

**COMPARATIVE EVALUATION OF SUPPLEMENTARY
RETENTIVE FEATURES ON RETENTION OF DIRECT
METAL LASER SINTERED CROWNS
: AN *IN-VITRO* STUDY**

Dissertation submitted to

**MAHARASHTRA UNIVERSITY OF HEALTH SCIENCES,
NASHIK**

In the partial fulfilment of regulations

for the award of the degree of

MDS

IN

**PROSTHODONTICS INCLUDING REMOVABLE, FIXED,
MAXILLOFACIAL AND IMPLANTOLOGY**

BRANCH –I

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**THROUGH
V.S.P.M'S DENTAL COLLEGE AND RESEARCH CENTRE,
HINGNA, NAGPUR**

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Certificate

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Has been prepared by

DR. OJAS A. GAJBHIYE

*under my direct supervision and guidance in the partial fulfilment
of the regulations for the award of the*

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His work on the subject has been checked by me time to time.

I am satisfied regarding the authenticity of his observations, clinical material and experimentation in this dissertation and it confirms to the standards of Maharashtra University of Health Sciences, Nashik.

I have great pleasure in forwarding it to Maharashtra University of Health Sciences, Nashik.

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Declaration

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from any University.*

DATE: 10/12/19
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CONTENTS

SR NO.	TITLE	PAGE NO.
1.	Introduction	1
2.	Aims and objectives	5
3.	Review of literature	6
4.	Materials and method	33
5.	Result	43
6.	Discussion	51
7.	Summary	60
8.	Conclusion	63
9.	Bibliography	65
10.	Tables and graphs	i-ii
11.	Annexure	iii

LIST OF TABLES

Table No.	Title	Page no.
1	Mean retention in three study groups along with different measures of variation	i
2.	Comparison of mean retention across three study groups by one-way ANOVA (Analysis of Variance)	i
3	Pair-wise comparison of Mean retention of three study groups by Bonferroni Multiple Comparison test	i

LIST OF GRAPHS

Graph 1	Title	Page no.
Graph 1.	Comparison of retention in three groups	ii

LIST OF ABBREVIATIONS

Abbreviations	Full form
DMLS	Direct Metal Laser Sintered
mm	millimetres
μ	micron
$^{\circ}\text{C}$	Degree celsius
SLI	StereoLithography Interface
RP	Rapid prototyping
3D	3-Dimensional object
YB-fibre	Ytterbium-doped optical fibre
SPSS	Statistical package for the social science
SD	Standard deviation
ANOVA	Analysis of variance

COLOR PLATES

Sr. no.	Title	Plate no.
1.	Auto polymerising acrylic resin	I
2.	Milling unit	
3.	Typhodont ivory Right Mandibular First Molar tooth	
4.	Dental surveyor (William's)	
5.	Air-rotor hand-piece	
6.	Straight flat diamond point (SF-12) Dumbbell shaped diamond point (EX-11) Tapered round ended diamond point (TR-26) Extra Fine Tapered round ended diamond point (TR-26EF)	
7.	Polyvinyl siloxane impression material and light body impression material	II
8.	Blue Inlay wax	
9.	Cobalt-Chromium alloy (Wironit)	
10.	Vacuum mixer (Speedymix)	
11.	Investment material (Wirovest)	
12.	Burnout Furnace	
13.	Induction casting machine (LC-cast)	
14.	Metal polishing kit	
15.	Aluminium oxide particles (110um)	
16.	Sand blasting unit (Santer labo-16)	
17.	CAD/CAM Digital Scanner	
18.	Milling EOS machine	
19.	EOS Cobalt-chromium alloy	
20.	Inverted cone high speed carbide bur RA-37 Tapered fissure high speed carbide bur HP-701	III
21.	Laboratory micro-motor and contra-angled hand-piece (Marathon - 3+)	
22.	Type-I Resin Modified Glass Ionomer Cement	

Sr. no.	Title	Plate no.
23.	Universal Testing Machine	IV
24.	Plastic box	V
25.	Typhodont tooth	
26.	Tooth submerged in acrylic block	
27.	Tooth preparation	
28.	Two-piece mould	
29.	Inlay Wax filled	
30.	Wax pattern of prepared tooth	
31.	Spruing	VI
32.	Investing	
33.	Casted metal dies	
34.	45 metal dies submerged in acrylic block	
35.	CAD CAM digital scanner	VII
36.	Pattern of metal die made	
37.	Material dispensing platform	
38.	Laser sintering process	
39.	Final prepared DMLS crowns with loops	VIII
40.	Horizontal grooving	
41.	Vertical grooving	
42.	Application of cement	
43.	Pressure of 1kg	
44.	Total 45 DMLS metal crowns cemented on metal dies	IX
45.	Retention testing of samples on universal testing machine	

Introduction

I suppose when you do it correctly, a good introduction and a good outro makes the song feel like it's coming out of something and then evolving into something

- Bruce Springsteen

Fabricating and maintaining fixed prosthodontics occupy a major portion of every restorative-treatment-based dental practice. As a subspecialty in the discipline of prosthodontics, the provision of fixed prosthodontics increased considerably in the past decade, with surveys indicating increasing demand in the future.^{1,2}

Recent material, technical and clinical innovations in fixed prosthodontics have increased the complexity of treatment planning and decision making. Many of these advances have not replaced but have augmented a wide variety of existing materials or treatment protocols, as well as clinical techniques and skills. Several

advances in dental technology reflects the public's increased awareness of the aesthetic potential of fixed-restoration procedures. The enthusiasm of some clinical proponents of these aesthetic procedures have resulted in a shift from restorative efforts directed toward a pleasing, natural appearance to procedures designed to achieve a better-than-natural's ideal.³

The loosening of dental crowns or bridges throughout mastication could be a notable problem. The main reason behind this loosening could be a lack of resistance and therefore the retention factor of the abutment teeth, though different causes include the dimensions of the abutment teeth, the conical type of the abutment teeth, and an absence of abutment teeth because of cavity. The failure of laboratory or cementation procedures might also cause the loosening of crowns.^{4,5} Adequate resistance to dislodgement depends on three factors: a) Magnitude and direction of the dislodging forces. b) geometry of tooth preparation. c) Physical properties of luting cements.⁶ Of those three factors, the magnitude and direction of the dislodging forces are an inherent patient issue that the dentist might not be able to control adequately.⁷ Sometimes, in everyday life, several of those higher than mentioned factors don't seem to be beneath the control of the patient and the practitioner. Hence, there arises a requirement to enhance the retention of crown by either modification of external surface of tooth or internal surface of crown with added features to counteract these clinical situations. So, numerous measures were taken in this direction by several authors.^{8,9}

Grooves and boxes increases the surface area considerably and improve the resistance form on short-walled abutments.¹⁰ Proximal (mesiodistal) grooves offer

additional resistance than buccolingual grooves do.⁶ Types of cement might also influence resistance or retention.¹¹⁻¹⁶ The supplemental use of interproximal grooves and boxes has been specifically counselled to be used in molar preparations of less than 4 mm in vertical height.¹⁷ The use of those adjuncts have been planned to offset the negative attributes of large axial wall inclination angles and/or vertical height deficiencies. However, in some investigations of those specific factors in molar-sized preparations didn't demonstrate a major counteraction of rotational dislodgement once they were placed into the tooth at an equivalent 20-degree total occlusal convergence angle as the axial walls of the tooth.¹⁸ It is not perpetually possible to perform preparation modification on the external surface of prepared tooth because the remaining dentinal thickness are often too less in root canal treated tooth. So, in order to enhance the retention of crown modification in internal surface of crown is the safest choice. To solve this problem, horizontal circumferential retentive grooves are often placed on the inner surface of the crown to aid in increased retention.⁹

It is usually understood, that the surface area, length of the opposing walls, total occlusal convergence, and resistance form together with the adhesive qualities of the cement provide the resistance to dislodgement of crowns placed intraorally. Sometimes, the clinician is challenged because of several local factors associated with the condition of the strategic tooth that includes short clinical height of the prepared tooth, excessive tooth structure loss because of caries, trauma, etc. faulty tooth preparations with increased total occlusal convergence and so on, that causes the loss of retention of the prosthesis. This lacuna is often rectified by modification of the prepared tooth or that of the prosthesis or in some cases by changing the choice of our luting agent. Modifying the already compromised prepared tooth can be an additional

challenge to the future prognosis of the prosthesis by making it more vulnerable for dislodgement. Also, as additional prone to catastrophic fracture as a result of any modification in an already compromised tooth can weaken it further.^{8,19}

Previous studies have investigated and suggested that, to get greater resistance, they need primary focus on the foremost applicable positioning of the grooves. Totally different forms of axial groove are available, as well as box-shaped grooves, formed grooves, and half round grooves, though half round grooves are most often used.^{4,5} The controversy of the nature of resistance type and therefore the lack of clinical guidelines make judgment tough, particularly when the preparation isn't ideal. Molar preparations would probably not satisfy these recommendations, and auxiliary features like boxes and grooves would be needed to enhance the retention form.^{20,17}

In this study, an attempt is made to investigate the retention factor by the incorporation of different grooves in the internal surface of DMLS crowns for respective groups.

Aim And Objectives

Aim

The aim of the study is to evaluate and compare the supplementary retentive features on retention of direct metal laser sintered crowns.

Objectives

1. Whether the supplementary retentive features incorporated in the internal surface of DMLS crowns, affects its retention?
2. Whether incorporation of one horizontal circumferential groove in the internal surface of DMLS crowns, affects its retention?
3. Whether incorporation of two vertical grooves (one on buccal surface and other on lingual surface) in the internal surface of DMLS crowns, affects its retention?

Review Of Literature

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

-Edward G. Bulwer-Lytton

Smith BG (1970)²¹ evaluated the impact of the surface roughness of ready dentin on the retention of castings. Thirty-six preparations were made up from extracted teeth and divided into three groups. The dentin surfaces of the three groups of twelve teeth were made (1) smooth, finished by polishing with stannic oxide on a calico wheel; (2) fine, finished with 220 mesh silicon carbide paper; and (3) rough, finished with sixty mesh flint paper. Open-top gold crowns were cast for every tooth and cemented with zinc phosphate cement. 10 samples from every group were separated twice underneath an axial tensile force and a pair of samples from every group were divided for study of the cement film thickness. He concluded that altering the roughness of a prepared dentin surface within a

range of 5-120 micro inches doesn't considerably have an effect on the retention of a completely vented cast crown. The retention of castings cemented to natural teeth, varies more than the retention of comparable castings cemented to plastic dies.

Gilboe DB and Teteruck WR (1974)²² classified and mentioned the fundamental principles and factors of tooth preparation for retention and resistance form. Parallelism: - As the axial walls approach parallelism, the restoration can withstand greater displacement from tensile and shearing stresses. Axial surface reductions, within 2 to 5 degrees of parallelism with the path of withdrawal of the preparation, provide optimal resistance and retention. Length: - As the length of the axial walls of the preparation increases, the resistance and retention form increase. The maximum length of the axial walls is maintained during preparation by removing minimal occlusal or incisal tooth structure to provide adequate bulk of restorative material for occlusion. Preservation of the inclined planes of the occlusal surfaces and the incisal angles of anterior teeth is the primary factor affecting this objective. Surface area: - A direct relationship exists between surface area and the retentive resistance potential of the retainer. The larger the cervical diameter of the tooth, the greater the surface area available to be included in the preparation. Thus, the greater the circumference of the tooth, the greater the potential resistance of the retainer to dislodgment. If the primary factor and its utilization are insufficient, secondary factors should be incorporated. The secondary factor should be located (1) with the line of withdrawal, (2) as far as possible from its reciprocal retentive feature, and (3) at a point which permits the maximum length. The appropriate factor to be incorporated is the one which resists the displacing forces while conserving the greatest amount of structure. Groove: - The groove is the secondary factor which best achieves resistance

form while conserving maximum tooth structure. It is, thus, the most commonly incorporated secondary factor. Box: - The box may be regarded as a wide groove with an increased surface area. Pinhole: - The pinhole may have tapered or parallel walls. Both types contribute more toward retention than resistance. The amount of retention is directly related to the area of the pin contacting the tooth and to the intimacy of the contact. Retention is a function of the length and diameter of the pin. a) The pin is most vulnerable when subjected to shearing stress. Therefore, bulk is always necessary adjacent to the body of the casting. b) A basis for the selection and application of these principles and factors to fulfil the biomechanical requirements of individual retainers have been presented. c) Adequate resistance and retention can be achieved during tooth preparation if a systematic approach, as outlined, is applied.

Willey RL (1976)²³ found that the angle of convergence will be changed according to the surface area of preparation to enhance retention. He stated that the preparations of larger surface area will be equally retentive with additional angle of convergence than the preparations with lesser surface area and lower axial taper. Factors helpful in obtaining extra retention were (a) less convergence, (b) more axial surfaces included, (c) additional gingival extension, (d) less occlusal reduction, (e) pinhole retention, (f) pin and amalgam core retention, and (g) endodontic therapy and dowel retention.

Woolsey GD and Matich JA (1978)⁶ conducted a study on effects of parallel axial grooves on resistance form of complete crown preparations. Fifteen sets of castings were fabricated to machine stainless steel dies of 5°, 10°, and 15° of taper and 3, 4, 6, 8, and 10 mm of preparation length. Each casting was loaded vertically on

its sloped surface in an attempt to unseat the casting. Only the castings of 3 and 4 mm of preparation length and 10° and 15° of taper were unseated. Two experiments were performed on these four sets of dies to test parallel proximal and parallel buccolingual grooves. Dies with grooves oriented on the proximal surfaces provided complete resistance to horizontal dislodgement, whereas dies with grooves oriented on the buccal and lingual surfaces provided only partial resistance to horizontal displacement and potential failure of the castings.

Potts RG, Shillingburg HT et al. (1980)²⁴ conducted a study to evaluate the effect of preparation designs on retention and resistance. Retention prevents removal of a cast restoration along the path of insertion or long axis of the tooth preparation. Resistance prevents dislodgement of the restoration by forces directed in an apical or oblique direction and prevents any movement of the restoration under occlusal forces.” Test dies were made for each of five preparation designs: three-quarter partial veneer crown without axial grooves, three-quarter partial veneer crown with axial grooves, seven-eighths partial veneer crown without axial grooves, seven-eighths partial veneer crown with axial grooves, and complete veneer crown without grooves. The preparations had axial walls 6 mm in length with a 6-degree taper. Axial grooves, when present, were approximately 5.5 mm long and 1 mm in diameter. Five preparation designs were tested for retention and resistance. Retention values for all partial veneer crowns were significantly lower than those for the complete veneer crown. They concluded that resistance values increased significantly with the addition of grooves and/or extension of axial surface coverage. Addition of grooves and/or extension of axial surface coverage produced small increases in retention values but marked increases in resistance values.

Chan KC, Hormati AA et al. (1981)²⁵ conducted a study to determine the effect of cement keys on the retention of complete crowns with good or poor retentive form. The retentive strength of cast gold crowns to fresh extracted human teeth was measured with 7- or 30-degree tapering walls. Auxiliary retention within the form of grooves was placed in 3 ways: (1) an impact with no auxiliary grooves, (2) one groove within the crown. (3) one groove in the tooth, and (4) opposing grooves in the crown and tooth. Zinc phosphate cement was used to cement all crowns. They found that a) Cement keys were an effective means of increasing the retention of complete cast gold crowns to preparations in extracted teeth. b) Single grooves placed in either the dentin or in the crown alone were not effective in increasing retention in 30-degree crowns. In 7-degree crowns, a single groove in the crown gave better retention than a single groove in the dentin. c) Crowns with a 7-degree taper had greater retentive strengths than 30-degree crowns treated identically. The retentive strength of 7-degree crowns with cement keys approached the tensile strength of zinc phosphate cement.

Van Nortwick WT and Gettleman L (1981)²⁶ compared the results of occlusal venting, horizontal vibration, and internal relief within cast crowns were investigated separately and altogether combinations-on the seating of cemented cast crowns using Zn phosphate cement. 10 Ticonium (cobalt-nickel-chromium) dies were fabricated to simulate full crown preparations of a bicuspid tooth with total taper of the preparations was 11 degrees, and two crowns were cast in Gold coloured Technique Alloy for every die. The primary crown was made to closely fit the die on all surfaces. Three layers of a die spacer were then brushed over all surfaces of the die except at the margin. A second crown was cast with internal relief because of the die

spacer during cementation, a static force of 7.2 kg was applied using an air cylinder. Vibration was obligatory on the crowns by pressing the working end of a portable Vibra-Seat horizontally against one aspect of the crown for ten seconds, whereas the static force was still being applied. They found that a) Vibration, applied horizontally, had no effect by itself or any interaction with venting or internal crown relief. b) Venting and internal relief alone effectively achieved good seating. c) Venting and internal relief together were the most effective combinations. d) When crowns were seated well, they tended to tilt less.

Ishikiriyama A et al. (1981)²⁷ conducted a study on the influence of cement film on the fit of cemented crowns. Maximum factors affecting cementation are the amount of cement placed into the crown before cementation, the appliance of vibration, and venting or etching of the crowns. In the study, cast gold crowns were cemented similar to methods used for patients. They concluded that: a) Fresh cement painted with a camel brush in the part of the crown to be cemented promotes a better fit than when the crown is completely filled with cement. b) Mechanical vibration of the crown at cementation promotes a better fit. c) Venting the crown, an internal relief by acid etching, or a combination of both these procedures improve the seating of the crown during cementation. d) The association of one or numerous variables used in this study considerably improves the fit of the cemented crown.

Witwer DJ, floor RJ et al. (1986)¹⁹ conducted a study to determine the effects of the tooth surface and grooving on the retention of cast prostheses, with and without circumferential grooving, when luted with zinc phosphate and zinc polycarboxylate cements. Twenty freshly extracted sound mandibular third molars of

similar size and shape were collected and the roots were embedded in acrylic blocks. The clinical crowns were fully exposed. A No. 2 TDX diamond bur was used for tooth preparation. The convergence angle of the prepared tooth was determined by the bur taper. Additional taper was placed on the occlusal one third of the facial surface to ensure removal of all tooth enamel. All preparations were 34 mm in circumference with an occlusal height of 5 mm. Preparation margins were a chamfer and bevel. No occlusal anatomy was used. Visual inspection of the crowns after failure showed that in all tests the zinc polycarboxylate cement was retained within the cast crown. In contrast, the zinc phosphate cement was found on both the clinical and the cast crowns. The greater portion of cement was retained on the tooth with the non-grooved cast crowns but most cement was found in the cast grooved crowns; the proportion was even greater with rough tooth finishes. The findings indicated that optimum crown retention using zinc polycarboxylate cement is obtained with rough tooth preparations and that grooving of the cast crown is unnecessary. In contrast, optimum cast 'crown retention is obtained for zinc phosphate cement with grooved crowns and a smooth tooth surface finish.

Felton DA, Kanoy BE et al. (1987)²⁸ compared the retention of crowns cemented on teeth prepared with carbide burs with crowns cemented on teeth prepared with diamond burs. Sixty recently extracted posterior teeth were cleaned and the root surfaces notched for anchorage. The roots were then embedded in individual blocks of acrylic resin to within 2 mm of the cement-enamel junction. A surveyor was used to ensure that the clinical crown of each tooth was parallel to the acrylic resin block. The rectangular base of each embedded sample was numbered. All samples were stored in a 100% humidity environment except during embedding, preparation,

cementation, and crown removal procedures. The numbered samples were randomly selected to be placed in one of two treatment groups of 30 samples each. Group I consisted of teeth prepared with carbide burs. Group II consisted of teeth prepared with diamond burs. They concluded that a) Other things being equal, teeth prepared for full crowns by using diamond, burs will have 31% greater retention than preparations made with carbide burs. b) If the dentist wishes to use the more efficient carbide burs, alternative retention features should be considered in the preparation design.

Nordlander J et al. (1988)²⁰ measured the convergence angles of full coverage preparations performed in a clinical environment. Teeth were prepared by the participants to do a 4- to 10-degree convergence angle. The dies examined throughout this study were collected from clinically successful crowns and fixed partial dentures created for either all-metal or ceramo-metal crowns. A total of 88 working dies in conjunction with full-coverage preparations by eight general practice residents (GPRs) and 120 dies by two prosthodontists were included. The dies were sorted into maxillary and mandibular groups and additionally divided into anterior, premolar, and molar categories. They found that a) The ideal convergence angle of 4 to 10 degrees is seldom achieved in clinical practice. b) Mean convergence angles for mandibular preparations were greater than mean maxillary convergence angles. c) Premolar convergence angles tended to be smaller than anterior convergence angles. Both were smaller than molar convergence angles. d) No significant differences were found between the mean convergence angles of crowns and fixed partial denture retainers. e) Auxiliary retention should be used in the molar region because these preparations were found to have large convergence angles.

Rosenstiel SF, Land MF et al. (1998)²⁹ reviewed to distill the recent scientific literature on luting agents and their use, to help identify properties of an optimal luting agent, and to assess how currently available materials meet that ideal. They concluded that Dental luting agents form the link between a fixed restoration and the supporting tooth structure. This literature review identifies biologic, mechanical, aesthetic, and working properties of an ideal material and summarizes published information as to how available materials conform to these ideals and how their performance is affected by manipulative variables. Summary tables are presented that include pertinent properties of the various classes of luting agents, indications, contraindications, and comparative data as provided by the manufacturers.

Tuntiprawon M (1999)³⁰ conducted a study to determine the marginal seating and retention of complete cast metal crowns cemented to teeth prepared with different grit sizes of diamond stones, with 3 contemporary luting agents. Coarse and fine diamond stones were used to create various surface roughness's of premolars. A milling machine was used to control the height and angle of the axial walls of tooth preparations. Ten cast metal crowns in 6 subgroups were luted with 3 cements (Phosphacap, Fuji Cap I, and Panavia 21). Marginal seating was recorded with a Digimatic indicator. Retention was determined by measuring the tensile force required to remove a metal crown with a Lloyd testing machine. They concluded that tooth surfaces prepared with a coarse diamond stone (grit size 120 mm) statistically increased the retention of artificial crowns compared with tooth surfaces prepared with a fine diamond stone (grit size 50 mm). Significant differences were recorded for luting agents: zinc phosphate, glass ionomer, and resin cements. No statistically

significant differences existed in the marginal seating of artificial crowns luted to rough and smooth preparations with cements in this investigation. a) Resinous cement (Panavia 21) provided the greatest retention of crowns but poorer marginal seating was evident. b) Glass ionomer (Fuji Cap I) cement recorded the best marginal seating for complete metal crowns.

Clinically implications: - Teeth prepared with coarse diamond stones had greater retention than those prepared with fine diamond stones. Resin cement provided the best retention, but poorest seating for complete metal crowns.

Goodacre CJ, Campagni WV et al. (2001)¹⁷ reviewed the the historic evolution of complete coverage tooth preparations and identifies guidelines for scientific tooth preparations. Authors concluded that a) The total occlusal convergence, or the angle of convergence formed between 2 opposing prepared axial surfaces, ideally should range between 10 and 20 degrees. b) Three millimeters should be the minimal occluso-cervical/ incisio-cervical dimension of incisors and premolars prepared within the recommended 10 to 20 degrees of total occlusal convergence. c) The minimal occluso cervical dimension of molars should be 4 mm when prepared with 10 to 20 degrees total occlusal convergence. d) The ratio of the occluso-cervical/inciso-cervical dimension of a prepared tooth to the facio-lingual dimension should be at least 0.4 or higher for all teeth. e) Whenever possible, teeth should be prepared so that the facio-proximal and linguo-proximal corners are preserved, thereby sustaining variation in the circumferential morphology that enhances resistance form. f) Teeth without natural circumferential morphology after tooth preparation (round teeth) or teeth that lack adequate resistance form should be

modified with the creation of grooves/boxes. g) Many molars need auxiliary grooves or boxes to enhance resistance form because of their short occluso-cervical dimensions and the unfavourable ratio of the occluso-cervical dimensions to the faciolingual dimensions. h) Axial grooves/boxes should be used routinely when mandibular molars are prepared for fixed partial dentures, and they should be located on the proximal surfaces. i) When tooth conditions and esthetics permit, finish lines should be located supragingivally. j) When subgingival finish lines are required, they should not be extended to the epithelial attachment. k) Chamfer finish lines approximately 0.3 mm deep are well suited for all-metal crowns. l) The type of finish line selected for use with metal-ceramic crowns should not be based on marginal fit but on personal preference, esthetics, formation ease, and type of metal-ceramic crown. The optimal clinical depth that is routinely achievable has not been determined. m) Both shoulder and chamfer finish lines can be used with all-ceramic crowns if the crowns are bonded to the prepared teeth. Depths greater than 1 mm are not required when a semi translucent type of all-ceramic crown is used. n) Axial and occlusal reductions for all-metal crowns should be at least 0.5 mm deep and 1.0 mm deep, respectively. For metal-ceramic crowns, facial/axial reductions in excess of 1 mm can compromise the remaining tooth structure external to the pulp, whereas 2.0 mm of occlusal reduction is commonly achievable even on a young tooth. With all-ceramic crowns, it is not necessary to exceed 1 mm of axial reduction with semi translucent systems and higher value, lower chroma shades. Two millimetres incisal/occlusal reduction is recommended for all-ceramic crowns. o) Line angles should be rounded on all-ceramic tooth preparations to reduce stress in the definitive restoration. With crowns that use metal, the primary purpose of line angle rounding is

to facilitate pouring impressions and investing wax patterns without trapping air bubbles and to facilitate removing casting modules. p) Smooth tooth preparation appears to enhance the fit of restorations. Surface roughness generally increases retention with zinc phosphate cement, but its effect with adhesive cements (polycarboxylate, glass ionomer, resin) has not been as definitely determined. A reasonably smooth tooth preparation is therefore recommended. Clinically implications: - The principles identified in this study can help dentists design, assess, and modify complete coverage tooth preparations to ensure clinical success for the treatment of a variety of unprepared and previously prepared teeth.

Zidan O and Ferguson GC (2003)³¹ evaluated the retention of full crowns prepared with 3 different tapers and cemented with 2 conventional and 2 adhesive resin cements. One hundred twenty sound human molar teeth were assigned randomly to 1 of 12 groups, (n_10). The groups represented the 4 cements: zinc phosphate (Fleck's), a conventional glass ionomer (Ketac-Cem); 2 adhesive resin cements (C&B Metabond and Panavia); and 3 tapers of 6-degrees, 12-degrees, and 24-degrees within each cement. Crowns were cast with a high noble alloy. The 6-degree taper was considered the control within each cement group. Retention was measured (MPa) by separating the metal crowns from the prepared teeth under tension on a universal testing machine. They concluded that a) The mean retentive strength of crowns prepared with the 3 tapers and cemented with zinc phosphate (3.7 MPa) or conventional glass ionomer (3.6 MPa) was significantly lower than the mean retentive strength of crowns cemented with either of the 2 resin cements (6.5 MPa). b) Use of the glass ionomer cement did not result in increased retentive strength over zinc phosphate cement in spite of the purported bonding of glass ionomer to tooth

structure. c) Increasing the taper of the preparation from 6 degrees to 12 degrees did not affect the retention of crowns within the different cement groups. The choice of cement for crowns prepared within this ideal range of taper might be of limited clinical significance. d) Increasing the taper to 24 degrees decreased the retention of crowns significantly. Crowns luted with resin luting agents demonstrated significantly greater bond strengths for preparations with taper greater than 12 degrees.

Clinical implications: - The adhesive resin cements used in this in vitro study yielded retentive values at 24-degree taper higher than the values obtained from conventional cements at 6-degree taper and may be considered for luting restorations on teeth with less than ideal taper.

Proussaefs P, Campagni W et al. (2004)¹⁸ evaluated the effects of different auxiliary preparation features on the resistance form of crowns with reduced axial wall and total occlusal convergence. An Ivorine tooth was prepared on a milling machine with 20-degree total occlusal convergence (TOC), 2.5 mm of occluso-cervical dimension, and a shoulder finish line. This design lacked geometric resistance form. The crown preparation was subsequently modified to include mesiodistal grooves, mesiodistal boxes, buccolingual grooves, occlusal inclined planes, an occlusal isthmus, and reduced TOC in the axial wall from 20 to 8 degrees TOC in the cervical 1.5mm of the axial wall. The grooves and boxes were placed into the tooth with the same 20-degree TOC as the initial axial walls. Ten standardized metal dies were used for each preparation design. Standardized complete metal crowns were fabricated for all specimens. The metal crowns were cemented on metal dies with resin-modified glass ionomer cement. A strain gauge was placed at the mid-

lingual cervical area of each crown preparation margin. The resistance of each specimen was evaluated when force was applied at a 45-degree angulation to the long axis of the die in a lingual to buccal direction. The peak loads during crown dislodgment, as well as the tensile stress at the mid-lingual cervical area, were measured using a universal testing machine (Kgs) for each specimen. The control group consisted of 10 dies, with the original crown preparation having no geometric resistance form and no auxiliary preparation features. The following conclusions were offered: - a) Decreasing the TOC from 20 to 8 degrees in the apical 1.5 mm of the reduced axial surfaces significantly increased resistance form. b) Two proximal grooves or 2 proximal boxes or 2 grooves (mid-buccal and mid-lingual) that followed the existing convergence of the axial walls (20 degrees) did not significantly enhance resistance form. c) Preparing the occlusal surface so it possessed inclined planes that paralleled the original inclined form of the occlusal surface (30 degrees relative to the long axis of the tooth preparation) did not significantly enhance resistance form. d) Preparing an occlusal isthmus 1 mm deep and 1.5 mm wide did not significantly improve resistance form. e) The most effective method of enhancing resistance form in a tooth preparation that lacks resistance is to decrease the total occlusal convergence of the cervical portion of the prepared axial walls

Clinical implications: - In this in vitro study, for a compromised situation in which a crown preparation had reduced resistance form (reduced axial wall height and/or reduced total occlusal convergence), the auxiliary preparation element that most effectively enhanced resistance form of the crown was reducing the cervical total occlusal convergence from 20 to 8 degrees.

Potts R G, Shillingburg H T et al. (2004)³² conducted a study to evaluate the effect of preparation designs on retention and resistance. Test dies were made for each of five preparation designs: three-quarter partial veneer crown without axial grooves, three-quarter partial veneer crown with axial grooves, seven-eighths partial veneer crown without axial grooves, seven-eighths partial veneer crown with axial grooves, and complete veneer crown without grooves. The preparations had axial walls 6 mm in length with a 6-degree taper. Axial grooves, when present, were approximately 5.5 mm long and 1 mm in diameter. They concluded that Five preparation designs were tested for retention and resistance. Retention values for all partial veneer crowns were significantly lower than those for the complete veneer crown. Resistance values increased significantly with the addition of grooves and/or extension of axial surface coverage. Addition of grooves and/or extension of axial surface coverage produced small increases in retention values but marked increases in resistance values.

Cameron S M, Morris W J et al. (2006)³³ conducted a study to evaluate the number of cycles required to dislodge a cemented complete crown casting under a cyclic lateral load as a function of taper and to compare this relationship for the resistive and nonresistive ranges of taper. Three dies were milled from stainless steel at each of the following tapers: 4, 8, 12, 16, 20, 24, 28, and 32 degrees. A gold-palladium metal-ceramic alloy crown was fabricated for each die, cemented, and subjected to lateral cyclic loading until failure or 1,000,000 cycles. The limiting taper for the dies with their given height and base was 26.6 degrees. Dies with taper less than 26.6 degrees had resistance form, whereas dies with taper larger than 26.6 degrees did not. A linear regression ($\alpha=.05$) was used to evaluate the relation of cycles at dislodgement to taper. They concluded that the number of cycles required to cause

crown dislodgement was linear after 12 degrees in the resistive area and nearly zero for preparations in the nonresistive area. The limiting taper concept closely predicted the transition point where the slope of the graph of cycles to dislodgement as a function of taper abruptly changed.

Clinical implications:- This study suggests that clinical success or failure of cemented cast restorations follows the on-off nature of resistance form, and this resistance form is a reasonable basis for determining minimally acceptable taper.

Abreu A, Loza M A et al. (2007)³⁴ conducted a study to evaluate the effect of alloy type and surface pre-treatments of base and noble metal copings on their tensile strength to minimally retentive preparations. Minimally retentive, standardized crown preparations were made on recently extracted human third molars (n=68). Noble (IPS d.SIGN 53) and base metal (Rexillum NBF) copings were fabricated. All copings received heat treatment for oxide formation. Three experimental groups were then developed for each metal type (groups ranging from 10 to 12 specimens each): oxide only, airborne-particle abraded, or metal-primed. Copings were cemented using a self-adhesive universal resin cement (RelyX Unicem) and were thermal cycled (500 cycles between 5 and 55°C) and stored (24 hours, 37°C) before debonding using a universal testing machine. Frequency of debond location was compared among specimen groups. The following conclusions drawn: a) There was no significant influence of metal type, surface pre-treatment, or their interaction on the bond strength of metal-ceramic copings cemented to minimally retentive, standardized preparations using a self-adhesive cement. b) Significant differences were noted among failure location sites with respect to metal type and surface pre-treatment. In general, the noble metal

tended to shift failure location to occur more frequently at the dentin/ cement interface and within the root than did use of the base alloy. Pre-treatment with the metal primer shifted debond locations in a similar manner as that noted for the noble metal type more so than treatment with oxide layer formation only or with airborne-particle abrasion. Airborne- particle abrasion was found to shift debonding more toward root failure than did the oxide layer only, which did not show any statistical preponderance of failure site location among the interfaces.

Clinical Implications; - When cementing a metal-based restoration to a minimally retentive preparation, using the prescribed luting agent, alloy type does not affect crown retention strength, but surface treatment may affect the debonding location.

Bowley JF and Lai WT (2007)³⁵ conducted a study to evaluate surface area improvement with the use of supplemental grooves in tooth preparations for complete crowns. The surface area preparation improvement in combinations of unfavourable/marginal height and axial-wall inclinations was quantified. A right regular pyramid was used to simulate a single mandibular molar tooth preparation with known axial-wall inclinations and vertical heights. Various combinations of these 2 variables allowed the calculation of surface areas with a formula for the area of a pyramid, cones, and right triangles through geometric/trigonometric manipulations. The pyramidal model system had a 9-mm square base with marginal and unfavourable vertical heights, 3 or 4 mm, and axial-wall inclination angles from 2 to 25 degrees. Conical-shaped grooves of varying lengths and widths, depending on height and axial-wall inclinations, were introduced with a tapered fissure bur. This

investigation had identified 3 adjuncts (1 and 2 grooves per proximal wall and the proximal box) to improve the fixed prosthodontic preparation surface area in simulated mandibular molar teeth. Significant differences in both 3- and 4-mm vertical preparation heights compared to the 2-degree Ideal were found. Both grooves and boxes provided significant improvement of total surface area for both the 3- and 4-mm vertical preparation heights. These supplemental preparation components were limited by interproximal occlusal surface width in the most unfavourable combinations. Maximum surface area would be expected to complement other resistance form attributes.

Clinical Implications; -Axial grooves and boxes improved the surface area of marginal or unacceptable simulated first molar-sized crown preparations with an increased luting agent-restoration interface.

Lu PC and Wilson P (2008)³⁶ conducted a study to examine the effect of auxiliary grooves on resistance to dislodgment of crowns on compromised molar preparations lacking resistance form. Thirty human molar teeth were randomly assigned to three groups of ten, and prepared to a height-to-width ratio of 0.3 with a total convergence of 50°, and 1-mm shoulder margin. Base metal alloy copings were constructed with a 45° loading platform and cemented with zinc phosphate cement under a 50 N load. Initially, resistance testing was conducted using a Universal Testing Machine (Instron) at 1 mm/min for all 30 specimens. Following crown dislodgment, Group 1 copings were recemented and retested, Group 2 had one axial groove added, and Group 3 had two axial grooves added. New copings for Groups 2 and 3 were made, cemented, and again tested for resistance. Standardized radiographs

were taken prior to initial cementation and scanned into digital images. The percentage of area occupied by the pulpal chamber above the acrylic mounting (PS), and the closest distance to pulp from the preparation surface (CD) were measured. They concluded that the dislodged crowns can be recemented without affecting resistance. In a compromised molar crown preparation, two grooves should be incorporated instead of one to enhance the resistance form. Sufficient enhancement of resistance form achieved with these auxiliary grooves can save the tooth from elective endodontic treatment. Teeth with large pulps and therefore less coronal dentine have more flexible cores, and thus poorer resistance form. Therefore, they would benefit from placement of auxiliary grooves.

Ayad M, Johnston W et al. (2009)¹² conducted a study to determine the relationship between the convergence angle of tooth preparations for complete metal crowns and the recementation strength of their respective restorations upon cementation and recementation with conventional and adhesive cements. One hundred twenty artificial crowns were cast for standardized complete metal crown tooth preparations accomplished with the use of a milling machine on extracted human teeth. Three different tapers, 5, 12, and 25 degrees, were used (n=40). The crowns in each group were subdivided into 4 subgroups (n=10) according to the luting cement: zinc phosphate cement (Fleck's), glass ionomer cement (Ketac-Cem), and adhesive resin cements (Panavia 21 and C&B-Metabond). Retention was evaluated by measuring the tensile force required to dislodge the crowns from the tooth preparations in a universal testing machine. Subsequently, the tooth preparations were scraped clean and polished with prophylaxis paste, and the intaglio surfaces of the artificial crowns were ultrasonically cleaned and airborne-particle abraded with 50-

µm aluminium oxide powder prior to recementation. the following conclusions were drawn: a) Tooth preparation taper and cement type significantly affected the initial and recementation bond strength of complete metal crowns. b) There is significant reduction between initial and recementation retentive strength for the tapers and luting cements evaluated. c) Among the tapers used, initial and recementation retentive strength of tooth preparations with a 5-degree taper is significantly greater than those with 12-degree and 25-degree taper. d) Among the cements used, Panavia 21 cement yielded the significantly highest initial and recementation retentive strength values. However, zinc phosphate cement exhibited significantly lower retention for initial and second cementations. e) Adhesive resin cements Panavia 21 and C&B-Metabond achieved significantly higher strengths than the conventional cements, zinc phosphate and glass ionomer cements.

Clinical implications: - The best initial and recementation retention is obtained when complete metal crowns are cemented with adhesive resin cements, regardless of tooth preparation taper. Therefore, resin cements should be considered for luting restorations on teeth with less than ideal taper.

Roudsari RV and Satterthwaite JD (2011)³⁷ evaluated the effect of different auxiliary features on the resistance form of crowns with reduced axial wall height and increased total occlusal convergence. An Ivorine tooth was prepared on a milling machine with 22 degrees of total occlusal convergence (TOC), 3.0 mm of occluso-cervical height, and a chamfer finish line (Group Ctrl). The crown preparation was subsequently modified to include proximal grooves (Group Grv), and reduced TOC from 22 to 4 degrees in the cervical 1.5 mm (Group Rdc). Ten standardized metal dies

were fabricated for each group. Cobalt-chromium copings were fabricated for all specimens. The metal copings were cemented onto their corresponding metal dies with zinc phosphate cement. The resistance of each specimen was evaluated when force was applied at a 45-degree angle to the long axis of the die with a universal testing machine in a buccal to lingual direction. The maximum force (newtons) was applied before coping dislodgment was measured. The following conclusions relating to the effectiveness of tooth preparation modifications on resistance form were drawn.

a) Decreasing the TOC from 22 to 4 degrees in the apical 1.5 mm of the reduced axial surfaces significantly increases resistance form. b) Two parallel mesiodistal grooves within a preparation with 22 degrees of convergence significantly enhances resistance form. c) The most effective method of achieving resistance form in a tooth preparation that lacks resistance is to decrease the total occlusal convergence of the cervical portion of the prepared axial walls.

Li Y, Wang H et al. (2012)³⁸ conducted a study to evaluate the relationship between the surface roughness of prepared teeth and the internal adaptation and retention of complete coverage restorations after preparation with diamond rotary cutting instruments of different grit sizes. Ninety-two extracted human teeth were divided into 4 groups and assigned to different final grit sizes of the diamond rotary instruments used for preparation following a grit decreasing sequence from coarse (125 to 150 μm), to medium (106 to 125 μm), to fine (53 to 63 μm), to extra fine (20 to 30 μm). After preparation, the surface roughness of 32 teeth was measured with a profilometer. The other 60 teeth were prepared as abutments, with 28 of these teeth used to measure microleakage and cement thickness. The remaining 32 teeth were used to test the retention between teeth and nickel-chromium alloy crowns with a

universal testing machine. The following conclusions were drawn: a) Teeth prepared with the finer grit rotary instruments have smoother tooth surfaces and yielded crown restorations with better internal adaptation. b) The retention force between tooth and complete coverage crown was not affected by the grit size of the diamond rotary cutting instrument used for the tooth preparation.

Clinical implications: - Preparing teeth with diamond rotary cutting instruments, following a sequence of grit sizes from coarse, to medium, to fine (53 to 63 μ m) is recommended.

O’Kray H, Marshall TS et al. (2012)⁹ the study was designed to determine the retention of such crowns can be increased without remaking the crown or by extensively modifying the tooth preparation. Ninety cast metal complete crowns, divided into 9 groups of 10, were fabricated to be slightly loose in their internal adaptation to metal dies with an optimal tooth preparation. Horizontal grooves were formed around the circumference of the internal crown surface and the external surface of the metal die, the control being the unaltered crown and die. The crowns were cemented with resin-modified glass ionomer cement and then subjected to a tensile force until they were dislodged. They concluded that, additionally, placing 2 grooves in a tooth may be difficult to achieve clinically. Retention gained by placing grooves in both the crown and die, for the most part, was comparable to placing a single groove in the crown alone. A minor exception was noted with the combination of 2 grooves in the crown and 1 groove on the die. This combination required a mean force of 1810 N to dislodge the crowns, which was less than when no groove had been placed on the die. This reinforced the idea that the grooves in the crowns were more important for retention than the grooves in the dies in this study.

Clinical implications: - Cast metal complete crowns that come loose from properly prepared teeth will have greater retention when 1 or 2 horizontal grooves are placed circumferentially around the entire internal crown surface. The formation of these grooves may make crown recementation a more successful treatment.

Puskar T, Jevremovic D et al. (2014)³⁹ studied the procedure and results of the investigation of ion release from Co-Cr-Mo dental alloys used by advanced DMLS technology and by conventional casting techniques were presented. The key difference between this and previous related studies is that the ion release was investigated in artificial saliva of different acidity, namely pH values of 6.8, 4 and 2.3. Based on the results obtained, the following concluding remarks may be stated: a) Metal elution in artificial saliva from the DMLS alloy was lower than the elution from the cast alloy. b) Cobalt produced the greatest release of ions. c) Acidity influenced the elution. d) The greatest elution occurred in the most acidic environment, i.e., 2.3 pH. e) The longer the investigated period, the higher the difference between the total metal ion release from the CM and DMLS alloys. f) Both alloys (CM and DMLS) showed a safe level of elution according to the ISO definition in all investigated acidic environments.

Amarnath G S et al. (2015)⁸ conducted a study to determine whether the addition of horizontal groove in the internal surface of the crown and/or tooth preparation will increase retention of the crowns, without remaking them and achieving better retention with cements. A total of 80 extracted human mandibular molars were taken and standard preparation was done. After the crowns were ready, the groove was made in the internal surface of the crown and on the tooth, which were

cemented with glass ionomer cement and resin cement. The tensile force needed to dislodge the crowns and teeth after cementation was found out. They concluded that

- a) The mean tensile bond strength values of crowns that were recemented with preparation modifications were higher than those recemented without any preparation modifications.
- b) The mean tensile bond strength value of the combination in which the crowns had groove and tooth had no groove was higher than any other combination group.
- c) The mean tensile bond strength value of the combination in which both crown and the tooth had groove had values, which came next among the combination group.
- d) The mean tensile bond strength value of the combination in which the tooth had groove, and the crown had no groove had least values among the combination groups.
- e) The mean tensile bond strength value of the combination was always higher when Resin cement was used as the luting agent to recement the dislodged crown than when GIC was used as the luting cement to recement

Ko E, Huang Y et al. (2015)⁴⁰ evaluates the effects of proximal grooves and abutment height on the resistance of single cast crowns in molars with inadequate resistance. Sixty extracted human molars were prepared to possess 20° of total occlusal convergence for single crown fabrication. All of the prepared teeth were divided into six groups and prepared according to three axial heights (2, 3, and 4 mm) with or without preparing a pair of proximal grooves. Alloy metal copings of 5% titanium were casted and cemented. A self-adhesive modified-resin cement was used for cementation. A lateral dislodgement test was performed with an increasing external force applied at a 45° angulation on a universal testing machine. The force required to dislodge the crown from the tooth or to break the core was recorded. They

concluded that a) For a single crown preparation, 3 mm is recommended as the minimal OC dimension for adequate resistance in prepared molars, when the TOC is 20° and self-adhesive modified-resin cement is used. b) Preparing a pair of proximal grooves only makes significant differences in resistance in groups with 4 mm abutment height. With the use of self-adhesive modified-resin cement, adding a pair of proximal grooves had no effect when the OC dimension was 2 mm or 3 mm.

Clinical Implication: -for a single crown preparation, 3 mm is recommended as the minimal OC dimension for adequate resistance in prepared molars, when the TOC is 20° and self-adhesive modified-resin cement is used. Preparing a pair of proximal grooves only makes significant differences on resistance in groups with 4 mm abutment height.

Arora A, Upadhyaya V et al. (2016)⁴¹ conducted study to evaluate the resistance at 22° taper with reduced occluso-cervical height with different auxiliary features. An ivorine tooth was prepared with computer-aided design-computer-aided manufacturing with total occlusal convergence (TOC) of 22°, shoulder finish line 0.9 mm wide, reduced occluso-cervical height, i.e. 2.5 mm, and reduced diameter. The crown preparation was subsequently modified to include interproximal grooves, interproximal boxes, and reduced TOC in the axial wall from 22° to 8° in the cervical 1.5 mm of the axial wall. A total of four groups with ten standardized metal dies were prepared for each design with the computer-aided milling machine. Standardized complete metal crowns using silicon mold were fabricated and cemented on metal dies with glass ionomer cement. They concluded that a) Decreasing the TOC from

22° to 8° in the cervical 1.5 mm of the reduced axial surfaces significantly increased the resistance form. b) Two interproximal boxes that followed the existing convergence of the axial walls (22°) significantly increased the resistance form. c) Two interproximal grooves that followed the existing convergence of the axial walls (22°) did not significantly increase the resistance form. d) The most effective method of enhancing resistance form is to decrease the TOC of the cervical portion of the prepared axial walls.

Hidayat A, Masulili C et al. (2017)⁴² conducted a study to determine the differences in resistance of full veneer metal crowns with various forms of groove preparation. The study involved the compressive strength testing of a total of 24 specimens, namely six specimens without groove preparation, six specimens with box-shaped grooves, six specimens with V-shaped grooves, and six specimens with half round grooves. The mean values of the metal crowns that separated from the teeth during testing were 27.97 ± 1.08 kgF for the crowns with box-shaped grooves, 6.15 ± 0.22 kgF for those with V-shaped grooves, 1.77 ± 0.12 kgF for those with half round grooves, and 0.95 ± 0.13 kgF for those without grooves. This study determined that there exist differences in terms of the resistance of dental crowns on conical and small molar teeth between crowns with no grooves and those with grooves. Of the three types of grooves investigated in this study, the box-shaped grooves exhibited the best resistance, followed by the V-shaped grooves and the half round grooves. Future studies should investigate in more depth the force that can remove dental crowns, since the force that occurs inside the mouth is hugely complex. This study can help to guide clinicians in choosing the most appropriate form of grooves when constructing crowns for small and conical molar teeth.

Qasim TQ, El-Masoud BM et al. (2018)⁴³ investigated the addition of resistance grooves to the proximal surfaces of the abutment teeth would enhance the fracture resistance of the zirconia crowns and to compare between the patterns of cracks development on the zirconia crowns after the application of mono loading versus cyclic loading forces. Thirty-six all-ceramic zirconia cored crowns were prepared on the same abutment. Resistance grooves were added to the mesial and distal surfaces of 16 abutments. Before testing, all specimens subjected to thermal aging. Two groups of crowns were then subjected to cyclic axial and lateral forces for 1,250,000 cycles in aqueous conditions. Two groups of samples were also tested in monoloading fashion. The results showed that the location of retention grooves halted the failure in the surfaces where it was located in all loading mechanisms used in this study. The grooves had no effect on the critical loads in the case of a mono loading; in contrast, the samples with grooves doubled the critical number of cycles to initiate radial cracks. As number of cycles increase, the contact area increases, which shifted the tensile, stress region to the side surfaces of the crowns and resulted in fracture at the side surfaces.

Materials and Method

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

- Murray Rothbard

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

The materials and methods are divided under following headings: -

A. Materials and Armamentarium

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

2. Materials/Instruments used for preparation of metal dies and crown fabrication.
3. Materials/Instruments used for placing horizontal and vertical grooves; and crown cementation
4. Materials/Instruments used for testing of samples.

B. Methodology

1. Mounting and preparation of typhodont ivory right mandibular first molar
2. Preparation of metal dies
3. Crown fabrication by DMLS technique
4. Placing of horizontal and vertical grooves in the internal surface of crown and crown cementation on respective metal dies.
5. Retention testing.

A. Materials and Armamentarium

1. **Materials / Instruments used for mounting and preparation of typhodont ivory tooth (Colour Plate 1)**

Sr. no.	Materials / Instruments	Manufacturer	Batch number
1.	Auto polymerising acrylic resin	(DPI-RR, Dental products of India Ltd., Mumbai)	12189 (polymer) 91812 (monomer)
2.	Milling unit	---	---

3.	Typhodont ivory Right Mandibular First Molar tooth	---	---
4.	Dental surveyor (William's)	MARATHON-103, Saeyang company, Korea	---
5.	Air-rotor hand-piece	Kavo Kerr, India	---
6.	Straight flat diamond point (SF-12) Dumbbell shaped diamond point (EX-11) Tapered round ended diamond point (TR-26) Extra Fine Tapered round ended diamond point (TR-26EF)	Mani Inc. Japan	D18A141800 18A135600 D16E133500 D181087400

2. Materials / Instruments used for preparation of metal dies and crown fabrication (Colour Plate 2)

Sr. no.	Materials / Instruments	Manufacturer	Batch number
1.	Polyvinyl siloxane impression material and light body impression material	Kerr, Germany	34070 792638
2.	Blue Inlay wax	Dheeraj industries	492098
3.	Cobalt-Chromium alloy (Wironit)	Bego, Germany	50030/12635
4.	Vacuum mixer (Speedymix)	Sirio, Italy	6603
5.	Investment material (Wirovest)	Bego Corp., Germany	0209584 51090
6.	Burnout Furnace	Unident dental products Ltd.	---
7.	Induction casting machine (LC-cast)	Confident, India	---

8.	Metal polishing kit	Shofu dental corporation, Japan	
9.	Aluminium oxide particles (110um)	KOREX 250	460575
10.	Sand blasting unit (Santer labo-16)	TISSI DENTAL	---
11.	CAD/CAM	Shining 3D EX pro VHF	---
12.	Milling EOS machine	EOSINT M270 DMLS machine e-manufacturing solutions	---
13.	EOS Cobalt-chromium alloy	EOSINT M	291201

3. Materials / Instruments used for placing Horizontal and Vertical grooves; and Cementation (Colour plate 3)

Sr. no.	Materials / Instruments	Manufacturer	Batch number
1.	Inverted cone high speed carbide bur RA-37 Tapered fissure high speed carbide bur HP-701	} SS White, U.S.A.	0459 +D6901488626
2.	Laboratory micro-motor and contra-angled hand-piece (Marathon - 3+)	Marathon, Korea	12081049
3.	Type-I Resin Modified Glass Ionomer Cement	Kerr, USA.	6499734

4. Materials / Instruments for testing of samples (colour plate 4)

Sr. no.	Materials / Instruments	Manufacturer
1	Universal Testing Machine	INSTRON

B. Methodology

1. Mounting and preparation of typhodont ivory right mandibular first molar: - Fig.1(a), Fig.1(b), Fig.1(c)

An acrylic block of 1x1 inch was made using plastic box. The root of ivory tooth were grooved to resist dislodgement from the auto-polymerising acrylic resin block. The auto-polymerising acrylic resin was packed in the dough stage. The ivory tooth was centered in the block maintaining cemento-enamel junction of the tooth 2 mm above the resin surface embedding the root completely.

Tooth preparation (Fig. 2)

For standardization protocol, during tooth preparation, an air rotor handpiece was mounted on the dental surveyor using test tube holder. In this assembly the diamond point was parallel to the long axis of the sample. Constant taper of 6° for the preparations was obtained as a negative image of a long round ended tapered diamond instrument. This was to ensure uniform taper, height, and mesio-distal diameter of the prepared tooth. The tooth preparations were done under copious water irrigation as follows:

- a) Occlusal reduction:** Using straight flat diamond point guiding grooves were placed for occlusal reduction. Following the anatomic configuration, occlusal reduction was done with dumbbell shaped diamond point, 1.5 mm on the functional cusp and 1 mm on the non-functional cusp.
- b) Axial reduction:** After occlusal reduction, 3 alignment grooves were placed in each buccal and lingual wall with a tapered round end diamond point. One

was placed in the centre of the wall, and one on each mesial and distal transitional line angle.

- c) **Finish line:** 1mm reduction was achieved using tapered round end diamond point to create a uniform chamfer finish line.
- d) **Placement of functional bevel and finishing:** A bevel of 45° was given at the axio-occlusal line angle by the straight flat diamond point. Care was taken to keep the width of the bevel relatively constant at 0.5 mm.
- e) **Finishing the preparation:** The preparation was finished using extra fine grit tapered round ended diamond point.

In this way, following the completion of uniform preparation, the sample was stored securely.

2. **Metal dies preparation: - Fig.3(a), Fig.3(b), Fig.3(c)**

Metal dies were made by duplicating the prepared ivorine tooth for which two-piece mould was made using polyvinyl siloxanes and light body impression material (putty and light body). The wax patterns were sprued using 2 mm sprue inlay wax. After this, powder and liquid (water) of high strength phosphate bonded investment material was mixed in vacuum mixer and the patterns were invested. Wax burnout was done at 800°C in burnout furnace, followed by casting using cobalt-chromium alloy, in induction casting machine. External surface of all castings were evaluated under magnification for any casting defects. Metal dies were finished and polished using metal polishing kit. **Fig.4(a), Fig.4(b), Fig.4(c)**. These were sandblasted using sandblasting unit with the 110μ aluminium oxide particles, and after this, all the samples were submerged into acrylic block for ease of scanning and fabrication of DMLS crowns. **(Fig. 5)**

3. Crown Fabrication by DMLS technique: - Fig.6(a), Fig.6(b), Fig.6(c)

All the metal dies were sent to the laboratory for the fabrication of the cobalt-chromium full veneer crowns, using DMLS technique. Each metal die was scanned with CAD-CAM machine optical scanner from all the surfaces to get the appropriate digital image of the tooth, which was used to design the cobalt-chromium full veneer crown. The crowns were designed on the image of the metal dies over which a loop was designed with the internal diameter of 3mm, to engage on the universal testing machine during pull-out test.

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

In the build chamber area, there is a platform for dispensing of the material and a build platform alongside a recoater blade which is used to move new powder over the build platform. It fuses metal powder into a solid part by sintering it locally using the centered light beam (200watt Yb-fiber optic laser). Parts were built up additively layer by layer, typically using layers 20 µm thick. This sintering continued until final dimension of the samples were obtained.

The surfaces of all DMLS crowns were prepared using carbide burs and subsequently polished on one flat surface with abrasive rubber wheels. (Fig. 7)

4. Placing of Horizontal and Vertical grooves in the internal surface of crown and crown cementation on respective metal dies: -

Group 1 acted as a control group, without any alterations.

For Group 2, (**Fig. 8**) one horizontal circumferential groove was placed free hand on the internal surface of all 15 crowns by inverted cone bur using laboratory micro-motor and contra-angled hand-piece. The groove placed on the internal surface of crown was approximately 3 mm from the cervical margin for which initially, markings were made over the circumference in the internal surface of crown. The dimension of groove was 0.5 mm in depth and 1.4 mm in width.

For Group 3, (**Fig. 9**) two vertical grooves were placed free hand on the internal surface of all 15 crowns by tapered fissure bur using laboratory micro-motor and contra-angled hand-piece. The grooves placed on the internal surface of crown, one on buccal surface and one lingual surface, for these grooves also, markings were made in the internal surface of crown, which was approximately 1.5 mm. from the cervical margin and perpendicular to the path of placement.

Groups	Modifications	No. Of samples
Group 1	No groove in the internal surface of crown.	15
Group 2	One Horizontal groove around the circumference in the internal surface of crown	15
Group 3	Two vertical grooves (one on buccal surface and other on lingual surface) in internal surface of crown	15

Crowns of all these three groups were luted using Type I Resin Modified Glass Ionomer Cement on respective metal dies.

Crown cementation: - Fig.10(a), Fig.10(b)

Type I Resin Modified Glass Ionomer Cement was used for cementation of crowns of all three groups ⁴¹. In order to achieve a maximum physical property of the cement used for luting the crowns, the cement was mixed according to the manufacturer's instructions. The cartridge of Nexus RMGIC was loaded and tip was attached. The dispensed paste was directly applied on the axial surface of the internal surface of the crown. The crown was then seated over the tooth sample for 30 seconds. This sample was kept on digital weighing machine and TARE button was pressed for zeroing of the weight. Then finger pressure of 1 kg was applied to the coping for 5 minutes and the weight was seen on the digital screen to monitor the exact weight. Excess cement was removed from all sides with a clean instrument. The same procedure was done for cementation of all crowns to respective prepared metal dies. (Fig. 11)

5. Retention testing:- (Fig. 12)

The retention testing of all samples was performed on the computerised software based Universal testing machine. Each sample was aligned in the centre of attachment of the testing unit and special care was taken to ensure that each tooth was fixed with its long axis congruent with the loading axis of the testing apparatus to ensure that the tensile load was directed along the long axis of each sample. A metal hook was engaged the loop of the crowns. One of the jaws of the load cell grasped the hook at open end and the other grasped the cemented sample on the aluminium blocks.

The built-in alignment of the two-load cell automatically ensured a perfect vertical orientation of the sample-hook assembly. Thus, as the load cells moved apart at the 0.5 mm/min cross-head speeds, a vertical tensional force was applied on the crowns consistently. The maximal tensile force used to separate the crown was recorded in Newton.

COLOUR PLATE - 1



Fig. 1 : Auto polymerising acrylic resin



Fig. 2: Milling unit



Fig. 3 : Typhodont ivoryine right mandibular first molar (William's)



Fig. 4 : Dental surveyor



Fig. 5 : Airtor handpiece



Fig. 6 : Diamond burs (SF-12, EX-11, TR-26, TR-26EF)

COLOUR PLATE – 2



Fig. 1: Polyvinylsiloxane impression material and light body impression material (Putty And Light body)



Fig 2 : Blue inlay wax



Fig. 3 : Cobalt chromium alloy



Fig.4 : Vacuum mixer



Fig. 5 : Investment material



Fig. 6: Burnout furnace



Fig.7: Induction casting machine



Fig. 8: Metal Polishing kit



Fig.9 : Aluminium oxide particles



Fig.10 : Sand blaster



Fig. 11 :CAD CAM Digital Scanner



Fig.12 :Milling EOS machine



Fig. 13 : EOS cobalt chromium alloy

COLOUR PLATE 3



Fig.1 Carbide burs (RA-37, HP-701)



Fig. 2 Laboratory micromotor, contra-angled handpiece and straight handpiece



Fig. 3 Resin modified Glass Ionomer Cement (Type I)

COLOUR PLATE – 4



Fig. 1. Universal Testing Machine

COLOUR PLATE - 5



Fig.1 a. Plastic box



**Fig.1 b. Typhodont
tooth molar**



**Fig.1 c. Tooth submerged
in acrylic block**



Fig 2: Tooth preparation



Fig. 3 a. Two-piece mould



**Fig. 3 b. Inlay Wax
filled**



**Fig. 3 c. Wax pattern of
prepared tooth**

COLOUR PLATE – 6



Fig . 4 a. Spruing



Fig .4 b. Investing



Fig 4. c. Casted metal dies



Fig. 5: 45 metal dies submerged in acrylic block

COLOUR PLATE - 7



Fig. 6 a. CAD CAM digital scanner



Fig. 6 b. Pattern of metal die made



Fig. 6 c. Material dispensing platform



Fig 6. d. Laser sintering process

COLOUR PLATE 8



Fig. 7. Final prepared DMLS crowns with loop



Fig. 8 : Horizontal Grooving



Fig. 9 : Vertical Grooving



Fig. 10 a. Application of cement



Fig. 10 b. Pressure of 1kg

COLOUR PLATE 9



Fig.11 Total 45 DMLS metal crowns cemented on metal dies



Fig. 12. Retention testing of samples on universal testing machine

Results

A work of art is the unique result of a unique temperament

-Oscar Wilde

In this study, retention of DMLS crowns using two different supplementary retentive grooves in the internal surface of crowns was investigated.

Standardize tooth preparation was done on typhodont ivorine right mandibular first molar. After taking the impression and casting procedure, 45 metal dies were fabricated. Over these metal dies, 45 full veneer cobalt-chromium crowns were fabricated using DMLS technique. These crowns were divided into three groups as follows: -

Sr. No.	Groups	Description	Samples
1	Group 1	No alterations (control group)	15
2	Group 2	One horizontal circumferential groove in the internal surface of crown	15
3	Group 3	Two vertical grooves (one on buccal surface and one on lingual surface) in the internal surface of crowns	15
Total			45

In these three groups, 15 crowns were cemented using Resin modified Glass Ionomer Cement on respective metal dies. After this, all 45 samples were subjected to retention testing on computerized software system primarily based Universal Testing Machine at 0.5 mm/min cross-head speed. A vertical tensile force was applied on the crowns consistently. Retentive force values at the point, where cemented crowns were dislodged from the prepared teeth were calculated in Newton (**Master chart and Graph 1**).

STATISTICAL ANALYSIS

Statistical analysis was done with Statistical Package for the Social Sciences (SPSS version 20, IBM, USA). Data comparison was done by applying specific statistical tests to find out the statistical significance of the results. Since the data was of continuous type, parametric tests were used for analysis. Mean and Standard Deviation (SD) were calculated. Statistical tests employed for the obtained data in this study were:

One-way Analysis of Variance (ANOVA) test followed by Pair-wise comparison of three study groups by Bonferroni Multiple Comparison test.

The hypothesis of no difference (Null Hypothesis) was:

H₀: There is statistically no significant difference in retention of DMLS crowns by incorporating of one horizontal groove and two vertical grooves in the internal surface of crowns

Alternate hypothesis: There is statistically significant difference in retention of DMLS crowns by incorporating of one horizontal groove and two vertical grooves in the internal surface of crowns

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

Mean and Standard deviation

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

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

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

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

b) Sample standard deviation was given by

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

A. ONE WAY ANALYSIS OF VARIANCE: (one-way ANOVA)

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

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

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

Sum of squares for variance between the samples = $\sum n_i(X_i - \bar{X})^2$

k- 1 represents degree of freedom.

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

Sum of squares for variance within the samples

$$= \sum (X_{1i} - \bar{X}_1)^2 + \sum (X_{2i} - \bar{X}_2)^2 + \dots + \sum (X_{ki} - \bar{X}_k)^2$$

n - k = degree of freedom

n = number of items in all samples.

$\bar{X}_1, \bar{X}_2, \dots, \dots, \dots, \bar{X}_k$ of each sample, when there are k samples.

\bar{X} = mean of the sample means.

$i = 1, 2, 3, 4, \dots$

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

One of the mean differences out of three-pair-wise comparisons (Group 1 vs 2, or 1 vs 3 or 2 vs 3) contributed to the above significant result was established by Bonferroni Multiple Comparison test.

Bonferroni Multiple Comparison test:

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

The Bonferroni test, also known as the "Bonferroni correction" or "Bonferroni adjustment" suggests that the "p" value for each test must be equal to alpha divided by the number of tests.

To perform a Bonferroni correction, divide the critical P value (α) by the number of comparisons being made.

Descriptive analysis:-

Table 1 gives descriptive statistics of mean retention value and standard deviation along with minimum and maximum values of retention. The results showed that mean retention value for **Group 1** (control group) was 216.258 N, for **Group 2** was 324.097 N, and for **Group 3** was 357.300 N.

Table 2 gives description of statistical analysis of mean retention values using ANOVA test.

Here **Group 1 (Control)** showed significantly less mean retentive value than **Group 2** and **Group 3** respectively. Whereas there was no statistically significant difference ($p > 0.05$) between the mean retentive values of **Group 2** and **Group 3**. Since p-value for the ANOVA was found out to be less than 0.05 ($p < 0.05$); indicates significance of difference between the means of three groups.

The results also showed that vertical grooving in the internal surface of crowns significantly increased the retention. The mean retention value for Group 3 was found to be higher than Group 2. However, the increase in the mean retention value was not statistically significant.

Table 3 shows descriptive analysis of comparison of mean retention of three study groups by Bonferroni Multiple Comparison test. However, the mean difference in retention for

Group 1 versus Group 2 was observed to be 107.84 and p value of 0.084 suggested not significant.

Group 1 versus Group 3 with the mean difference of 141.042 and p value of 0.014 suggested highly significant.

Group 2 versus Group 3 with the mean difference of 33.203 and p value of 1.000 suggested not significant.

From the statistical data of table 3, mean difference was found the highest in the pair of **Groups 1 versus Group 3** i.e. 141.042 and p value of 0.014 highly significant.

The results of the study showed that the mean retention value for **Group 1** (Control) 216.25N, for **Group 2** 324.09N, and 357.3 N for **Group 3** which were assessed statistically using ANOVA test (Table 2). Since p-value for the ANOVA was seen less than 0.05($p < 0.05$); indicates significant difference between the means of 3 groups. Unaltered DMLS crowns (Group 1) showed considerably less mean retentive value than the crowns with one horizontal groove and two vertical grooves i.e. Group 2 and Group 3 respectively. Whereas there was no statistically significant difference ($p > 0.05$) between the mean retentive values of Group 2 (one horizontal groove) and Group 3 (two vertical grooves). The results stated that incorporation of vertical grooves in the internal surface crowns considerably increased the retention of DMLS crowns. Hence, from the statistical data the Null Hypothesis H_0 is rejected and the alternate hypothesis H_1 is accepted.

The mean retention value after inserting two vertical grooves (Group 3) was seen to be higher than that Group 2 (one horizontal groove) but the increase in the mean retention value wasn't statistically significant. This reinforced the conception that the placing vertical grooves in the internal surface of crown considerably increase the retention. But in spite of placing one horizontal groove, retention decreases considerably (Graph 1).

Discussion

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

-Noam Chomsky

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

The success of any treatment modality is measured in terms of its dependability, durability and same applies to fixed restorations. The prosthesis should be reliable, comfortable and tailor made alternative to the lost teeth. To attain a fruitful outcome of a successful fixed restoration, all the steps concerned within the process should be meticulously followed. In order to realize the same, dentist should

direct his or her efforts in diagnosis, treatment planning and execution of the planned treatment. To achieve a positive outcome, the planning, fabrication and placement of fixed restorations should be ruled by basic principles. These principles are often classified into biological, mechanical and esthetic principles.⁴⁴ The history of complete coverage tooth preparation recognize guidelines for scientific tooth preparations and reviewed with stress on evidence-based information acquired throughout the last fifty years.¹⁹ The success of fixed restorations has been attributed to its retention & resistance form. As dental restoration is subjected to repetitive dynamic loading which is a mixture of compressive and tensile stresses on the restoration throughout mastication and parafunction, efforts should be made to take into consideration of these factors.¹⁵

The long-term success of fixed restoration is multifactorial which has numerous factors that are either within the control of the operator or patient related factors. Hence, the prosthodontist should attempt hard to identify maximum number of such factors and control them to the most effective of his skills. Even the smallest and apparently insignificant factor will form a chain of inappropriate decisions which can ultimately result in failure of fixed prosthesis. For a restoration to accomplish its purpose, it has to stay in its desired position on the tooth. So, retention form is the most important factor.⁴⁴

Three primary variables have an effect on the retention of prosthetic crowns. These are: a) the convergence of the preparation walls, b) the area of retentive surface and c) the length of the axial walls. Crown retention and resistance to tensile and shear stresses is inversely proportional to the convergence of the preparation walls,

proportional to the area of retentive surface, and increase with the length of the axial walls of the preparation.^{22, 23} In several clinical situations, however, secondary means of increasing crown retention are advisable. The addition of pin holes, vertical grooving, with or without circumferential grooving, in the clinical and prosthetic crowns will considerably increase retention.^{24, 45, 25} The surface roughness of the preparation and also the internal surface of crown may also affect retention.⁴⁶ Surface roughness of the preparation could have little effect on retention of the cemented crown,²¹ but may increase shear bond strength.⁴⁷

To provide retention and resistance type to the preparation, the preparation is modified by crown lengthening, shoulder preparation, proximal groove, proximal box or occlusal isthmus, and pins or posts. Generally, internal features like groove, box form, and pin hole are interchangeable and may be substituted for an axial wall or for each other. It is explicit that adding axial grooves or boxes to a preparation doesn't markedly have an effect on its retention as a result of the surface area isn't increased significantly. However, on the other hand, the addition of a groove aids in increased retention by limiting the ways of removal.³²

Several factors, excluding surface texture, influence the retention of a restoration. These factors mentioned by Kaufman, Coelho, and Lawrence,⁴⁸ Horn,⁴⁹ and others,⁵⁰⁻⁵⁷ are summarized as: a) factors with reference to the cement such as adhesion, type, powder-liquid ratio, compressive and shear strength, viscosity, film thickness, particle size and cementing pressure; b) the accuracy of fit - the uniform proximity of the gold and tooth surfaces within the uncemented state; c) the taper of the preparation; d) the ratio of axial to lateral dimensions - a long thin crown

preparation is additional retentive than a short broad one; e) auxiliary retention devices, for example - pins, boxes, and grooves, f) the area of the bond; g) the differences within the coefficients of expansion of the casting, the cement, and also the tooth; and h) the surface texture of the casting and also the preparation.

The supplemental use of interproximal grooves and boxes have been specifically suggested to be used in molar preparations of less than 4 mm in vertical height.¹⁷ The utilization of those adjuncts have been proposed to offset the negative attributes of large axial wall inclination angles and/or vertical height deficiencies. The tooth preparation designs that provide resistance form to the tooth are studied extensively; hence, the initial reports in the literature were targeted on the retention form of tooth preparations.^{58, 48, 55} The importance of clinical relevance of resistance form will be investigated later.^{6, 59-63} Several parameters will have an effect on the resistance of a tooth to forces applied on axis other than the path of placement.⁵⁹ The parameters are divided into those which are related to the tooth preparation design and those associated with the crown fabrication and modification. **Reisbick and Shillingburg**⁵⁹ were the first to analyze the features of a crown preparation that increases resistance form. They reported that the addition of interproximal grooves and boxes increases the resistance form of the tooth preparation. **Potts et al,**²⁴ **Kishimoto et al,**⁶⁰ and **Owen**⁶¹ more emphasized on the importance of the placement of grooves to the resistance form of a tooth preparation.

Casting technology has come back a long way in manufacturing accurate castings. DMLS is a clean alternative to casting. Messy tasks of deflasking, cleaning molds, elaborate steps are often dispensed with. Coping thickness, pontic design and

cement thickness will all be standardized with this technique. Laser sintering is a computer-controlled, precise method that ensures consistent work quality. The chances of inclusions or defects that are usually introduced within the manual casting methods are dispensed with.⁶⁴ Laser sintering is comparatively new; manufacturers claim that the technique is simple to use, produces correct restorations, simplified post process procedures, free of porosity unlike conventional castings and improved electromechanical characteristics.⁶⁵

Various investigators had worked on this side. However, there's no uniform consensus regarding the impact of modification of internal surface of crown with reference to retention. In this study, the internal surface modification was done by placing one horizontal and two vertical grooves on DMLS crown, luted with Resin Modified Glass Ionomer Cement onto prepared metal dies.

In this in-vitro study ivorine molar tooth was fixed in auto-polymerising acrylic resin using plastic box. The root of ivorine tooth were grooved to resist dislodgement from the auto-polymerising acrylic resin block. For standardization of tooth preparation procedure, an air rotor handpiece was mounted on the dental surveyor using test tube holder in such a way, that the diamond point was parallel to the long axis of the sample. Constant taper of 6° for the preparations was obtained as a negative image of a long round ended tapered diamond instrument. This was to ensure uniform taper, height, and mesio-distal diameter of the prepared tooth. By duplicating the prepared ivorine tooth, two-piece mould was made using polyvinyl siloxane impression material and light body impression material. The wax patterns were fabricated and invested in phosphate bonded investment material. Using cobalt-

chromium alloy, and casting in induction casting machine, metal dies were retrieved. External surface of all castings was evaluated under magnification for any casting defects. Metal dies were finished and polished using metal polishing kit. Each metal die was scanned with CAD-CAM machine optical scanner from all the surfaces to get the appropriate digital image of the tooth, which was used to design the cobalt-chromium full veneer crown by milling EOS machine. The crowns were designed on the image of the metal dies over which a loop was also designed with the internal diameter of 3mm. The purpose of loop was to attach into the hook of universal testing machine after cementation, during testing procedure.

All 45 samples were divided in three groups. Group 1 (control group) without any modification, Group 2 with one horizontal groove in the internal surface around the circumference of crown and Group 3 with two vertical grooves in the internal surface of crown on buccal and lingual surface. In these three different groups, 15 crowns were cemented using Resin modified Glass Ionomer Cement on respective metal dies. After this, all 45 samples were subjected to retention testing on computerized software system primarily based Universal Testing Machine at 0.5 mm/min cross-head speed. A vertical tensile force was applied on the crowns consistently. Retentive force values at the point, where cemented crowns were dislodged from the prepared teeth were calculated in Newton.

After statistical analysis, the results of the present study showed that the mean retention value for Group 1 (Control) was 216.25 N, for Group 2, it was 324.09 N, and for Group 3 it was 357.00 N. The results showed that incorporation of vertical grooves within the crowns considerably increased the retention of DMLS crowns.

Hence, the Null Hypothesis was rejected for Group 1-2 and Group 2-3 however it got accepted for group 1-3. The mean retention values of crowns with one horizontal groove (Group 2) and two vertical grooves (Group 3) were noted to be considerably higher than that of Group 1.

Thus, the results of this study showed that incorporation of supplementary retentive features on the internal surface of DMLS crowns considerably increased the retention, compared to the control Group (Group 1). Incorporation of one horizontal circumferential groove in the internal surface of DMLS crown increases the retention (Group 2). These results were in accordance with **Ko E, Huang Y et al (2015)**⁴⁰ in which they concluded that placing 1 or 2 horizontal circumferential grooves and proximal grooves increased the retention made for optimal tooth preparations. This was attributed to the increased surface area with increased mechanical interlocking of the luting cement within the groove which significantly increased the retention of the cobalt chromium crowns. This helps the future need of re-cementation procedure, simple for the clinician and beneficial for the patient. The present study also showed that incorporation of two vertical grooves (one on buccal and one on lingual) in the internal surface of DMLS crown, increases the retention, considerably (Group 3). Vertical or axial grooves reduced the rotational radius. By incorporating two grooves, the rotational radius is divided in half. It was found that changing the internal surface of crown, by adding vertical grooves, provide additionally more surface area and resistance form. This may force the setting cement into better tooth contact providing mechanical reinforcement. Thus, it significantly increased the retention.^{9, 66} Therefore the alternate hypothesis is accepted.

Taking into consideration of fixed prosthesis/restorations, its long-term durability, the results obtained from this study, it is apparent that the crowns with two vertical grooves shows better retentive properties than the unaltered (control group) and the one with the horizontal groove. Either of the groove can be incorporated into the internal surface of the crowns, depending on the clinical situations like poor tooth foundation, to avoid dislodgement of prosthesis and for favourable prognosis of fixed restorations.

Clinical Implications: -

1. Grooving the internal surface of the crown either horizontal / vertical is the most efficient method for obtaining additional retention if all other parameters are standardised.
2. Either of these grooves will be effective at increasing retention form for a short clinical preparation during day to day clinical practice.
3. These retentive features incorporated in the internal surface of crown are effective in increasing retention in case of dislodged crowns during re-cementation procedure. Thus, beneficial to the clinician as well as for the patient.

Limitations of this study: -

This being an in-vitro study could not replicate the conditions present in the oral environment. Also, most prepared molars in the oral cavity are not uniform in the height circumferentially. The dislodging forces to that fixed restoration, subjected in the oral cavity are multidirectional might it be vertical, lateral or oblique forces

however on the other hand the dislodging force exerted by the universal testing machine is unidirectional. So, the direct comparison between dislodging forces encountered in the oral cavity and those exerted by the universal testing machine is ambiguous.

Further scope: -

There arises a desire for future clinical research following a similar technique with different parameters, using other retentive features like boxes, using different luting agents, so that final conclusive remarks can be made regarding retention.

Summary

Egotism is the source and summary of all faults and miseries

-Thomas Carlyle

The present study was done with an aim to evaluate and compare the retention of DMLS crowns using two different supplementary retentive grooves.

For achieving the longevity of the prosthesis, modifications have been already done on the tooth surface. In this, retention plays very important role. It is not always possible to alter the tooth surface depending on various clinical situations. In order to overcome this problem, modification in the internal surface of crowns will be the option.

With this background, an in-vitro study was taken for comparative evaluation of supplementary retentive features on retention of DMLS crowns.

An acrylic block of 1x1 inch was made using plastic box. The root of ivorine tooth were grooved to resist dislodgement from the auto-polymerising acrylic resin block. The auto-polymerising acrylic resin was packed in the dough stage. The ivorine tooth was centered in the block maintaining cemento-enamel junction of the tooth 2 mm above the resin surface embedding the root completely. For standardization protocol, a technique was used for tooth preparation, in which an airtor handpiece was mounted on the dental surveyor with the help of test tube holder. This assembly was such that the diamond point was parallel to the long axis of the sample.

Constant taper of 6° for the preparations was obtained as a negative image of a long round ended tapered diamond instrument. This was to ensure uniform taper, height, and mesio-distal diameter of the prepared tooth. Metal dies were made by duplicating the prepared ivorine tooth for which two-piece mould was made using polyvinyl siloxane impression material and light body impression material. The wax patterns were fabricated and invested in phosphate bonded investment material. Using cobalt-chromium alloy, and casting in induction casting machine, metal dies were retrieved. External surface of all castings was evaluated under magnification for any casting defects. Metal dies were finished and polished using metal polishing kit. Each metal die was scanned with CAD-CAM machine optical scanner from all the surfaces to get the appropriate digital image of the tooth, which was used to design the cobalt-chromium full veneer crown. The crowns were designed on the image of the metal dies over which a loop was also designed with the internal diameter of 3mm. The purpose of loop was to hold the hook of universal testing machine after cementation during testing procedure.

All 45 samples were divided in three groups. Group 1 (control group) without any modification, Group 2 with one horizontal groove in the internal surface around the circumference of crown and Group 3 with two vertical grooves in the internal surface of crown on buccal and lingual surface. In these three different groups, 15 crowns were cemented using Resin modified Glass Ionomer Cement on respective metal dies. After this, all 45 samples were subjected to retention testing on computerized software system primarily based Universal Testing Machine at 0.5 mm/min cross-head speed. A vertical tensile force was applied on the crowns consistently. Retentive force values at the point, where cemented crowns were dislodged from the prepared teeth were calculated in Newton.

Statistical analysis was done for the calculation of mean and standard deviation. Data comparison was done by applying specific statistical tests to find out the statistical significance of the results. The results of the study showed that the mean retention value for **Group 1** (Control) 216.25N, for **Group 2** 324.09N, and 357.3 N for **Group 3**. These mean retention values were assessed statistically using ANOVA test. Since p-value for the ANOVA was seen to be less than 0.05($p < 0.05$); indicates significance of difference between the means of 3 groups.

By using Bonferroni multiple comparison test, mean difference was found the highest in the pair of **Groups 1 versus Group 3** i.e. 141.042 and **p value** of 0.014 highly significant. The results stated that incorporation of vertical grooves in the internal surface crowns considerably increased the retention of DMLS crowns. The study also revealed that the incorporation of grooves significantly increases in the retention of DMLS crowns. The incorporation of vertical grooves in the internal surface of crown was found satisfactorily method to improve retention.

Conclusion

Despair is the conclusion of fools.

-Benjamin Disraeli

The aim of the study is to evaluate and compare the supplementary retentive features on retention of direct metal laser sintered crowns.

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

1. Incorporation of retentive grooves in the internal surface of crown increases the retention.
2. The retention of DMLS crowns significantly increased when one horizontal groove was placed in the internal surface of crown.
3. The retention of DMLS crowns significantly increased when two vertical grooves were placed in the internal surface of crown.

There was no statistically significant difference between the mean retention value of Group 2 (one horizontal groove) and Group 3 (two vertical grooves).

The incorporation of two vertical grooves in the internal surface of DMLS crowns was found to be a satisfactory method to improve the retention.

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TABLES AND GRAPHS

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

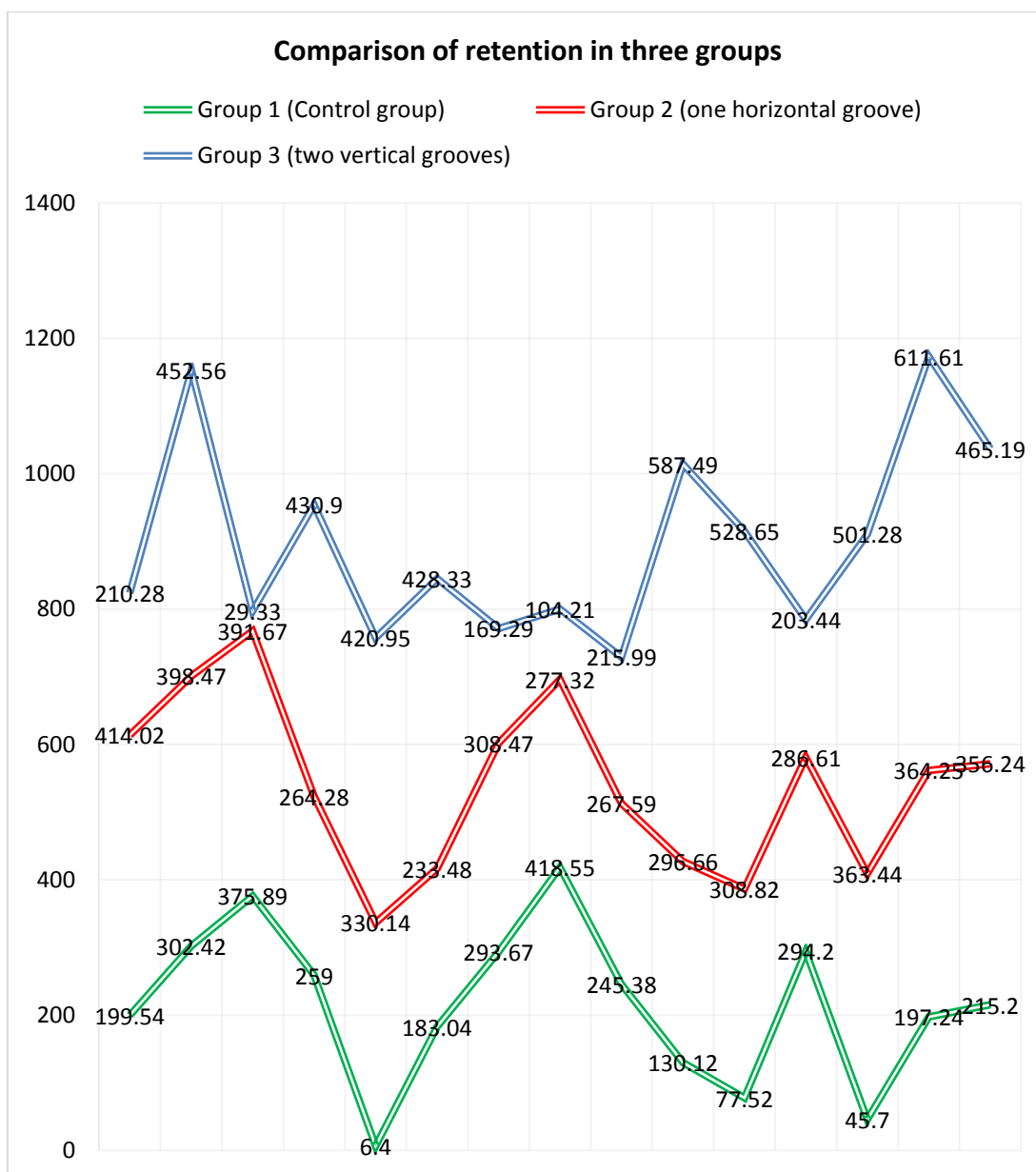
Groups	Observations	Mean	Standard Deviation	Minimum	Maximum
GROUP 1	15	216.258	116.531	6.4	418.55
GROUP 2	15	324.097	54.915	233.48	414.02
GROUP 3	15	357.300	184.236	29.33	611.61

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

Source	SS (sum of samples)	df (degree of freedom)	MS (mean sum of squares)	F (statistics)	Prob > F (P value)
Between groups	163122.9 18	2	81561.4589	4.84	0.0128
Within groups	707537.9 82	42	16846.1424		
Total	870660.9	44	19787.7477		

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

Group-wise pairs	Mean of two comparison groups	Mean difference	P-value
Group 1 Versus Group 2	216.258 versus 324.097	107.84	0.084
Group 1 Versus Group 3	216.258 versus 357.3	141.042	0.014
Group 2 Versus Group 3	324.097 versus 357.3	33.303	1.000



Graph 1: - Comparison of retention in three groups

Master chart

Maximum load in Newton			
Sr.	Group 1	Group 2	Group 3
1	199.54	414.02	210.28
2	302.42	398.47	452.56
3	375.89	391.67	29.33
4	259	264.28	430.9
5	6.4	330.14	420.95
6	183.04	233.48	428.33
7	293.67	308.47	169.29
8	418.55	277.32	104.21
9	245.38	267.59	215.99
10	130.12	296.66	587.49
11	77.52	308.82	528.65
12	294.2	286.61	203.44
13	45.7	363.44	501.28
14	197.24	364.25	611.61
15	215.2	356.24	465.19
TOTAL	3243.87	4861.46	5359.5
MEAN	216.258 N	324.097 N	357.300 N