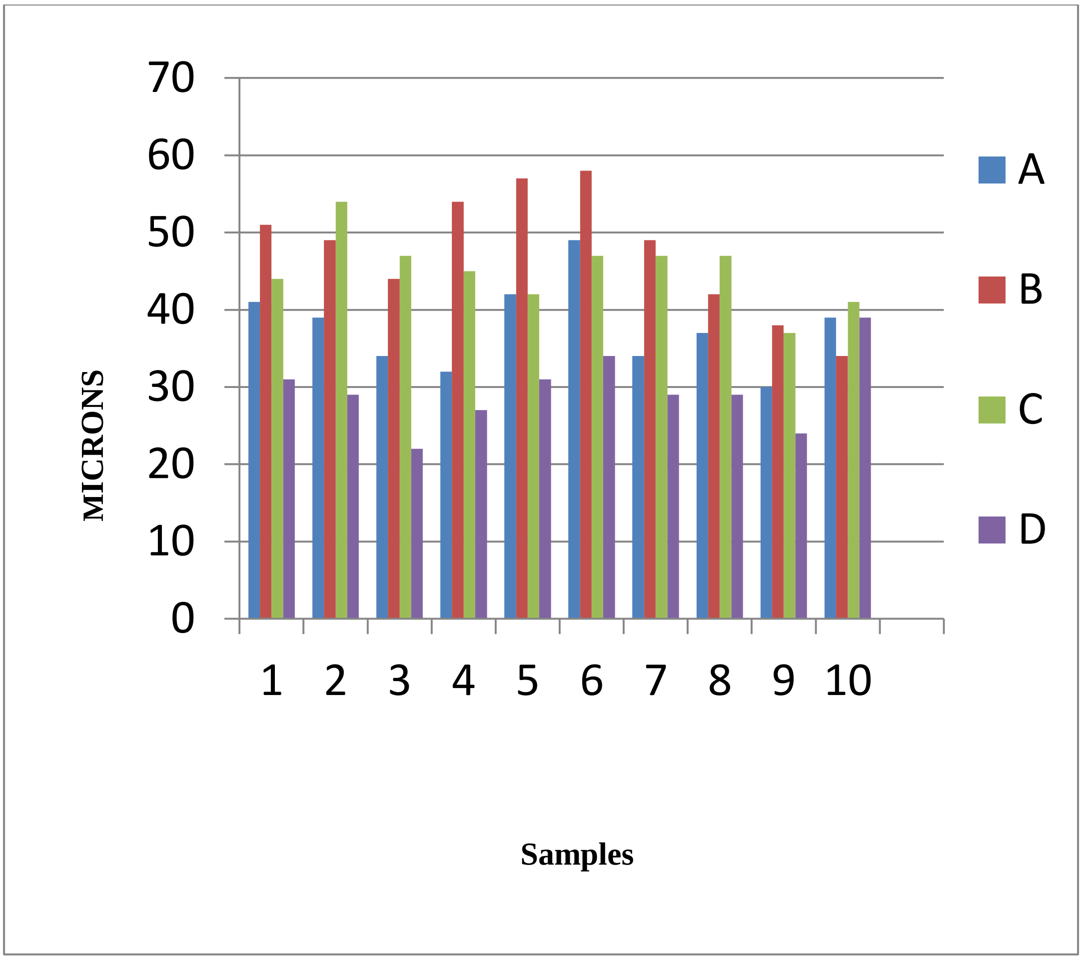
test samples



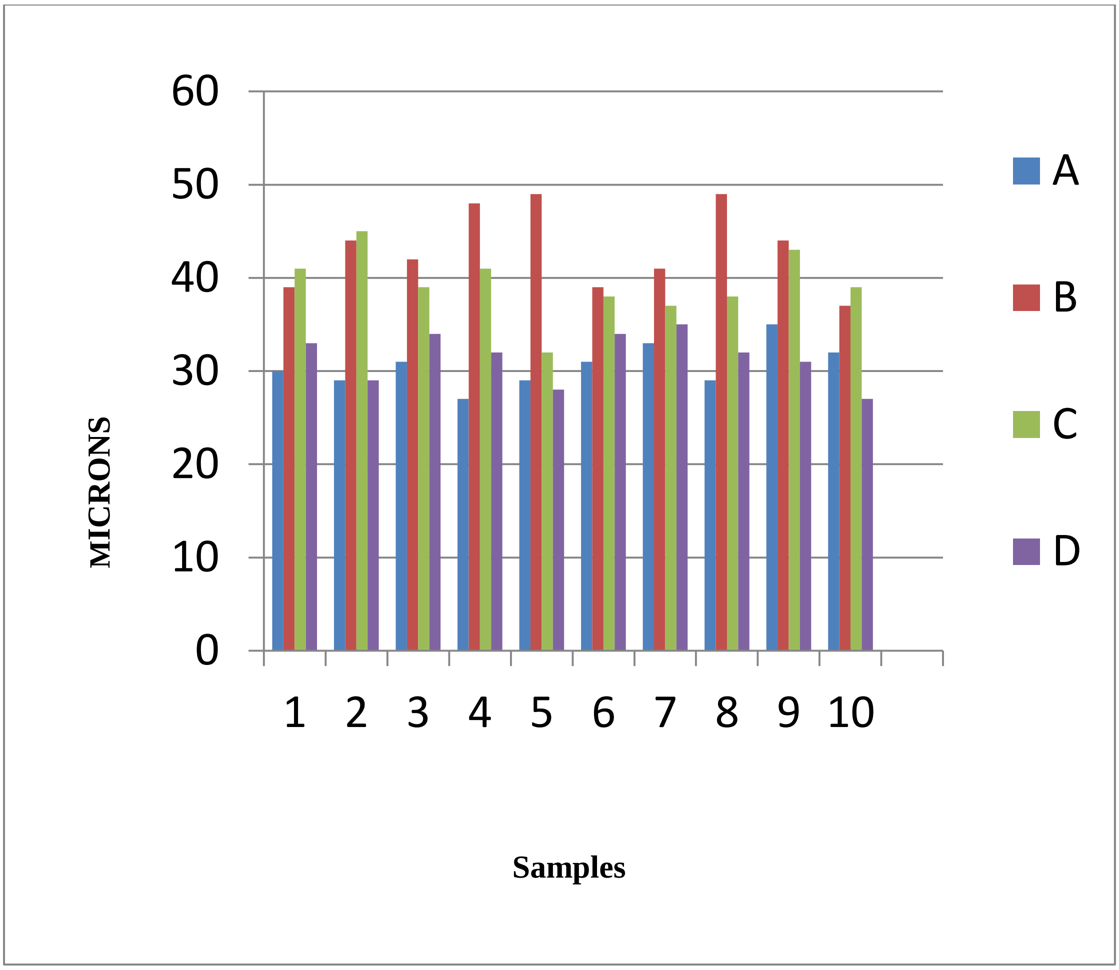
Graph 3: Basic Data of Vertical Marginal Gap of Group 3 (G3) test samples



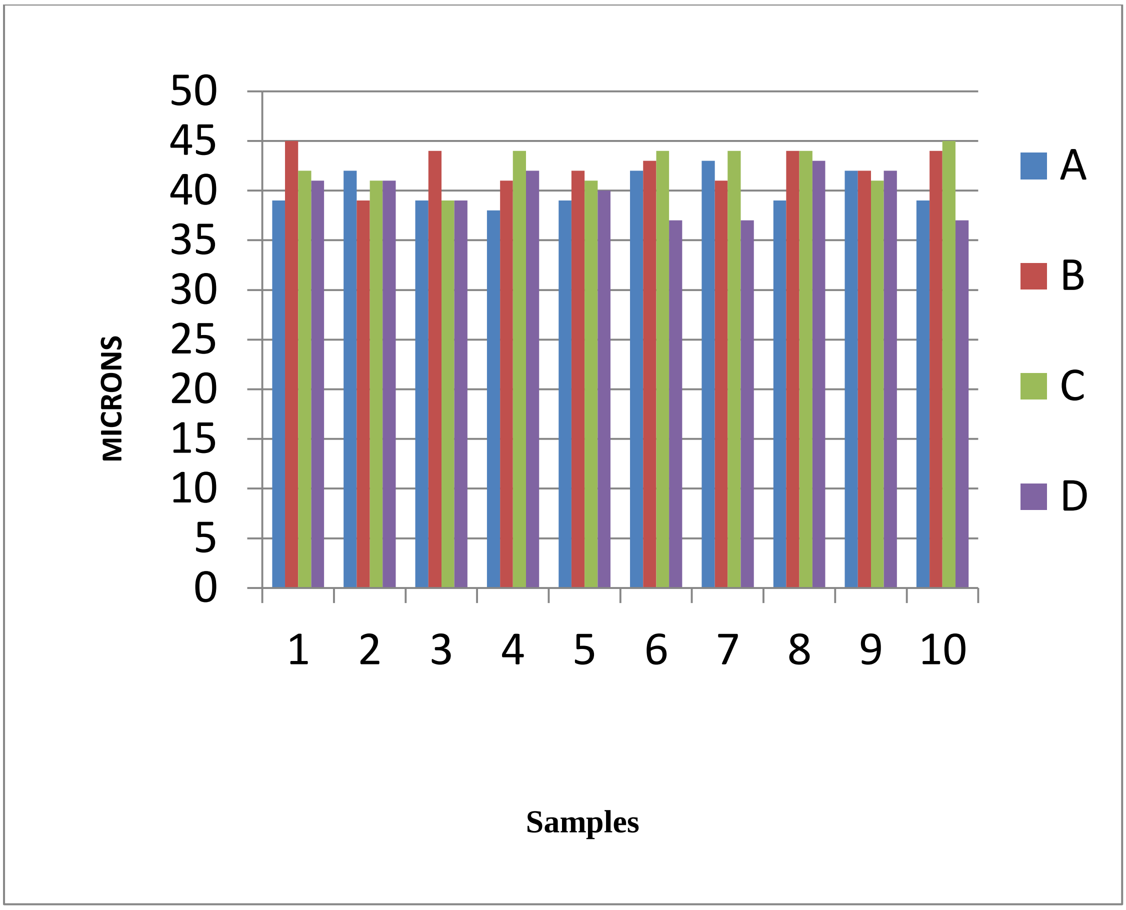
Graph 4: Basic Data of Internal Gap of Group 1 (G1) test samples



Graph 5: Basic Data of Internal Gap of Group 2 (G2) test samples



Graph 6: Basic Data of Internal Gap of Group 3 (G3) test samples



DISCUSSION

The fabrication of acceptable copings is an important variable that can affect marginal and internal fit of the restoration. Many factors like preparation of tooth, manipulation or compatibility of dental materials used both in clinical and laboratory affect overall acceptability of cast restorations. In spite of availability of proper clinical and laboratory techniques there is always a microscopic gap at the interface. The extent of misfit of dental restorations at this gap is believed to be closely associated with the development of secondary caries and periodontitis.[20,23,39,43]

Dimensional accuracy is essential for successful dental casting. The production of accurate dental castings by lost wax technique involves casting molten alloy into a refractory mold. Taggart in 1907 introduced lost wax casting technique for casting alloys. Till now this technique sensitive method has been widely used for making cast copings in fixed partial denture.[15,37,47,49.]

Ideally, cemented crown margins meet prepared tooth margins in perfect non-detectable junctions. In actuality clinical perfection is equally difficult to achieve and difficult to verify. Hence minimal marginal gap is nominally approximately acceptable[7,50.] The term marginal gap and internal gap do not have single definition. Holmes et al, who established several gap definitions according to contour difference between the crown and tooth margin, states that “the perpendicular measurement from inner surface of casting to the axial wall of preparation is called internal gap, and the same measurement at the margin is called marginal gap”[20]. Increase in internal space thickness will lead to compromised retention. But the essence of concern is the space existing between the restoration and tooth preparation margin where both meet the oral environment, as gap measurement at the margin quantify the fit. [7,20]

Historically the most desirable location for cervical margin has been debated, but most favour supra or equigingival placement whenever possible[32]. Some believe the sub gingival margin irrespective of quality, are detrimental to gingival health as they approach the base of gingival crevice. The location and fit of cervical crown margins are important to biological or mechanical restorative failure. Margins incorporating an inclined vertical configuration have been recommended to minimize these problems.[26] The present study was done to simulate a supra gingival margin where vertical gap which expose cement to the oral environment was measured.

There are many clinical and laboratory factors responsible for the marginal and internal adaptation of dental cast restorations.[5,8] Technical errors such as damage to the margins during die trimming, excessive thickness of die spacer, inaccurate wax adaptation, incorrect investment and casting failures may occur. In order to minimize marginal and internal fit inaccuracies the following methods and technique have been advocated by various authors.[43] Overwaxing the margin of wax pattern, removing wax from internal surface of wax pattern, [15,16] die relief with application of die spacer, internal relief of cast restoration by sandblasting, mechanical milling, acid etching and electrochemical milling, occlusal venting for escape of restoration.[30,33,36,37,38,51.]

Main causes for casting inaccuracies are the disadvantageous properties of material used to fabricate pattern. Wax which had been used over many decades have shrinkage and stress relaxation properties and resins have polymerization shrinkage.[28] Recently introduced computer aided design/computer aided manufacturing like three dimensional printing and Polyjet have been used to fabricate patterns using wax and resins accurately, but final fit of restoration is determined by the technique sensitive casting procedures employed to cast these patterns.

In previous years noble alloys were used for casting purpose which were later replaced by base metal alloys like Ni-Cr and Co-Cr. The substitution of base metal alloys for noble metals in fixed prosthodontics has placed greater demands on dentists in selection of casting materials and techniques. A common problem with base metal alloys is undersized casting as a result of greater thermal contraction from higher solidification temperatures, than that which occurs with noble metals[53]. Co-Cr alloys were primarily used for RPD frameworks. Currently they are also used more commonly than Ni-Cr alloys for fixed prosthesis[52]. Co-Cr alloys contain predominantly cobalt and sometimes tungsten in small amounts and possess high rigidity and hardness. Electrochemical studies show that Co-Cr alloys are more resistant to corrosion than Ni-Cr alloys[31]. Nickel based alloy also have greater sensitization potential than cobalt chromium alloys, whereas Co-Cr alloy allergies are rare,[1,34,48,53,57] hence it was selected as the material of choice for this study.

Many studies have been done to improve the fit of the cast restoration[43]. Multiple protocols to minimize errors and yield best internal and marginal fit of the cast restoration also had been suggested.[30,33,,37,38,51] However very few studies have reported about obtaining metal copings directly using CAD/CAM technique[24,27,48,49]. Studies comparing discrepancies of the copings made using conventional casting and DMLS is also lacking.

The present in-vitro study was conducted to comparatively evaluate the marginal gap and the internal gap of Co-Cr copings fabricated by conventional casting procedures and with Direct Metal Laser Sintering (DMLS) technique. In the conventional casting procedures, two different pattern forming techniques namely conventional inlay casting wax pattern fabrication and 3D printed resin pattern fabrication were employed.

A standardized custom made stainless steel master model was made based on model recommended by Ushiwata O et al in their study[50].Model used in this study had a deep chamfer margin with 6 degree axial wall taper and 10 degree occlusal inclination. A single stage impression of the master model with polyvinyl siloxane was made and a master die was made using

Type IV die stone. This master die was used for fabricating all the 30 patterns used in this study. Many of the previous studies had used individual dies for each coping they have fabricated which involves multiple laboratory steps, thus incorporating multiple variables in the study. Hence to overcome multiple variables, one impression was made and single master die was fabricated which was used for fabricating all the samples in the study. Also a trough was designed around the base of the tooth preparation section to collect the overflowing excess inlay casting wax while fabricating the wax pattern. The pressure that builds in during fabrication of wax pattern dissipates through slits in the master model former assembly and the excess wax reaches the trough via the slits and results in wax patterns of equal thickness (Fig10d). Master die was scanned by 3 shape D700 scanner for making 3D printed resin patterns and the same die was scanned with lava ST scanner for obtaining direct metal copings. Then the die was used for making wax pattern in the conventional manner after application of die hardner, die spacer and die lube.

A total of 30 test samples were made of which 10 were made using casting the inlay casting wax pattern 10 samples were made using casting the 3D printed resin pattern and casted and 10 samples were made using DMLS technique. Twenty samples obtained using inlay casting wax pattern and 3D printed resin pattern were subjected to casting procedures and twenty Co-Cr cast copings were obtained. These twenty samples were then divested, sandblasted and steam cleaned. These completed test samples were grouped as

(G1) which were cast copings obtained from inlay casting wax pattern (10 nos) and (G2) which were cast copings obtained from 3D printed resin pattern (10 nos.). 10 copings for third group were obtained directly from DMLS technique and they were sandblasted and steam cleaned and labled (G3) test samples.

All the test samples of each group was coated on the internal surface with a thin layer of pressure indicating paste (fit checker) and seated on stainless steel master die, sequentially under 2 kg load which was placed on a platform mounted on the vertical arm of an surveyor for 2 minutes to simulate a coping cemented in the oral condition. Fit checker was used because it was easy to be removed from inner surface without damaging the inner surface of the copings. After setting, the assembly was removed from the surveyor and excess paste was removed. The assembly was placed under Video Measuring System (VMS2010F) for evaluation of vertical marginal gap. This gap was measured in 8 predetermined reference points (Fig.5a). The octagonal shape of the master model base (C2) (Fig.3a), prevented the model from moving while measuring of vertical and internal gaps. Copings were then removed and the fit checker paste on the inner surface was removed. The copings were partially sectioned as shown in (Fig.22a) leaving a band of metal coping which involves the entire margin. This partially sectioned coping was again reseated in the same position onto the stainless steel master model (Fig.22c). The presence of occlusal bevel and the part of coping in direct contact with master model 1mm above the chamfer margin helps to reorient the coping in the previous position. The same 2kg load was applied which was placed on the platform table mounted on the vertical arm of surveyor and excess paste was removed after setting and internal gap was measured at 4 predetermined reference points as shown in (Fig.5b). This procedure was done sequentially for all the samples and readings obtained were noted. All the copings were reoriented on the same stainless steel master model. This was done to test the discrepancy in the test samples with differences in the fabricating techniques only.

The basic data obtained in this study shows a mean vertical marginal gap of 45.36µm for cast copings obtained from inlay casting wax pattern (G1), 27.22µm for cast copings obtained from 3D printed resin pattern (G2) and 10.52µm for copings obtained using DMLS technique (G3).

The reason for comparatively high vertical marginal gap 45.36µm for (G1) may be due to the shrinkage and stress relaxation of the inlay casting wax. The mean vertical marginal discrepancy of cast copings obtained from 3D printed resin pattern (G2) is 27.22µm, Magix software which compensates for polymerization shrinkage and increased precision without any chance of manual errors during fabrication process could be attributed for this.

Mean vertical marginal gap of the copings obtained using DMLS technique (G3) 10.52µm shows comparatively least value than the other two groups which could be attributed to the fact that this process have completely eliminated casting and manual errors, yields good results, compared to induction coil casting procedure which was used to melt the alloy for group 1and group2 used in this study. This induction coil heating melts alloy at higher temperature than its melting range which causes the alloy to lose its low melting point compositional elements making it more viscous and affecting its flow. Another factor is the delayed time to melt alloy in an electrical machine, a condition that can also modify the alloys composition and consequent viscosity[37].

Marginal fit of cast restoration is one of the most researched subjects in fixed prosthodontics. Mc Lean et al concluded from their study that after casting, marginal gap ranged from 40-61.5µm. It has also been suggested in this study that marginal gap of 120µm is the maximum clinical acceptable gap[22,47]. Hung et all reported that practical range for clinical acceptability of fit seems to be approximately 50 to 75µm[25]. Iglesias allen et all compared the marginal fit of wax, autopolymerising acrylic resin and light polymerized resin patterns and concluded that for full crown patterns, marginal discrepancy ranged between 10-23µm, with the exception of acrylic resin prepared by bulk technique which ranged from 40-46µm[26]. White SN concluded from their study that vertical marginal discrepancies were all considered clinically satisfactory with mean of 55µm or less[56]. Dedmon showed that mean un-cemented marginal openings by group of prosthodontists were 105 and 95µm for vertical and horizontal openings respectively[13].

Results of this study regarding vertical marginal gap of (10.52-45.36 µm) from all 30 copings were within the acceptable range and in consensus with those of Dedmon, White SN, Mc Lean and, Hung, Swartz et al.

The mean internal gap of 39.97µm for copings obtained from inlay casting wax pattern (G1), 36.15µm for copings obtained using 3D printed resin pattern (G2) and 41.27µm for copings obtained using DMLS technique (G3)

The mean internal gap of the group 1(G1) were 39.97µm which was statistically more compared to the group 2(G2), discrepancy between mold expansion and casting shrinkage could be the reason for this. The mean internal gap of (G2) copings 36.15µm was statistically significant than (G1). Magix software which compensates for polymerization shrinkage and increased precision without any chance of manual errors during fabrication process can be attributed as a reason for this difference. Group 3 (G3) showed a mean internal gap of 41.27µm.The same group had least marginal gap but the internal gap of these samples was statistically higher than the group 2 (G2) and group1 (G1) this could be because while scanning the master die and constructing three dimensional coping shell model image, the margin determination was done under manual adjustment while the external surface scanning of the master die was determined by the nonuniform offsetting and shelling algorithm in the scanning system software. Also the composition of Co-Cr alloy used for laser sintering has lower molybdenum content compared to that Co-Cr alloy used for conventional casting. Presumably; Laser sintering of alloy is facilitated by the absence of such refractory metals which have higher melting range than cobalt and chromium[49]. Further research would be of great use in these areas. Yurdanur Ucar et al did a study on internal fit evaluation of crowns fabricated using conventional casting technique and Laser sintered technology. Results from his study showed the mean internal gap widths of cast Co-Cr copings were 50.6µm and that of Laser sintered technique was 62.6µm which were in acceptance with the results obtained in this study[49]. Bindl and Mormann reported internal gap width of (81 to 136µm) for different all ceramic CAD/CAM crowns which were greater than the mean internal gap found in this study[49].

Results of internal gap of this study (36.15-41.27µm) from all 30 copings were within the acceptable range and in consensus with those of Yurdanur Ucar, Bindl and Mormann.

The limitation in this study other than that this is a in vitro study which cannot simulate oral conditions was that the marginal gap were evaluated before sectioning of the casted copings and internal gap was evaluated after sectioning which could resulted in minimal fit discrepancy, but this was common for all test samples. The internal gap was measured 2 dimensionally, 3 dimensional evaluation of this gap would have yielded more accurate results regarding the space occupied by the luting agent. Also the horizontal gap was not evaluated.

Groten et all reported that approximately 50 measurements were needed for clinically relevant information about the gap size regardless of the gap definition or cementation condition[20]. In this study 8 predetermined reference areas were used to measure marginal gap and 4 predetermined areas points were used for the evaluation of internal gap. More number readings could yield better results.

Nevertheless several limitations mentioned above, this in vitro study suggested marginal fit of cast copings with three different fabrication techniques were within the range of clinically acceptable values as mentioned in the literatures.

In this in vitro study the copings obtained from DMLS technique show the least marginal gap when compared to cast copings obtained from inlay casting wax and 3 D printed resin pattern and the internal fit was least for 3D printed resin pattern copings than copings from DMLS technique and inlay casting wax pattern which had results within clinically acceptable values. Conventional casting techniques and DMLS have yielded results within clinically acceptable range, but compared to conventional casting methods, the technique sensitive procedures are being completely eliminated in the DMLS technique. So further studies on this newly introduced 3D printed technology and DMLS technique should be carried out with various parameters to obtain confirmative and consistent estimate of the marginal and internal discrepancy with these techniques for their acceptance in dentistry.

CONCLUSION

The following conclusions were drawn from the data obtained in this in-vitro study which was conducted to comparatively evaluate the vertical marginal gap and the internal gap of Co-Cr copings fabricated by conventional casting procedures and with Direct Metal Laser Sintering (DMLS) technique. In the conventional casting procedures, two different pattern forming techniques namely conventional inlay casting wax pattern fabrication and 3D printed resin pattern fabrication were employed.

A vertical marginal gap was observed for all 30 test samples and after partial sectioning the internal gap was observed for all 30 test samples using Video Measuring System (VMS2010F) in microns.

1. The vertical marginal gap of 10 cast Co-Cr copings obtained from inlay casting wax pattern (G1) showed a mean value of 45.36µm.
2. The vertical marginal gap of 10 cast Co-Cr copings obtained from 3D printed resin pattern (G2) showed a mean value of 27.22µm.
3. The vertical marginal gap of 10 Co-Cr copings obtained from DMLS technique (G3) showed a mean value of 10.52µm.
4. The internal gap of 10 cast Co-Cr copings obtained from inlay casting wax pattern (G1) showed a mean value of 39.97µm.
5. The internal gap of 10 cast Co-Cr copings obtained from 3D printed resin pattern (G2) showed a mean value of 36.15µm.
6. The internal gap of 10 Co-Cr copings obtained from DMLS technique (G3) showed a mean value of 41.27µm.

7. The order of discrepancy of vertical marginal gap is as follows:
   - Minimum vertical marginal gap for Co-Cr copings obtained using DMLS technique (G3) 10.52µm.
   - Moderate vertical marginal gap for cast Co-Cr copings obtained using 3D printed resin pattern (G2) 27.22µm.
   - Maximum vertical marginal gap for cast Co-Cr copings obtained using inlay casting wax pattern (G1) 45.36µm.

The vertical marginal gap of all 30 Co-Cr copings obtained by 3 different fabrication techniques show statistically significant difference between three groups (G3<G2<G1).

8. The order of discrepancy of internal gap is as follows:
   - Minimum internal gap for cast Co-Cr copings obtained using 3D printed resin pattern (G2)36.15µm.
   - Moderate internal gap for cast Co-Cr copings obtained using inlay casting wax pattern (G1) 39.97µm.
   - Maximum internal gap for Co-Cr copings obtained using DMLS technique (G3) 41.27µm.

The mean internal gap was not statistically significant between group 1 and group3 (G1=G3).

The mean internal gap was statistically significant between group 1 and group 2 & between group 2 and group 3 (G2<G1and G3).

SUMMARY

An in vitro study was conducted to comparatively evaluate the marginal gap and internal gap of Co-Cr copings fabricated by conventional casting procedures and with Direct Metal Laser Sintering (DMLS) technique. In the conventional casting procedures, two different pattern forming techniques namely conventional inlay casting wax pattern fabrication and 3D printed resin pattern fabrication were employed.

A total of 30 test samples (G1, G2 and G3) were fabricated using Co-Cr alloy in three different fabricating techniques. All the samples were made from single master die which was a replica of the stainless steel master model. 10 cast copings were made from patterns obtained from inlay casting wax. 10 cast copings were made from 3D printed resin pattern. 10 copings were obtained from DMLS technique. Patterns made from inlay casting wax and 3D printed pattern resin were invested, burn out procedure was carried out and casting procedure was done with Co-Cr alloy to obtain cast copings. Cast copings were divested, sandblasted, steam cleaned and finishing procedures were done. Copings obtained from DMLS technique were also sandblasted and steam cleaned.

The test samples were then cemented sequentially on stainless steel model using pressure indicating paste to simulate a coping cemented in the oral condition and the copings were evaluated for vertical marginal gap in microns. The vertical marginal gap was measured in 8 predetermined reference areas using Video Measuring Systems (VMS2010F).

The test samples were removed from the master model, and pressure indicating paste was separated from the inner surface of test samples. They were then partially sectioned and reseated on the master model with pressure indicating paste and were evaluated for internal gap. The internal gaps were measured with Video Measuring System (VMS2010F) at 4 predetermined reference areas. The results obtained for both marginal and internal gap were tabulated and statistically analyzed.

The results obtained in this study indicate the presence of vertical marginal gap and internal gap for all the test samples .The vertical marginal gap of the copings obtained by three different fabrication techniques methods were statistically significant to each other. 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. Cast copings obtained from 3D printed resin pattern and copings obtained from DMLS technique also showed statistical significance. But there was no statistical difference between cast copings obtained from inlay casting wax and copings obtained using DMLS technique.

The manufacturing process influences marginal and internal accuracy of the dental restorations. An increase in vertical marginal gap exposes the cement to the oral environment thereby affects the health of the remaining supporting structure and increase in internal gap affects the retention of the restoration, hence both are important parameters to be considered for longevity of a restorations. Results of this study showed the vertical marginal gap of Co-Cr copings obtained by three different fabrication techniques were within the clinically acceptable range of (10-160µm).[13,22,43,47] The internal gap of Co-Cr copings obtained from three different techniques were also within the clinically acceptable range (81-136µm).[49]

In this study a new fabricating procedure (DMLS) was used for the fabrication of Co-Cr copings. The vertical marginal gap of the Co-Cr coping obtained by this technique was (10.52µm) least compared to other two techniques. However the internal gap of Co-Cr copings by DMLS procedure (41.27µm) was maximum among the three groups.Though results obtained in this in vitro study fall within the clinically acceptable range, the DMLS technique had an edge over the other two techniques used, as it exhibited minimal gap in the marginal region which is an area of chief concern. In terms of marginal fit and internal fit, both conventional casting technique and DMLS have yielded results within clinically acceptable range but the difficulties encountered during conventional casting procedures are being completely eliminated in DMLS technique which seems to yield promising results. Future studies regarding the mechanical properties and biocompatibility of laser sintered Co-Cr would be of great use before their acceptance into dental laboratory and practice.

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