European Review for Medical and Pharmacological Sciences 2023; 27: 2232-2240

Retention of different all ceramic endocrown materials cemented with two different adhesive techniques

Z.N. EMAM[1,2], S.M. ELSAYED[1,2], M. ABU-NAWAREG[3,4], A.Z. ZIDAN[5,6], E.M. ABUELROOS[7,8], H.M.R. SHOKIER[9,10], H.A. FANSA[11,12], H.A. ELSISI[7], K.A. ELBANNA[1]

[1]Department of Oral and Maxillofacial Surgery and Rehabilitation, Fixed Prosthodontics Division, Faculty of Dental Medicine, Umm Al-Qura University, Mecca, Saudi Arabia
[2]Department of Fixed Prosthodontics, Faculty of Oral and Dental Medicine, Cairo University, Cairo, Egypt
[3]Department of Restorative Dentistry, Faculty of Dentistry, King Abdulaziz University, Jeddah, Saudi Arabia
[4]Department of Biomaterials, Faculty of Dentistry, Cairo University, Cairo, Egypt
[5]Dental Biomaterials Science, Faculty of Dental Medicine, Umm Al-Qura University, Mecca, Saudi Arabia
[6]Faculty of Dentistry, October University for Modern Science and Arts (MSA), Giza, Egypt
[7]Department of Oral and Maxillofacial, Removable Prosthodontics Division, Faculty of Dental Medicine, Umm Al-Qura University, Mecca, Saudi Arabia
[8]Department of Prosthodontics, Faculty of Dentistry, Cairo University, Cairo, Egypt
[9]Department Oral and Maxillofacial Surgery and Rehabilitation, Maxillofacial Surgery Division, Faculty of Dental Medicine, Umm Al-Qura University, Mecca, Saudi Arabia
[10]Department of Oral and Maxillofacial, Faculty of Dental Medicine (Girls Branch), Al-Azhar University, Cairo, Egypt
[11]Department of Basic and Clinical Oral Sciences, Faculty of Dental Medicine, Umm Al-Qura University, Mecca, Saudi Arabia
[12]Department of Oral Biology, Faculty of Dentistry, Alexandria University, Alexandria, Egypt

Abstract. – OBJECTIVE: The purpose of this *in vitro* study was to evaluate the influence of two adhesive techniques on the retentive force of four all ceramic endocrowns.

MATERIALS AND METHODS: Forty maxillary first molars of approximately similar size and shape were collected. The teeth were all decoronated 2 mm above the level of proximal cement-enamel junction (CEJ) and were all endodontically treated. The teeth were then randomly divided equally into four groups (10 each) according to all ceramic material used, as follows: Group I (VE) – Ten prepared molars were restored with hybrid ceramic (Vita Enamic); Group II (LU) – Ten prepared molars were restored with resin Nano-ceramic (Lava Ultimate). Group III (CD) – Ten prepared molars were restored with zirconia-reinforced lithium di-silicate ceramic material (Celtra Duo); Group IV (LZ) – Ten prepared molars were restored with zirconia ceramic (Lava Zirconia). Each group was then subdivided into two equal subgroups (n=5) according to the type of cement (adhesive technique) used for cementation. Subgroup A (RX ARC): the endocrowns were cemented with a total-etch adhesive resin cement (RelyX ARC). Subgroup B (RXU): the endocrowns were cemented with self-adhesive resin luting cement (RelyX UniCem). The restorations were designed with an outer cylindrical handle located on buccal and palatal surfaces to provide a mean for the removal of the endocrowns during the pull-out testing. The cemented endocrowns were thermocycled and then removed along the path of insertion using a universal testing machine at 0.5 mm/min. The retentive force was recorded, and the stress of dislodgement was calculated using the surface area of each preparation.

RESULTS: The highest mean dislodgement stresses were 64.3 MPa for Group I (VE), whereas there was no statistically significant difference between Group I, II and III and LZ showed the lowest values with significant difference between the other three groups. Regarding the type of cement, there was a statistically significant difference between RelyX ARC (mean=60.09 MPa) and RelyX Unicem (mean=49.73 MPa).

Corresponding Author: Zeinab N. Emam, MD; e-mail: Znabil2008@hotmail.com

CONCLUSIONS: Retention of Vita Enamic, Lava Ultimate, and Celtra Duo are significantly higher than Lava Zirconia.

Key Words:
Vita enamic, Lava ultimate, Celtra duo, Zirconia, Total etch resin cement, Self-adhesive resin cement, Pull-out testing, Retentive force, Resin nano ceramics, Adhesive techniques.

Introduction

The treatment of harshly damaged and endodontically treated teeth is continually a challenge in reconstructive dentistry[1,2]. Endodontically treated teeth struggle with many drawbacks such as reduced fracture resistance when compared to vital ones[3]. This is mainly due to loss of structural integrity associated with caries, trauma, and extensive cavity preparation, rather than dehydration or physical changes in the dentin[4-6]. Therefore, the longevity of an endodontic treatment depends on the selection of an appropriate restoration, which is concerned with preserving the tooth structure, as well as the selection of appropriate restorative materials[7]. Many different treatment options have been developed for restoring non-vital teeth, including post-core systems and conventional crowns which is the preferred technique of most dentists and have been reported[8,9] to exhibit a higher success rate compared with directly placed restorations. Endo-crown is a treatment option that denotes a restoration that unites the crown and core in a single unit. Endo-crown gets its retention through the macro-retention from the pulp chamber and the micro-retention through bonding. Teeth with insufficient coronal tooth structure and limited interocclusal distance that are not indicated for conventional extra-coronal crowns could be rebuilt with the endo-crown restorations[10,11]. The selection of the materials used for endocrown fabrication has a great impact on the success and longevity of the restorations. A new resin nano-ceramic, recently introduced by 3M ESPE, called Lava Ultimate CAD/CAM restorative, has a unique chemical composition combining the advantages of highly cross-linked, heat-cured composite combined with nanoceramic technology for strength and polish retention. This truly hybrid material has several proposed advantages such as ease of use, tooth-like properties, durability, and aesthetics[12]. Minimally invasive preparations to preserve a maximum amount of tooth structure are considered the gold standard for restoring teeth. Endo-crowns strictly follow this rationale owing to a decay-oriented design concept. This type of preparation consists of a circular butt-joint margin and a central retention cavity inside the pulp chamber, constructing both the crown and core as a single unit. The endocrown technique utilizes the available surface in the pulp chamber to obtain stability and retention of the restoration through adhesive bonding. Computer-aided design/computer-aided manufacturing (CAD/CAM) systems provide the possibility of chair-side design and automatic production of these single-unit ceramic restorations. Adhesive cementation increases the strength and the resistance of ceramics to fracture[13,14]. Resin-based types of cement are widely used for luting inlays, onlays, endo-crowns, crowns, and veneers because they adhere to metal and ceramics. However, teeth and restorations require surface treatments, such as etching and bonding, when conventional resin-based cement is used[15,16] making the luting operation technique sensitive. Thus, if the surface treatment is insufficient, the bond strength will be impaired. Self-adhesive cement does not require any surface treatment of the teeth or restorations, so they are easier to handle and have clinically effective bond strength. It is reported[15,17-20] that self-adhesive resin cement provides the equivalent bond strength of conventional resin cement to dentin[17,18], gold alloy, glass ceramics[15], and zirconia[19,20]. The adhesive properties of a luting agent to ceramics can be assessed using several laboratory tests. The most common laboratory tests are bond strength tests, such as shear, tensile, microtensile, or push-out tests. The advantages of bond strength tests, if designed properly, are the reproducibility of results within same test lab and the ease of conducting the test. The main criticism is that the bond strength test does not reflect the clinical situation. Therefore, laboratories developed crown pull-off tests where crowns were used to extract human teeth to simulate the clinical procedure[3]. This testing procedure is complex and technique sensitive but provides information on the retentive performance of a material[21]. Thus, this *in vitro* study aimed to evaluate the retention of endocrowns fabricated using four different materials. The proposed null hypothesis in this study was that the retentive force of the selected material is not influenced by the cement bonding mechanism.

Materials and Methods

Teeth Collection and Preparation

Forty intact, non-carious, human maxillary first molars were collected. All teeth were checked for the absence of root caries, root fillings, or root cracks. The teeth were selected to be approximatly of comparable size and shape regarding root length and crown dimensions, and the buccolingual and mesiodistal widths at the cement-enamel junction (CEJ) were measured in millimeters using a graduated caliper (0-25 mm, 0.01 mm, Germany). The teeth were soaked for 2 hours in 0.5% sodium hypochlorite (NaOCl) solution to remove any foreign substances and then placed in a saline solution for a maximum of one month until the experiment began. All teeth were decoronated, 2 mm above the level of proximal CEJ, using a diamond disc (Diamond discs 910P, Drendel+Zweiling DIAMANT Gmbh, Kalletal, Germany). The root canal instrumentation was done to all selected teeth using the step-back technique with K-files (Mor-Flex K-Type File, Moyco Union Broach, York, PA, USA). Obturation of the canals was done with gutta-percha (Meta Dental Co., Ltd. Chongiu, Korea) and sealer (AH-26, Dentsply Detry GmbH, Konstanz, Germany) using lateral condensation technique. The roots of the selected teeth were notched for retention and embedded along their vertical alignment in an auto-polymerizing acrylic resin (Acrostone, acrostonedental factory, Cairo, Egypt) with the cement-enamel junction positioned 1 mm above the top of the acrylic resin. All samples were prepared to receive endocrowns. The preparation was designed with a circular butt margin 2 mm above cement-enamel junction and a central cavity with a standardized depth and wall thickness[9,11].

Specimen Grouping

All the samples of this study were prepared by the same operator. The prepared teeth were randomly divided into four equal groups of ten teeth each, according to the material used for the construction of the endocrowns, as follows: Group I (VE): Ten prepared molars were restored with bybrid ceramic material (Vita Enamic). Group II (LU): Ten prepared molars were restored with resin nano-ceramic material (Lava Ultimate). Group III (CD): Ten prepared molars were restored with zirconia-reinforced lithium disilicate ceramic material (Celtra Duo). Group IV (LZ): Ten prepared molars were restored with zirconia ceramic material (Lava Zirconia). Each group was then subdivided into two equal subgroups (n=5) according to the type of cement (adhesive technique) used for cementation. Subgroup A (RX ARC): the endocrowns were cemented with a total etch adhesive resin cement (RelyX ARC). Subgroup B (RXU): the endocrowns were cemented with self-adhesive resin luting cement (RelyX UniCem). The chemical composition and the manufacturers of the materials used in this study are presented in Table I.

All samples of this study were prepared by the same operator. Endocrowns for Group I was milled from Vita Enamic ceramic blocks, while for Group II from resin nano-ceramic Lava Ultimate blocks, whereas for Group III Celtra Duo ceramic blocks were used and for Group IV Lava Zirconia ceramic blocks were used for endocrowns construction. All prepared samples were scanned, designed, and milled using ZirkonZahn CAD/CAM 5 Tec machine (ZirkonZahn, Gais, Italy) according to the manufacturer's instructions for each selected ceramic block. The endocrowns were designed with an outer cylindrical handle located on buccal and lingual surfaces below the occlusal-axial line angles by 2 mm. The length and the diameter of the handles were 3 mm and 3 mm, respectively. These handles were added, milled, and sintered to the endocrowns to provide a means for the removal of the coping during the pull-out testing. The cement space was adjusted to 40 µm. Before cementation, the areas of the axial and the occlusal surfaces of each prepared tooth were calculated. For each specimen, the boundaries of the buccal surface were marked as an area extending from the mesiobuccal line angle to the distobuccal line angle and from the cervical finish line to the occlusal-axial line angle using an indelible pencil. The same was done for the palatal, mesial, distal, and occlusal surfaces. For each specimen, the area of interest was captured by a CCD digital camera (DP10-Olympus, Japan) mounted on a stereo microscope. The area of each surface on each specimen was assessed at the predetermined marked areas. These readings were calculated as an area using image analysis software (Image J- 1b, USA). The sum of the areas of the mesial, distal, buccal, palatal, and occlusal surfaces was calculated to obtain the total surface area of each prepared endocrown cavity.

In subgroup A: (RX ARC), RelyX ARC adhesive resin cement was used. The scotch bond etchant (3M Scotchbond, Etchant, 3M ESPE, Seefeld, Germany) was applied to dentin for 15

Table I. The chemical composition and the manufacturers of the materials used in this study.

Material	Composition	Manufacturer
Celtra Duo	SiO_2, Li_2O, ZrO_2, P2O_5, Al2O_5, K_2O, CeO_2 and pigments	Ivoclar Vivadent
Vita Enamic	Ceramic part: 86% wt. SiO_2 (58 - 63%), Al_2O_3 (20-23%), Na_2O (9-11%), K_2O (4-6%), B_2O_3 (0.5-2%), ZrO_2	VITA Zahnfabrik, Germany
Lava Zirconia	3% yttrium oxide treated tetragonal zirconia polycrystals with a very small concentration of alumina (< 0.25%) to prevent leaching of the yttrium oxide.	3M ESPE, Germany
Resin Nano Ceramic Lava Ultimate "LU"	Total nanoceramic material content is 80% by weight: - silica nanomers (20 nm), - zirconia nanomers (4-11 nm). - zirconia-silica nanoclusterparticles (0.6-10 μm). Highly cross-linked methacrylate-based resin matrix Silane coupling agent	3M ESPE, Germany 3M ESPE, Germany
RelyX ARC	Paste A: zirconia/silica filler 68%, amine, photo-initiator, pigment Paste B: zirconia/silica filler 67%, benzoyl peroxide	
Rely X Unicem Resin Cement	Powder: - Alkaline (basic) fillers - Silanated fillers - Initiator components - Pigments Liquid: - Methacrylate monomers containing phosphoric acid groups - Methacrylate monomers - Initiator components - Stabilizers	3M ESPE, Germany

seconds and then rinsed for 10 seconds. Two consecutive coats of single bond adhesive (Single bond adhesive, 3M ESPE, Seefeld, Germany) were applied to etched dentin for 15 seconds, and air thinning for 5 seconds was done. Light curing for 10 seconds was done per bonding surface. The fitting surfaces of the copings were blasted with aluminum oxide ≤40 μm then the blasted surfaces were cleaned with alcohol and dried with water and oil-free air. RelyX Ceramic primer (3M scotch bond ceramic primer, 3M ESPE, Seefeld, Germany) was applied to the fitting surfaces of each coping and dried for 5 seconds. The cement was mixed onto a mixing pad for 10 seconds. A thin layer of cement was applied to the fitting surface of the copings. The copings were seated onto their abutments and 5 kg force was applied for 10 minutes; excess cement was removed 3-5 minutes after seating. Light curing was activated on buccal, palatal, mesial, distal, and occlusal surfaces for 40 seconds for each surface.

In subgroup B; (RXU), self-adhesive resin cement with phosphate monomer (RelyX Unicem, London, UK) was used. The fitting surfaces of the copings were blasted with aluminum oxide ≤40 μm then the blasted surfaces were cleaned with alcohol and dried with water and oil-free air. The RelyX Unicem capsule was mixed in a high-frequency mixing unit (DeGötzen, Milan, Italy) for 15 seconds. The cement was applied to the fitting surface of each coping. All the endocrowns were seated onto their corresponding abutments and 5 kg force was applied for 10 minutes. The cement in excess was eliminated. Light curing was started and activated on buccal, palatal, mesial, distal, and occlusal surfaces for 20 seconds for each surface using a light curing unit (Mini LED, 1,250 mW/cm^2, Satelec, Acteon). All specimens were subjected to 2,000 thermal cycles between 5°C and 55°C (Willytecthermocycler, Berlin, Germany) with a dwell time of 30 seconds in each water bath. Each acrylic embedded tooth with its own cemented coping was secured with tightening screws to the lower fixed compartment of a materials testing machine (Model LRX-plus; Lloyd Instruments Ltd., Fareham, UK) with a load cell of 5 kN and data were recorded using computer software (Nexygen-MT Lloyd Instruments, Nexygen, China). The coping was suspended from the upper movable compartment of the testing machine through a custom-made double loop made of orthodontic wire. This wire was bowed around the cylindrical handles and the cemented copings were pulled off along the path of insertion. A tensile load with the pull-out mode of force was employed *via* materials testing machine at a crosshead speed of 0.5 mm/min. The

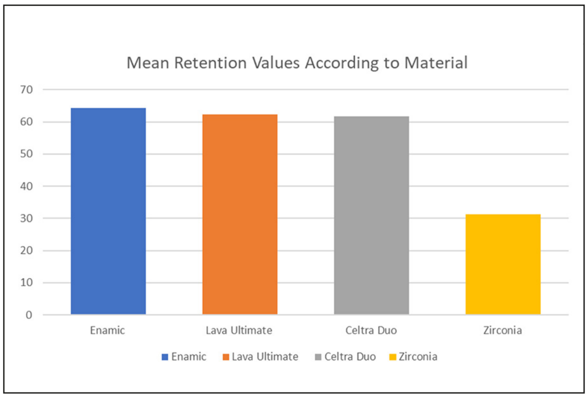

Figure 1. Mean retention values in this study for different materials.

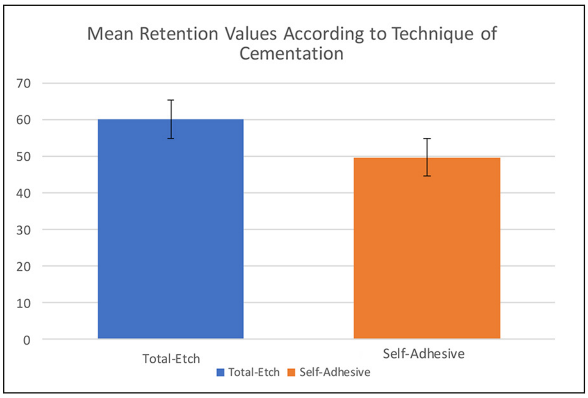

Figure 2. Mean retention values according to technique of cementation.

Table II. Means (standard deviations) of retention (MPa) according to the material used.

	Enamic	Lava ultimate	Celtra duo	Zirconia
Mean of retention (standard deviation)	64.3 (7.75)[a]	62.33 (7.74)[a]	61.7 (8.29)[a]	31.3 (9.35)[b]

Rows with different letters indicate a statistically significant difference $^{a}p \leq 0.05$; $^{b}p \leq 0.001$.

force at dislodgement (MPa) was documented and the stress of removal was calculated using the surface area of each preparation.

Statistical Analysis

Data were analyzed and tabulated using statistical analysis software SPSS v. 9 (SPSS Inc., Chicago, IL, USA). The data were tested for normal distribution using the Shapiro-Wilk test. Normal distribution was not found. Kruskall-Wallis test was used to compare different materials and the interaction between materials and cementation techniques, and the Tukey HSD test was used for pair-wise post hoc comparisons. The Mann-Whitney test was used for comparison between the two cementation techniques. A *p*-value lower than 0.05 was considered significant.

Results

Data were analyzed and tabulated using statistical analysis software (SPSS Inc., Chicago, IL, USA). The data were tested for normal distribution using the Shapiro-Wilk test. Normal distribution was not found. Kruskall Wallis test was used to compare different materials and the interaction between materials and cementation techniques, and the Tukey HSD test was used for pair-wise posthoc comparisons. The Mann-Whitney test was used for the comparison of the two cementation techniques. The results of this study showed that Vita Enamic had the highest mean retention values though not statistically significant than Lava Ultimate and Celtra Duo. Zirconia had the lowest mean retention value which was significantly lower than the other three ceramic materials (Figure 1). The mean retention value of the total-etch cementation technique (60.09 MPa) was significantly higher than self-adhesive cementation (49.73 MPa) (Figure 2, Table II).

The combination between the total-etch cementation technique and Vita Enamic ceramic material yielded the higher mean retention value (68 MPa) while the combination between self-adhesive cementation and zirconia had the least mean value (22.8 MPa) (Table III). There was no significant difference between the in-

Table III. Means (standard deviations) of retention (MPa) according to the technique of cementation used.

	Total Etch	Self-Adhesive
Mean of retention (standard deviation)	60.09 (13.73)[a]	49.73 (16.69)[b]

Rows with different letters indicate a statistically significant difference $^{a}p \leq 0.05$; $^{b}p \leq 0.001$.

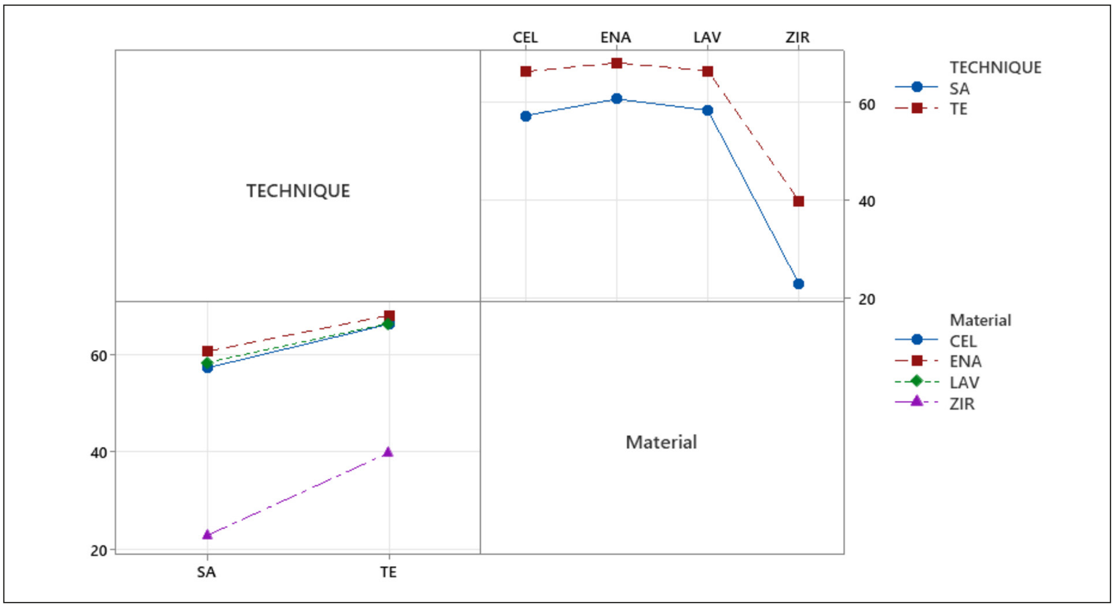

Figure 3. The interaction between materials and cementation techniques.

teraction between materials and cementation techniques except for zirconia which showed a significantly lower retention mean value than the other ceramic materials for both cementation techniques (Figure 3 and Figure 4). Moreover, there was a significant difference within the zirconia material itself between total-etch (39.8 MPa) and self-adhesive (22.8 MPa) cementation techniques (Table IV).

Discussion

The restoration of endodontically treated teeth is considered to be a continuous challenge in restorative dentistry. It shows a noticeable biome-

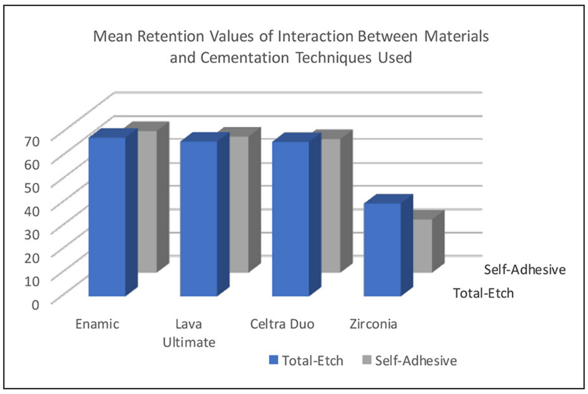

Figure 4. Mean retention values of interaction between materials and cementation techniques used.

chanical difference in comparison with its vital equivalents, representing a multifactorial dissimilarity that includes dehydration and changes in dentin collagen. This results from using chemical irrigants and medicaments as well as the general weakness result from the carious lesion, previous restorations, and endodontic access cavity preparation[22,23]. Endocrown restorations have many advantages such as a simple and conservative technique because it avoids root dentine removal to gain retention, time-saving due to fewer clinical and laboratory steps, supra-gingival margins which facilitate plaque control, and reduced treatment cost when compared to post-core-crown restoration[12-14]. The type of material used reported a significant influence on retention for all tested groups.

Resin-infiltrated hybrid ceramics and zirconia-reinforced lithium di-silicate showed the highest retentive force than Lava Zirconia endocrowns. The retentive force of the four tested materials is significantly high with the total-etch technique compared to the self-adhesive bonding mechanism thus the null hypothesis is rejected. Valentina et al[24] evaluated the clinical performance of endocrowns fabricated with the Cerec CAD/CAM system and endocrowns manufactured with the Empress II system and it was concluded that both systems have constructed endocrowns with excellent clinical quality in terms of retention and esthetics. Resin bonding of ceramic material restorations permits a strong

Table IV. Means (standard deviations) of retention (MPa) according to interaction between material and technique of cementation used.

	Enamic	Lava ultimate	Celtra duo	Zirconia
Total Etch	68 (7.91)[a]	66.36 (8.19)[a]	66.20 (7.98)[a]	39.8 (3.7)[b]
Self-Adhesive	60.60 (6.19)[a]	58.30 (5.22)[a]	57.2 (6.34)[a]	22.8 (1.48)[c]

Rows with different letters indicate a statistically significant difference [a]$p \leq 0.05$; [b]$p \leq 0.001$; [c]Statistical significant difference with [a] and [b].

bonding between the tooth structure and the restoration. Regarding the surface treatment of tooth structure for total-etch bonding mechanism, enamel, and dentine areas were etched with phosphoric acid that dissolves the hydroxyapatite crystals producing micro-irregularities leading to the formation of resin micro tags that provide micromechanical retention, thus improving adhesion potential[25].

Resininfiltrated ceramics is composed of a twofold network of pre-sintered feldspar porous ceramic matrix combined with organic polymers forming the polymer-infiltrated ceramic network[26]. Hydrofluoric acid etching for 60 s eliminates some of the glass matrix, producing micro-porosities[27]. Exposed etched glass is silanated to promote active bonding formation of a chemical bond[11]. In the current study, resin-infiltrated ceramics showed high retention values which were comparable to zirconia-reinforced lithium disilicate ceramic[28]. This high bond strength of resin-infiltrated ceramics could be interpreted due to its hybrid surface that results in that superior chemical bonding[26]. Regarding Lava Zirconia endocrowns, due to their chemical composition and the absence of an etchable glassy phase, the bonding procedure of this material is obscured[29]. The favored treatment method is airborneparticle abrasion with Al_2O_3 to provide superior bond strengths with the cementing medium. Therefore, the bonding difficulty of Lava Zirconia due to its chemical composition may interpret the low retention values reported in the current study[30]. The combination between the total-etch cementation technique and Vita Enamic ceramic material yielded the higher mean retention value (68 MPa) while the combination between self-adhesive cementation and zirconia had the lower mean value (22.8 MPa). There was no significant difference in the interaction between materials and cementation techniques except for zirconia which showed a significantly lower retention mean value than the other ceramic materials for both cementation techniques. Moreover, there was a significant difference within the zirconia material itself between total-etch (39.8 MPa) and self-adhesive (22.8 MPa) cementation techniques.

Regarding the type of cement, the results obtained in this study showed that Rely X total-etch resin cement resulted in statistically significant higher debonding load values than self-adhesive resin cement in all tested groups. These findings were in agreement with other studies[31-33] that reported superior bond strength values of total-etch resin cement compared to self-adhesive resin cements. Total etch cement relies on a separate etching procedure to remove the thick surface smear layer and smear plugs in dentinal tubules, formed during preparation and allow more effective micromechanical retention of resin-based cements[32,33]. Marginal adaptation is an important criterion that should be considered during the selection of the restorative material. Therefore, further investigation into the marginal adaptation of endocrowns is needed to ensure the durability of the endocrown materials to withstand the clinical performance.

Conclusions

Within the limitations of this study, using resin-infiltrated ceramics and zirconia-reinforced lithium disilicate as restorative materials to construct endocrowns and restore severely damaged endodontically treated teeth, recorded significantly higher retention values. Meanwhile, using Lava Zirconia for the same purpose recorded a lower retentive force with an increased possibility of tooth fracture. Luting endocrowns with total-etch cement is more reliable than using self-adhesive cement regarding retention.

Conflict of Interest

The Authors declare that they have no conflict of interests.

Ethics Approval

Ethical approval was obtained from the IEC of Oral and Maxillofacial Surgery and Rehabilitation Department, Faculty of Dental Medicine, Umm Al-Qura University, Mecca, Saudi Arabia.

Informed Consent

Informed consent was obtained from the participants with the option to withdraw from the study at any time.

Availability of Data and Materials

All data are provided in this study and raw data can be requested from the corresponding author.

Funding

No financial support was obtained for this research.

Authors' Contribution

SMES, ZNE and KAE: concepts, design, data analysis, statistical analysis, manuscript preparation, manuscript review, guarantor. MAN, AZZ, HAE, EMA, HAF and HMRS: definition of intellectual content, literature search, experimental studies, data acquisition, manuscript editing.

References

1) Lee Y, Chae M, Kim KH, Kwon TY. Effect of dental silane primer activation time on resin–ceramic bonding. J Adhesion Sci Tech 2015; 29: 1155-1167.
2) Kitayama S, Nikaido T, Takahashi R, Zhu L, Ikeda M, Foxton R, Sadr A, Tagami J. Effect of primer treatment on bonding of resin cements to zirconia ceramic. J Dent Mater 2010; 26: 426-432.
3) Casucci A, Montielli F, Goracci C, Mazzitelli C, Cantoro A, Papacchini F, Ferrari M. Effect of surface pretreatments on the zirconia ceramic-resin cement microtensile bond strength. J Prosthet Dent 2011; 27: 1024-1030.
4) Guazzato M, Albakry M, Ringer SP, Swain MV. Strength, fracture toughness and microstructure of a selection of a selection of all-ceramic materials. Part II. Zirconia-based dental ceramics. Dent Mater J 2014; 20: 449-456.
5) Kelly JR, Denry I. Stabilized zirconia as a structural ce- ramic: an overview. Dent Mater J 2008; 24: 289-298.
6) Inokoshi M, Zhang F, Vanmeensel K, De Munck J, Minakuchi S, Naert I, Vleugels J, Van Meerbeek B. Residual compressive surface stress increases the bending strength of dental zirconia. Dent Mater J 2017; 33: e147-154.
7) Lawn BR, Deng Y, Lloyd IK, Janal MN. Materials design of ceramic-based layer structures for crowns. J Dent Res 2002: 81: 433-438.
8) Cho G. Evidence-based approach for treatment planning options for the extensively damaged dentition. J Calif Dent Assoc 2004; 32: 983-990.
9) Abdullah A, Tsitrou E, Pollington S. Comparative in-vitro evaluation of CAD/CAM vs conventional provisional crowns. J Appl Oral Sci 2016: 24: 258-263.
10) Alhawari M, Al-zordk W, Abo-madina M. Fracture resistance of endodontically treated teeth: effect of cad-cam post-core and endocrown materials. J Dent Med Sci 2019; 18: 65-68.
11) Sevimli G, Cengiz S, Oruc MS. Endocrowns. J Istanb Univ Fac Dent 2015; 4: 57.
12) Naumann M, Schmitter M, Krastl G. Post endodontic restoration: Endodontic post and core or no post at all? J Adhes Dent 2018; 20: 19-24.
13) Weiser F, Behr M. Self-adhesive resin cements: a clinical review. J Prosthodont 2015; 24: 100-108.
14) Chang CY, Kuo JS, Lin YS, Chang YH. Fracture resistance and failure modes of CEREC endo-crowns and conventional post and core-supported CEREC crowns. J Dent Sci 2009; 4: 110-117.
15) Hasan I, Frentzen M, Utz KH, Hoyer D, Langenbach A, Bourauel C. Finite element analysis of adhesive endo- crowns of molars at different height levels of buccally applied load. J Dent Biomechan 2012; 3: 1-11.
16) Stewart GP, Jain P, Hodes J. Shear bond strength of resin cements to both ceramic and dentin. J Prosthet Dent 2002; 88: 277-284.
17) Mak YF, Lai SC, Cheung GS, Chan AW, Tay FR, Pashley DH. Microtensile bond testing of resin cements to dentin and an indirect resin composite. Dent Mater 2002; 18: 609-621.
18) De Munck J, Vargas M, Van Lanuyat K, Hikita K, Lambrechts P, Van Meerbeek. Bonding of an auto-adhesive ma- terial to enamel and dentin. Dent Mater 2004; 20: 963-971.
19) Hikita K, Van Meerback B, De Munck J, Ikeda J, Van Landuyt K, Maida T, Bonding effectiveness of adhesive luting agents to enamel and dentin. Dent Mater 2007; 23: 71-80.
20) Piwowarczyk A, Lauer HC, Sorensen JA. In-vitro shear bond strength of cementing agents to fixed prosthodontic restorative materials. J Prosthet Dent 2004; 92: 265-273.
21) Ernst CP, Cohnen U, Stender E, Willerhausen B. In-vitro retentive strength of zirconium oxide ceramic crowns us- ing different luting agents. J Prosthet Dent 2005; 93: 551-558.
22) Palacios RP, Johnson GH, Philips KM, Raigrodski AJ. Retention of zirconium oxide ceramic crowns with three types of cements. J Prosthet Dent 2006; 96: 104-114.
23) Ernst CP, Wenzi N, Stender E, Willershausen B. Retentive strengths of cast gold crowns using glass ionomer, com- pomer, or resin cement. J Prosthet Dent 1998; 79: 472-476.

24) Valentina V, Aleksandar T, Dejan L, Vojkan L. Restoring endodontically treated teeth with all-cer. amic endo-crowns: case report. Stomatol Glas Srb 2008; 55: 54-64.

25) Laden G, Fjolla K, İzgen K, Esra Cengiz Y, Nuran U. Micro shear bond strength of resin cements to Er, Cr: YSGG laser and/or acid etched enamel. Laser Phys 2018; 28: 105-111.

26) Nguyen JF, Ruse D, Phan AC, Sadoun MJ. High temperature pressure polymerized resin infiltrated ceramic networks. J Dent Res 2014; 93: 62-67.

27) Özcan M, Volpato CÂ. Surface conditioning and bonding protocol for polymer infiltrated ceramic: How and why? J Adhes Dent 2016; 18: 174-175.

28) Rohr N, Brunner S, Märtin S, Fischer J. Influence of cement type and ceramic primer on retention of polymer infiltrated ceramic crowns to a one piece zirconia implant. J Prosthet Dent 2018; 119: 138-145.

29) Pereira GK, Graunke P, Maroli A, Zucuni CP, Prochnow C, Valandro LF. Lithium disilicate glass ceramic vs translucent zirconia polycrystals bonded to distinct substrates: Fatigue failure load, number of cycles for failure, survival rates, and stress distribution. J Mech Behav Biomed Mater 2019; 91: 122-130.

30) Blatz MB, Phark JH, Ozer F, Mante FK, Saleh N, Bergler M. In-vitro comparative bond strength of contemporary self adhesive resin cements to zirconium oxide ceramic with and without air particle abrasion. Clin Oral Investig 2010; 14: 187-192.

31) Rathke A, Haj Omer D, Muche R, and Haller B. Effectiveness of bonding fiber posts to root canals and composite core buildups. Eur J Oral Sci 2009; 117: 604-610.

32) Goracci C, Sadek FT, Fabianelli A, Tay FR, Ferrari M. Evaluation of the adhesion of fiber posts to intraradicular dentin. Oper Dent 2005; 30: 627-635.

33) Sano H, Van Meerbeek B. Microtensile bond strength of eleven contemporary adhesives to enamel. Am J Dent 2003; 16: 329-334.