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FRACTURE RESISTANCE OF ENDODONTICALLY TREATED TEETH RESTORED WITH FOUR DIFFERENT RESTORATIVE TECHNOLOGIES

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ABSTRACT

This study was conducted to evaluate both the effect of different cavity designs and different ceramic, composite CAD/CAM blocks and regular direct resin composite on the fracture resistance of endodontically treated teeth.

Materials and methods: A total of 80, non-carious, crack-free freshly extracted human maxillary premolars were used in this study. The teeth received a standardized endodontic treatment and then were divided in to two groups (40 each) according to the cavity design Design1 (MOD cavities) and Design2 (MOD with buccal and lingual cusp reduction), the two groups were further subdivided into sub groups (10 each) according to the type of restorative material used, either IPS e max CAD, Lava Ultimate, Vita Enamic, or Filtek Z 350 XT. Teeth were mounted in a universal testing machine, compressed with crosshead speed of 1mm/min, for testing their fracture resistance.

Results: One-way ANOVA was used to test each main effect separately. One-way ANOVA for the effect of cavity design showed statistical significant difference between both designs (P= 0.003). The post-hoc test revealed that Design 2 has the significantly higher mean fracture resistance (P= 0.001) than did Design 1. Meanwhile, One-way ANOVA for the effect of type of restorative material used showed statistical significance for types of restorative material used (P= 0.001). The post-hoc test revealed that IPS e max CAD has significantly the highest mean fracture resistance (P= 0.001). Moreover, Lava Ultimate and Vita Enamic had significantly higher mean fracture resistance than that of Filtek Z 350 XT (P= 0.001).

Conclusions: Within the limitations of the study, it can be concluded that

- Endodontically treated maxillary premolars prepared with an extensive loss of tooth structure and restored with chair-side indirect esthetic restorations had a resistance to fracture under simulated occlusal load significantly higher than that of direct resin composite restorations.
- Chair-side CAD/CAM ceramic restorations are superior over hybrid ceramics.
- Allowing a cusp coverage of approximately 2.5 mm in bulk would enhanced fracture resistance of dentin-bonded onlays over inlay preparations with no cusp coverage in vitro.

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INTRODUCTION

Computer-aided design/computer aided manufacturing (CAD/CAM) technologies were introduced in dentistry since 1980s. During the last decade CAD/CAM system in dentistry have rapidly gained importance and popularity. CAD/CAM generated dental restorations that meet standardized manufacturing processes with uniform material quality and reproducibility of restorations.(1-2)

The first CAD/CAM ceramic blocks were introduced to the dental market in 1985, having a flexural strength of approximately 120 MPa. These blocks were subjected for fabrication of inlays, onlays and veneers. Improved ceramic blocks containing approximately 30-volume % of fine distributed crystals of Leucite were developed in 1991. This ceramic material had enamel-like abrasion characteristics. Therefore, it was considered suitable for fabrication of inlays, onlays and monolithic anterior crowns and veneers and single tooth restorations.(3-5)

The first composite resin block for CAD/CAM systems was introduced in 2000, and was originally a product polymerized by light activation using factory processes. Concurrently with the development of ceramic blocks for CAD/CAM, Composite resin technology made considerable progress with the development of Nano-filled and Nano-hybrid composite resin. The new Nano filler-containing composite resin exhibited equivalent mechanical properties to the clinically proven micro-hybrid type composite and were thus recommended for direct posterior restorations. This development led to the application of these materials for indirect restorations through combined light and heat polymerization modes. Generally, the properties of composite resin still depend largely on the resin matrix used; the filler loading, type, shape and size; and on the filler/matrix interface coupling.(6-9)

Currently, more demands for esthetics, and shorter chair-side time from both dentists and patients are critical challenges for researchers trying to develop the best restorative material. The advantages of a composite resin block are that it is easy to polish, it does not require sintering or crystallization firing, have lower milling time, longer milling tools service life and is repairable in the mouth. Newly available CAD/CAM composite resin blocks are fabricated by high-pressure/high-temperature polymerization resulting in improved mechanical properties. The flexural properties of composite resin CAD/CAM blocks were reported to be comparable to those of ceramic blocks and were suggested to be more suitable for single premolar crown restoration. However, a restoration in a patient's mouth is subjected to wear from several factors, such as food and daily cleaning.(10)

When compared with vital teeth, endodontically treated teeth are less resistant to fractures. it does not arise only from differences in the biomechanical properties or moisture content of hard tissues, but also due to tooth structure loss which occurs during caries removal and endodontic access cavity preparation. Loss of hard tooth tissue due to endodontic access cavity preparation diminishes the flexural strength of cusps. In addition, pulpless teeth may be more heavily loaded than their vital counterparts before a pain response is initiated, thereby predisposing them to fracture. Intra-coronal strengthening of teeth is important to protect them against fractures, especially in posterior teeth where stresses generated by occlusal loading can lead to fracture of unprotected cusps.(11-13)

With the advent of adhesive dentistry, the need for posts and filling cores has become less evident. Moreover, the production of ceramics that had high mechanical strength and were capable of being acid etched (such as those reinforced with leucite or lithium disilicate), coupled with the adhesive capacity of adhesive system and resin based cement, made it possible to restore posterior teeth, especially molar, without cores and posts. Thus, it become feasible to restore posterior teeth with extensive coronal destruction by means of onlay and/or overlay restoration and, more recently, with endo-crowns. Without the use of intra-canal posts and while using the entire extension of the pulp chamber as a retentive resource.[14-15]

In clinical studies, it was observed that the premolars showed more failures than the molars. This may occur because premolars have a smaller adhesion surface when compared to molars. Additionally, premolars have greater crown heights, which, consequently, compromises the mechanical properties of the endo-crown. It is also suggested that endo-crowns should be made only with reinforced ceramic. This has been shown to be an advantageous technique because the procedure is more easy.[11-16]

The ceramic composite inlays have been manufactured for reinforcement of prepared weakened tooth structure, recent studies[17-19] have shown that ceramic and composite inlays have comparable fracture resistance of that of sound tooth structure. Several cavity designs have been introduced to improve fracture resistance of the endodontically treated teeth.[11]

The aim of this study was to evaluate both the effect of different cavity designs and different ceramic, composite CAD/CAM blocks and regular direct resin composite on the fracture resistance of endodontically treated teeth.

MATERIALS AND METHODS

A total of 80, non-carious, crack-free freshly extracted human maxillary premolars were collected and selected to be of the same dimensions. The teeth were cleaned, from any deposits, soft tissues and calculus using periodontal scalar.

Preparation and grouping of specimens

The teeth were mounted in auto polymerized Acrylic resin (Meliodent, Heraeus Kulzer Hanau, Germany) to the level 2m below cement-enamel junction. Roots of the teeth were covered first with polyether impression material (Impergum Garant L Duo soft, 3M ESPEAG, Seefeld, Germany) to simulate periodontal ligament before being embedded in acrylic resin, periotest instrument (periotest, Siemens AG, Bensheim, Germany) was used to evaluate vertical and horizontal mobility dimensions to be standardized value of ≤+7 to simulate natural dentition.

Interaction of all tested variables were summarized in table (1) while list of examined materials and it is chemical composition were listed in tables (2, 3, & 4)

TABLE (1) Interaction between tested variables

Resin-ceramic material	**Cavity Design**	
	D1	D2
M_1	M_1D_1	M_1D_2
M_2	$M_2 D_1$	$M_2 D_2$
M_3	$M_3 D_1$	$M_3 D_2$
M_4	$M_4 D_1$	$M_4 D_2$

N=10 Specimens for each group

M_1: Lava Ultimate

M_2: Vita Enamic

M_3: IPS e max CAD

M_4: Filtek Z 350 XT

D1: Cavity Design 1

D2: Cavity Design 2

For all the selected teeth standardized endodontic treatment was done using standardized root canal enlargement and filling procedures. Access cavity preparation was done using diamond bur (FG 8514, Intensive, Gruncia, Switzerland) mounted in high speed contra-angle hand piece (CA lis L Micro-series, Bien-Air, Dental Beinne, Switzerland). Gates gladden bur size 3-2-1, Mailefer, Ballaigues, Switzerland) was used for orifice widening. The canals were prepared using machine- driven rotary file (profile.04, DENTSPLY, Germany).

TABLE (2) List and Composition of materials used in this study

Material	**Material class**	**Material matrix**	**Material filler**
Lava ultimate 3M ESPE, St, Paul, MN USA (Lot.Nr399025)	Composite resin blocks	Bis-Gma , UDMA Bis-EMA , TEGDMA 20 wt.%	Zirconia, Silica, aggregated zirconia/ silica cluster 80 wt.%
Vita Enamic Vita Zahnfabrik, Bad Sackinger Germany (lot-Nr 311004)	Hybrid composite ceramic blocks	UDMA , TEGDMA 14 wt.%	Feld spathic ceramic with aluminum oxide 86 wt.%
IPS e-max CAD Ivoclar vivadent Amherst, N.Y.	Ceramic blocks	Lithium disilicate glass-ceramic CAD/CAM blocks Component Sio2 Additional content Li2o, K2o, Mgo, Al2o3 p2o5 and other oxides	
Filtek Z 350 XT 3M ESPE (Lot-Nr 283256)	Conventional Nano hybrid composite	Bis-GMA , UDMA Bis-EMA,TEGDMA PEGDMA 23 wt.%	Silica, Zirconia aggregate of silica/zirconia cluster 73 wt.%

TABLE (3) Description of luting agent used in this study

Material	Material class	Application	Manufacturer	Chemical composition
RelyX™ Ultimate Auto mix	Dual Light- and/or self-curing luting composite	Paste/paste; automatic mixing syringe	3M ESPE, Seefeld, Germany	**Basic paste:** methacrylate monomer, X-ray dense silalinated filler, initiator components, stabilizer, rheological additives. **Catalyst paste:** methacrylate monomer, X-ray dense alkaline filler, initiator components, stabilizer, pigment, rhelologcal additives, fluorochrome, dark curing activator

Table (4) Description of bonding agents used in this study

Material and manu-facturer	Type	Composition	Technique of application
Adper Single Bond 2, 3M ESPE, St.Paul, MN, 55144-1000,USA	Total-etch Two-steps	BisGMA (biphenyl a diglycidyl ether di methacrylate), HEMA (2-hydroxyethyl methacrylate), dimethacrylates, ethanol, water, a novel photo initiator system and a methacrylate functional copolymer of polyacrylic and polyitaconic acids.	Apply Scotchbond™ Etchant to dentin, Wait 15_S and Rinse for 10_s. Blot excess water using a cotton pellet, the dentin surface should appear shiny without pooling of water. Immediately after blotting, apply 2-3 consecutive coats of adhesive for 15_s with gentle agitation using a fully saturated micro brush. Gently air thin for 5_s to evaporate solvent. Light-cure for 10_s using Elipar Free Light2.
Monobond S, Ivoclar vivadent AG Schaan, Liechtenstein	Ceramic primer	Ethanol, [3-(methacryloyloxy) propyl]trimethoxysilane	ceramic surfaces are coated with Monobond S for 60sec. and allowed to air dry for 5 min.

Tooth length was adjusted using digital radiographs (Digora Optima, soredex, itelsiniki, Finland). Canals enlarged to size #40 and sodium hypochlorite (1% wt.) was used as irrigating solution between different files. Following root canal preparation, the canals were irrigated and dried with paper points (Dr Wild, corsasel, Switzerland) and obturated using cold lateral condensation with gutta-percha points #40 in all canals (Roeko, Lungenau, Germany) and sealer (AH pilus, DENTSPLY). Excess gutta percha was cut at the level of the orifice of the canals. Pulp chamber was filled with a layer of resin modified glass ionomer Liner/Base material (Vitrebond; 3M, ESPE, USA).

Cavity preparation (Design1):

Mesio-occlusal-distal (MOD) Cavities were made by the same operator using periodontal probe and parallometer (Parasskop, Bego, Bremrn, Germany) to ensure standardized preparations. The cavities were made using tapered diamond with 6° convergence (inlay preparation set 4261, Komet, Lemgo, Germany), followed by the recommended sequence of the specific diamond burs of the inlay preparation set with taper of 8-10° degree, under constant air/water coolant. The inlay preparation characterized by rounded internal line angles, occlusal cavity was 50% of inter cuspal distance, proximal portions ended 1.5 mm above CEJ. Smoothing, roundation, and polishing of internal line angles was done using diamond tips and rubber cup.

Cavity preparation (Design2):

After complete MOD inlay cavity preparation 2.5 mm/horizontal reduction of buccal and lingual cusps of half of the teeth to present cavity design2. Schematic diagram of the different cavity designs are shown in figure (1).

Restorative Procedures

For each cavity design, teeth were divided into four groups according to type of restorative material used either ceramic or composite.

For the groups of direct resin composite, before cavity preparation an impression was taken with a vinyl polysiloxane material. The impressions were cut in a mesiodistal direction, and served as guides for application of the resin composite restoration[23]. After application of dentin bonding agent [Adper single bond 2 (3MESPE, ST, Paul MN, USA)] (Table 4), the direct resin composite [Filtek Z 350 XT] was applied in an incremental technique, with an increment thickness of 2mm.

All other groups from both cavity designs were covered with optical reflection powder (cerec powder, vita zahna fubrik) to receive optical digital impression for the inlay preparation using CEREC (BlueCam, sirona dental system Bensheim Germany). The inlays were designed and milled using Cerec 4 system software.

Finally, the fitting surface of the inlay was etched with 5% hydrofluoric acid for 20sec. as recommended by the manufacturers to be ready for cementation. The interior surface of all specimens were salinized using porcelain primer (Monobond S, Ivoclar vivadent AG Schaan, Liechtenstein), [table (4)]. After application of the bonding system [Adper single bond 2 (3MESPE, ST, Paul MN, USA)] on the preparation according to manufacturer instruction, [table (4)]. Reply X Ultimate Auto-mix was applied to the ceramic surface and inside the cavity then the

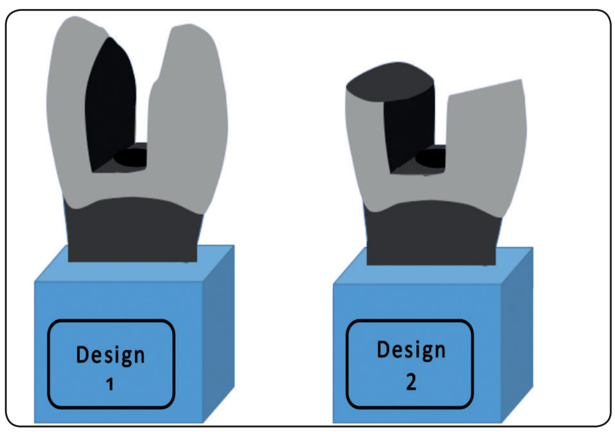

Fig. (1) Schematic diagram of the proximal surface of maxillary premolars showing different designs prepared for the study ceramic restoration was seated perpendicular to the pretreated surface using finger pressure and excess cement was removed by dental probe.

Restorations were polymerized with light intensity of 400 mw/cm² (Eliper free light, 3M ESPE) for 20sec. from each direction. Cement margin was finished using flexible polishing discs (Soflex XT pop- On, 3M ESPE). All specimens were stored in saline solution at 37°C for one week till testing.

Testing procedure

Teeth with their acrylic rings were mounted in a universal testing machine (Autograph AG-10K Nis, Shimadzu, and Kyoto, Japan). For this purpose, a stainless steel bar with 4 mm-diameter ball end was mounted in the moving arm, which was in contact with both buccal, palatal cusp ridges, and the restoration's center with equal distance during the compression with crosshead speed of 1mm/min, and the fracture load was recorded.

RESULTS

The mean fracture strength (N) and standard deviations for all the eight tested groups are presented in table (5) and figure (2).

Two-way ANOVA was used to test the two main effects namely, cavity design and types of restorative material used. A significant interaction was noticed between the two main effects therefore; One-way ANOVA was used to test each main effect separately. One-way ANOVA for the effect of cavity design showed statistical significant difference between both designs (P= 0.003). The post-hoc test revealed that Design2 has the significantly higher mean fracture resistance (P= 0.001) than did Design1.

TABLE (5) Mean fracture resistance and standard deviation of the tested cavity designs and restorative materials in Newton

Restorative material	Design1		Design2	
	Mean (N)	**St. dev.**	**Mean (N)**	**St. dev.**
Lava Ultimate	2221.21 (d)	11.32	2444.01 (c)	21.49
Vita Enamic	2209.05 (d)	5.71	2452.18 (c)	14.58
IPS e max CAD	2529.17 (b)	26.57	2767.17 (a)	18.47
Filtek Z 350 XT	1764.01 (f)	15.66	1948.18 (e)	15.71

The same superscript letters in the first left column for each design, indicates insignificant difference.

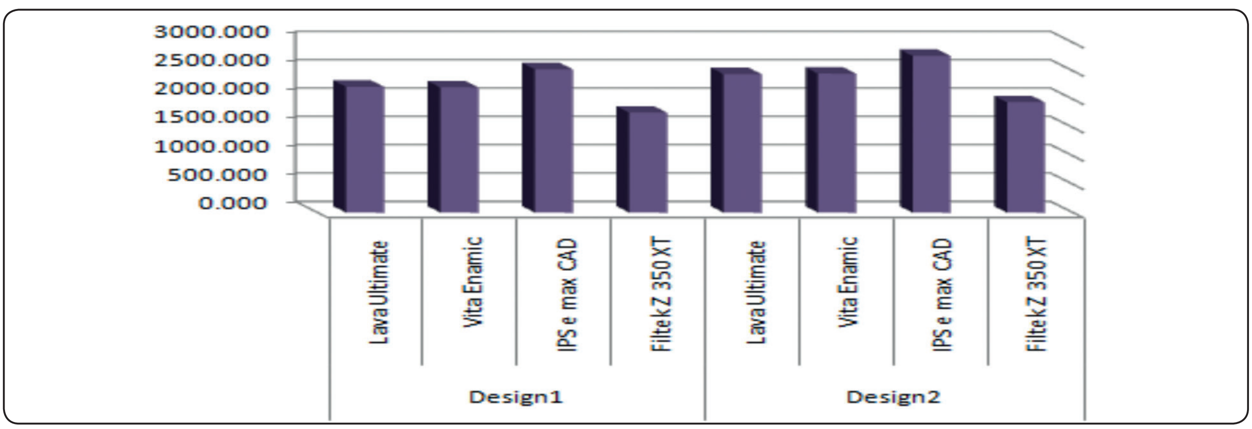

Fig. (2) Mean fracture resistance of the tested cavity designs and restorative materials in Newton

Meanwhile, One-way ANOVA for the effect of type of restorative material used showed statistical significance for types of restorative material used (P= 0.001). The post-hoc test revealed that IPS e max CAD has significantly the highest mean fracture resistance (P= 0.001). Moreover, Lava Ultimate and Vita Enamic had significantly higher mean fracture resistance than that of Filtek Z 350 XT (P= 0.001).

DISCUSSION

This study evaluated both the effect of different cavity designs and different ceramic, composites CAD/CAM blocks and regular direct resin composite on the fracture resistance of endodontically treated maxillary premolars.

Computer-aided design/ computer-aided manufacturing (CAD/CAM) technologies such as the CEREC system (Sirona) enable chairside production of restorations (e.g. veneers, inlay, onlays, or partial crowns) from prefabricated CAD/CAM blocks. Mostly, these CAD/CAM blocks consist of silicate ceramics (i.e. feldspathic ceramics, lecuite-reinforced, or lithium-disilicate glass ceramics) or of resin composites.[18]

More recently, two CAD/CAM materials were marketed that consist of different resin composite and ceramic component. One of these resin ceramic CAD/CAM materials is Lava Ultimate (3M ESPE), a so-called "resin nano ceramic". Lava Ultimate, named also "nanoparticle and nanocluster-filled resin or "CAD/CAM (resin) composite ", contains nanoceramic particles (silica- and zirconia filler/ cluster filler) bound in a resin matrix. The other resin-ceramic CAD/CAM material is VITA ENAMIC (VITA Zahnfabrik), which also called "hybrid dental ceramic" containing a feldspathic-based ceramic network and a reinforcing polymer network. Previously also named "resin infused ceramic hybrid" or "polymer infiltrated-Feld spathic ceramic-network material". Disregarding the varying nomenclature due to the different composition of the two materials, both manufactures claim their material to have numerous advantages such as high flexural strength, lower fragility than silicate ceramic, or optimized wear resistance.[18-22]

On the survival rate of endodontically treated teeth, it has emerged that preserving sound tooth structure is the key to improving their longevity. In retrospective look to clinical reports, mutilated premolars were found to be the most frequently endangered teeth.[23]

Cavity design should be founded on conservatism, keeping in mind the limitation inherent in the restorative materials. Also designing a cavity for restorative materials should be in accordance with principles of adaptation, resistance & retention, occlusion and esthetics[24-25-26]

Nowadays, it is proved that adhesion can reinforce restorative systems, diminishing many adverse effects, thus increasing their fracture resistance[23-27].

Upon restoring mutilated teeth, sacrificing conservatism is one of the impositions that are faced by many clinicians in several clinical situations, which ends in further tooth tissue loss. Mutilated teeth restored regardless of a protective principle are doomed[25]. Owing to their occlusal anatomy, maxillary premolars are the most affected teeth[26].

The use of either direct or indirect esthetic restorations have been proved to recover part of the lost fracture resistance of endodontically treated first bicuspids[23-17-28].

In the current study, a compression force was applied to the specimens until failure of the restorative system. A stainless steel bar with 4 mm-diameter ball end was used in order to contact both buccal, palatal cusp ridges, and the restoration's center with equal distance. Moreover, the same idea of three-point contact was used in previous studies[29-30]. The load applied in the present study was in the direction of the long axis, and numerous studies have used the same direction to test fracture resistance of restorative systems(29-30-31). In a trial to simulate clinical conditions, others tried to simulate lateral movements of the jaw by changing the angle of the applied load to thirty degrees (32) or thirty-five degrees(33).

A cusp coverage should allow a uniform thickness for the restorative materials of approximately 2 mm. By means of adhesive techniques, cusp coverage not only provide retention but also enhanced fracture resistance and sealing of dentin-bonded onlays in-vitro(34).

The current results showed that fracture resistance of design2 cavity preparations was superior over design1, and this result is consistent with those reported in a previous study by: Alshiddi & Aljinbaz (2016). (35)

The performance of the restorative materials can be explained by their modulus of elasticity as IPS emax CAD have 95GPa modulus of elasticity followed by Vita Enamic 30GPa and Lava ultimate 16GPa (36-37-38).

Compressive and tensile strength is of particular importance because of chewing forces. Hybrid dental ceramic restoratives have comparable compressive strength to leading chair-side materials, yet the IPS emax CAD is characterized by superior material homogeneity and crack propagation resistance, which can explain their performance in the current study.

Upon considering that the maximum chewing forces of the stomatognathic system (880 N) (25,39), the least fracture load recorded in the current study was (1764 N), slightly exceeded twice the former value. Thus, it could be assumed that both of the two tested designs and four restorative materials could perform adequately under normal functional loads. Yet, this study followed a cross-sectional design and as such does not take into account factors such as aging, cyclic loading, time or para-functional habits that might alter force distribution patterns.

The results of the present study were higher in values than that of Soares et al. (2008a) (1124.6 N) (29), Mondelli et al. (1998) (1698.3 N)(25), Habekost et al. (2006) (1303.4 N)(40), Habekost et al. (2007) (1577.8 N)(31), and Morimoto et al. (2009) (1170 N) (23) . It is hypothesized that the variations in these values are related to differences in cavity design used, the speed and angle of the load that was applied.

The limitations of this study must be recognized. The experimental protocol used for in-vitro evaluation do not accurately reflect intraoral situations. There are a number of factors that may interfere with fracture resistance, such as the differences between specimens, tooth embedment method, type & direction of load application, and crosshead speed used.

CONCLUSIONS

Under the limitation of this study it could be concluded that:

- Endodontically treated maxillary premolars with extensive loss of coronal tooth structure and restored with chair-side indirect esthetic restorations had a resistance to fracture under simulated occlusal load significantly higher than that of direct resin composite restorations.
- Chair-side CAD/CAM ceramic restorations are superior over hybrid ceramics.
- Allowing a cusp coverage of approximately 2.5 mm in bulk would enhanced fracture resistance of dentin-bonded onlays over inlay preparations with no cusp coverage in vitro.

REFERENCES

1. Conrad HJ, Seong WJ, Pesun IJ. Current ceramic materials and system with clinical recommendations: Asystematic review. J Prosthet Dent 2007;98:389-404.
2. Giordano R. Materials for chairside CAD/CAM – produced restorations. J Am Dent Assoc 2006; 137: 14S-21S.

3. Fuster-Torres MA, Albalat-Estela S, Alcaniz-Raya M, peñarrocha-Diago M.CAD/CAM dental system in implant dentistry; Update. Med Oral Patol Oral Cir Bucal 2009; 14: E141-145.

4. Mörmann Wh. The evolution of the CEREC system. J Am Dent Assoc 2006; 137: 7S-13S.

5. Giordano R, Cima M, Pober R, Effect of surface finish on the flexural strength of feldspathic and aluminous dental ceramic. Int J Prosthodont 1995; 8: 311-319.

6. Giordano R, McLaren EA, Ceramics overview: classification by microstructures and processing method. Compend contin Educ Dent 2010; 31: 682-700

7. Krejci I, Lutz F, Reimer M. Wear of CAD/CAM ceramic inlays: Restorations, opposing cusps, and luting cements. Quintessence Int 1994; 25: 199-207.

8. Fradeani M, Redemagni M, Corrado M, Porcelain Iaminate veneers: 6- to 12-years clinical evaluation-A retrospective study. Int J Periodontics Restorative Dent 2005; 25: 9-17.

9. Klink A, Huettig F. Complication and survival of mark II restorations: 4-year clinical follow-up Int J Prosthodont 2013; 26: 272-276.

10. Vichi A, Sedda M, Del Siena F, Louca C, Flexural resistance of Cerec CAD/CAM system ceramic blocks. Part 1: Chairside matrials. Am J Dent 2013; 26: 255-259.

11. Valentina V, Aleksandar T, Dejan L, & Vojkan L(2008) Restoring endodontically treated teeth with all-ceramic endo/crowns – case report. Serbian Dental Journal 5554-64.

12. Pissis P(1995) Fabrication of a metal-free ceramic restoration utilizing the monobloc technique practical periodontics and Aesthetic Dentistry 7(5) 83-94.

13. Bindl A, & Mörmann WH (1999) Clinical evaluation of adhesively placed Cerec endocrowns after 2 years-preliminary results Journal of Adhesive Dentistry 1(3) 255-265.

14. Otto T (2004) Coputer-aided direct all-ceramic crowns: Preliminary 1 year results of a prospective clinical study international Journal of periodontics and Reestorative Dentistry 24(5) 446-445.

15. Chaio C, Kuo J, Lin Y, & Chang Y(2009) Fracture resistance and failure modes of CEREC endo-crown Journal of Dental Sciences 4(3) 110-117

16. Bindl A, Richter B, & Mörmann WH (2005) Survival of ceramic-computer-aided/manufacturing crowns bonded to preparations with reduced macroretention geometry international Journal of prosthodontics 18(3) 219-224.

17. Lava Ultimate "Restorative Instruction for USA". 3M ESPE 2015

18. Awada A, Nathanson D. Mechanical properties of resin-ceramic CAD/CAM restorative materials. J Prosthet Dent 2015; 114: 587-593.

19. Shembish FA, Tong H, Kaizer M, Janal MN, Thompson VP, Opdam NJ, Zhang Y. Fatigue resistance of CAD/CAM resin composite molar crowns. Dent Mater 2016; 32: 499-509.

20. Stawarczk B, Liebermann A, Eichberger M, Güth JF. Evaluation of mechanical and optical behavior of current esthetic dental restorative CAD/CAM composites. J Mech Behave Biomed Mater 2015; 55: 1-11.

21. VIYA ENAMIC "Technical and scientific documentation". VITA Zahnfabrik 2015.

22. Morimoto S, Vieira GF, Agra CM, Sesma N, Gil C. Fracture Strength of Teeth Restored with Ceramic Inlays and Overlays Braz Dent J (2009) 20(2): 143-148

23. Larson TD, Douglas WH, Geistfeld RE. Effect of prepared cavities on the strength of teeth. Oper Dent 1981;6:2-5.

24. Mondelli RF, Barbosa WF, Mondelli J, Franco EB, Carvalho RM. Fracture strength of weakened human premolars restored with amalgam with and without cusp coverage. Amer J Dent 1998; 11: 181-84.

25. Jagadish S, Yogesh BG. Fracture resistance of teeth with Class 2 silver amalgam, posterior composite, and glass cermet restorations. Oper Dent 1990;15:42-47.

26. Mondelli J, Sene F, Ramos RP, Benetti AR. Tooth structure and fracture strength of cavities. Braz Dent J 2007; 18: 131-140.

27. Van Dijken J.W., Direct resin composite inlays/onlays: an 11 year follow-up. J. Dent. 28 (2000), 299–306.

28. Hannig, C., Westphal, C., Becker, K., Attin, T., 2005. Fracture resistance of endodontically treated maxillary premolars restored with CAD/CAM ceramic inlays. J. Prosthet. Dent. 94 (4), 342–349.

29. Soares P.V. , Santos- Filho P.C., Martins L.R.M., and Soares C.J. Influence of restorative technique on the biomechanical behavior of endodontically treated maxillary premolars. Part I: Fracture resistance and fracture mode. J. Prosthet. Jan 2008, Vol99, Issue 1, 30-37.

30. Soares P.V., Santos-Filho, P.C., Gomide, H.A., Araujo, C.A., Martins, L.R., Soares, C.J., 2008b. Influence of restorative technique on the biomechanical behavior of endodontically treated maxillary premolars. Part II: strain

measurement and stress distribution. J. Prosthet. Feb 2008 Dent. 99 (2), 114–122.

31. Habekost LV, Camacho GB, Azevedo EC, and Demarco FF. Fracture resistance of thermal cycled and endodontically treated premolars with adhesive restorations. J. Prosthet. Sept 2007; Vol 98, Issue 3, 186-192.
32. Yamada Y., Tsubota, Y., Fukushima, S., 2003. Effect of restoration method on fracture resistance of endodontically treated maxillary premolars. Int. J. Prosthodont. 2004 17 (1), 94–98.
33. Plotino G., Buono, L., Grande, N.M., Lamorgese, V., Somma, F., 2008. Fracture resistance of endodontically treated molars restored with extensive composite resin restorations. March 2008, J. Prosthet. Dent. 99 (3), 225–232.
34. Van Dijken J.W and Hasselrot L. A prospective 15-year evaluation of extensive dentin–enamel-bonded pressed ceramic coverages dental materials 26 (2010) 929–939
35. Alshiddi IF Aljinbaz A. Fracture resistance of endodontically treated teeth restored with indirect composite inlay and onlay restorations – An in vitro study. Saudi dental journal 2016 28, 49-55
36. Scientific Documentation IPS e.maxÒ CAD Ivoclar Vivadent.
37. Lava™ Ultimate CAD/CAM technical product profile 3M ESPE.
38. Vita Enamic: The concept. VITA Zahnfabrik.
39. Salameh Z., Ounsi H. F., Aboushelib M. N.,·Hamdan R., Sadig W., & Ferrari M. Effect of different onlay systems on fracture resistance and failure pattern of endodontically treated mandibular molars restored with and without glass fiber posts. American journal of dentistry, Vol 23, No2, April 2010
40. Pereira-Cenci T, Pereira L.J., Cenci MS, Bonachela WC, and Del Bel Cury AA. Braz Dent J (2007) 18(1): 65-68 Maximal bite force and temporomandibular disorders
41. Habekost Lde V, Camacho GB, Pinto MB, Demarco FF. Fracture resistance of premolars restored with partial ceramic restorations and submitted to two different loading stresses. Oper Dent. 2006 Mar-Apr;31(2):204-11.