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Microleakage of Lithium Disilicate Ceramic Crowns and Nano Ceramic Crowns: A Comparative Study

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ABSTRACT

Aim and Hypothesis

The aim of this study was to evaluate and compare the microleakage of CAD/CAM crowns made of nano ceramics (CERASMART, GC, Tokyo, Japan) and lithium disilicate ceramics (IPS e.max, Ivoclar Vivadent AG, Liechtenstein) on extracted teeth after thermocycling testing. It was hypothesized that lithium disilicate crowns would have lower microleakage values compared to nano ceramic ones.

Materials and Method

Thirty extracted human third molar teeth were prepared in a consistent way to receive full-coverage CAD/CAM crowns. The specimens were scanned, planed, and then designed using the CEREC system. The crowns were fabricated from CERASMART CAD/CAM blocks and IPS e.max CAD blocks using a CEREC milling machine. The specimens were randomly distributed into two groups. The crowns of both groups were cemented using RelyX Ultimate resin cement. All crowns were subjected to 10,000 thermocycles and then immersed in silver nitrate followed by using a photo-developer. Specimens were segmented buccolingually and the microleakage was measured at 1.0 magnification using a stereomicroscope. The percentage on the microleakage scale was calculated based on the buccal and lingual surfaces, and this percentage was used in the statistical analysis. For the

ordinal microleakage scale, results of the buccal and lingual surfaces were kept separate, and both were included in the statistical analysis.

Results

For the continuous percentage data, the CERASMART group showed lower median microleakage at 5.9% (IQR=20.7) than the e.max group, which showed a median microleakage of 7.4% (IQR=13.9). No statistically significant difference between the groups was found ($p = 0.806$). For the ordinal data, there was no statistically significant difference between the groups ($p = 0.605$).

Conclusion

Within the limitations of this study, no proven evidence showed a systematic difference when comparing the microleakage of lithium disilicate crowns and nano ceramic crowns.

Dedication

To my parents, Abdulillah and Wedad, for your endless encouragement, support, and valuable advice. My dream would not come true without your inspiration. To my wife, Fatimah, for all your support, sacrifices, and being patient since the first day I started my journey. My life is much more exciting with you. To my son, Eyad, for the thrilling moments we always have together. To my siblings, Shoroque, Hassan, Maytham, and Ala, for your help and care. To all of my family members and friends, thank you for your support.

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CAD/CAM: Computer-aided design and computer-aided manufacturing.

ºC: Celsius.

GEE: Generalized estimating equations.

IQR: Interquartile range.

mm: Millimeter.

N: Newton.

SD: Standard deviation.

µm: Micrometer.

wt%: Weight percent.

Microleakage of Lithium Disilicate Ceramic Crowns and Nano Ceramic Crowns: A Comparative Study

Introduction

In 1965, McLean first presented the metal-free, all-ceramic crown restorations. With the expansion of esthetic requests and demand, the artistic all-ceramic crown acted as a substitute to porcelain fused to metal (PFM) crowns because they permitted light transmission through the underlying tooth structure and the prosthesis. [1-3]

The traditional way of producing the conventional crowns is technique sensitive and requires many steps that take time. Moreover, it requires the restorative process to take place in multiple visits, increasing chair time and possible complications. [4] The availability of computer-aided design/computer-aided manufacturing (CAD/CAM) systems permitted dental practitioners to create crowns in an independent visit, dispensing with the requirement for making temporary crowns that might prompt postoperative complications and diminishing treatment time. [4-6]

One of the most critical factors of crown restorations, which influences their clinical success, is crown adaptation. [7,8] Potential problems such as microleakage, recurrent caries, and periodontal disease are associated with the increase of the marginal gap. [9,10] Holmes et al. reported that the marginal gap is considered to be the perpendicular value from the preparation finish line to the intaglio surface of the prosthesis. [11]

Lithium disilicate glass ceramics, IPS e.Max CAD (Ivoclar Vivadent AG, Liechtenstein) is a robust dental material that can be utilized to produce all-ceramic crowns using CAD/CAM systems. [12] Like other all-crowns that are produced by various strategies, the elements deciding the achievement of such crowns incorporate satisfactory cementation, precise fit, sensible esthetics, and mechanical properties. [13] Developments in science permitted makers to deliver materials that could save the needed esthetic characteristics of porcelain while possibly disposing of a percentage of the undesirable elements. [14] Industrial assembling enhances the mechanical properties when contrasted with direct composite resin restorations by permitting the utilization of post-curing methods. [15] CERASMART CAD/CAM block (GC, Tokyo, Japan) is a hybrid ceramic that is thought to be another option when planning for all-ceramic crowns as it might demonstrate fewer crack spreads under exhaustion strengths than several CAD/CAM blocks. [16]

It was reported by Hill et al. that the utilization of resin adhesive cement is prescribed for metal-free crowns because of its capacity to adhere to both silica-based ceramics and tooth structure, [17] although its inclination to ingest water and experience hydrolytic degradation can antagonistically influence both microleakage and fracture quality of ceramic prosthesis. [18] Moreover, a moderately heavy layer of luting cement can build the measure of water absorption [19] and exacerbate the impact on the ceramic prosthesis. [20]

The purpose of this study was to assess the microleakage of restorations made of IPS e.Max CAD blocks on extracted intact third molars subsequent to thermocycling testing that reproduces a clinical administration of one year and contrast this with the CERASMART CAD/CAM crowns experiencing the same situations.

Literature Review

Marginal and internal adaptation of dental restoration

There is no general agreement as to what represents a biologically tolerable marginal gap. Previous studies have reported the clinically tolerable measurements for this gap ranging from 39 µm to 120 µm. [21,22] For cemented crown prosthesis, Boening et al. described the clinically satisfactory marginal inconsistency range from 25 to 40 µm. [23] Numerous projects have been directed at assessing the marginal gaps of non-CAD/CAM prosthesis. These gaps were from 0 µm to 313 µm with a mean gap of 155 µm. [24,25] The marginal gap of under 120 µm was reported by McLean and von Fraunhofer et al. to be clinically satisfactory for the traditionally cemented crowns [26], which was much more prominent than the recommended and conceivably doubtful minimal gap of 25 µm to 40 µm for cemented crowns. Different reports in concurrence with these authors have additionally proposed satisfactory clinical life span with negligible gaps of 100 µm to 200 µm.[27]

CAD/CAM systems have been shown to permit the construction of better-fitting implant frameworks and crowns than those made with the customary lost-wax methods.[5] Reports and findings are in agreement that the adaptation of the CAD/CAM prosthesis counterparts that of conventionally produced ones.[27] In-vitro studies regarding CAD/CAM-fabricated, all-ceramic crowns revealed marginal gaps ranging from 64 µm to 83 µm.[28] For the Procera CAD/CAM system, the internal gap was reported to range from 49 µm to 63 µm, compared with 123 µm to 154 µm for the conventional all-ceramic crowns.[28]

CAD/CAM lithium disilicate posterior crowns are reported by Reich et al.[29] to have an axio-occlusal internal gap that ranges from 173 µm to 273 µm, and occlusal internal gap that ranges from 229 µm to 319 µm. Souza et al. reported that the clinically tolerable internal gap value might extend up to 300 µm,[9] although the best resin cement performance was reported when values ranged from 50 µm to 100 µm.[30] To minimize stresses inside the all-ceramic prosthesis, 90-µm values were reported.[31]

Microleakage and Its Relationship to the Marginal Gap

Microleakage of composite restoration is one of the clinical issues that were reported previously.[25] Microleakage is characterized by the passage of microbes, ions, fluids, or particles between a cavity wall and the therapeutic material connected to it.[4] Marginal adaptation is a standout among the most imperative criteria assessed clinically for fixed restorations as it influences the life span of any prosthesis.[4] To reduce the risk for periodontal problems, mechanical breakdown, and recurrent decay, a good-adapted restoration is required.[32]

Holmes et al. defined the internal gap to be the dimension between the intaglio surface of the restoration and the axial wall of the prepared tooth whilst the same estimation at the margin is called "marginal gap."[11] A poorly fitted prosthesis is possibly destructive for supporting periodontium and abutment teeth by allowing entrance to oral microbes adherence, which might prompt caries and/or gingival irritation. Endodontic inflammation could occur due to microleakage through the dentinal tubules. Furthermore, the prosthesis itself can be influenced by the ill margin that might diminish the long-term success and the quality of the prosthesis due to the creation of stress concentration areas.[33]

A few efforts have been made to diminish and/or eliminate microleakage, despite the fact that Larson et al. reported that it is difficult to dispose of microleakage totally. [34] Some of these endeavors concentrated on dental materials and enhancing the adaptation of the indirect prosthesis. [34] One study revealed that low shear bond strength adhesives displayed higher microleakage and lower dentin wetting values than other ones [35] and and having adhesive shear bond strength of 21 MPa might reveal the lowest potential microleakage values. [36]

Microleakage Test

Numerous methods and techniques have been utilized to investigate microleakage, including impression replica technique, cross-sectional view, direct view, air pressure, fluid filtration, electrochemical and radioisotope methods, with dye penetration technique being the most popular method. [37] This method gains its popularity because of its feasibility and simplicity. [37]

In-vitro simulation of oral environment

To simulate oral environment conditions, several in-vitro methods were developed. [38] Two of these methods are mechanical loading and thermocycling. Thermocycling mirrors the temperature variance occurring in the oral cavity. [38] It was reported by Gale et al. that if one year of clinical service is the aim, then 10,000 cycles are required. [39] Mechanical loading simulates food chewing. [38]

The literature has reported different numbers of cycles. To estimate 15 months of clinical function, Kohorst et al. used 1,000,000 cycles and reported that an individual masticates 800,000 cycles a year.[40] Another study by Kassem et al.[41] proposed that 1,000,000 cycles are comparable to 60 to 120 months of service. Seydler et al.[42] compared the fracture strength of IPS e.Max restorations that have dissimilar wall thickness by combining 10,000 thermocycles with 1,200,000 mechanical loading cycles, keeping in mind the end goal to reproduce five years of clinical function.

Although several studies have used distinctive aging procedures, number of cycles, and magnitude of force for mechanical loading,[43] the purpose behind picking such numbers is not given and is by all accounts subjective.[38] That is the reason it is hard to contrast the after-effects of various studies.[38]

Resin Adhesive Cements

Dental resin restorative materials are made of three core constituents: inorganic fillers, organic resin matrix and a coupling agent that binds the first two components.[44] Taking into account their mode of polymerization, they can be categorized into dual-cured, chemical-cured, and light-cured. Moreover, based on their adhesive scheme, they can be grouped into self-adhesive, self-etch, and total-etch.[45] The cement that etches both dentine and enamel using 30%-40% phosphoric acid to open dentinal tubules by eliminating the smear layer is the total-etch resin cement.[45,46] The cement that needs a primer on the abutment tooth before using it is the self-etch cement,[45] while the self-adhesive resin cement is the one that is capable to create adhesion deprived of an etchant or a separate adhesive.[46]

To cement an all-ceramic prosthesis, adhesive resin cement is preferred for the increased ceramic retention and for its superior mechanical characteristics.[47,48] Also, resin cement can produce a solid connection between a ceramic restoration and tooth structure as it bonds directly to ceramic, enamel and dentin[44] This type of bonding leads to the fortification of the tooth and ceramic restoration.[49]

Examples of Self-Adhesive Resin Cements

RelyX™ Unicem Self-Adhesive Universal Resin Cement (3M ESPE, St. Paul, MN)

RelyX Unicem was the first self-adhesive resin cement in the business sector. It combines the simplicity of use with the adhesive properties of adhesive cements.[50] Several investigations have shown that this cement interacts only superficially with the tooth structure due to its limited demineralization capacity. Behr et al. reported that RelyX Unicem showed equivalent or lower values of bond strength in bonding to dentin or enamel when competed to conventional luting systems.[51] Capa et al. reported that when compared to glass ionomer cement, RelyX Unicem revealed superior strength in bonding to restorative materials.[52]

RelyX™ Ultimate Adhesive Resin Cement (3M ESPE, St. Paul, MN)

RelyX™ Ultimate is a dual-cure cement used with indirect glass ceramic prosthesis as a self-etch resin or total-etch cement and is offered in multiple shades.[53] Scotchbond™ universal adhesive, the first adhesive available on the market,[54] is usually used in combination with RelyX™ Ultimate.[53] Scotchbond™ can bond to roughened metal and zirconia because it encloses a phosphate monomer.[54] It also encloses silane, which explains its ability to bond to ceramics.[54]

Fabricating All-Ceramic Crown Restorations

Nowadays, different systems are utilized to fabricate metal-free prosthesis: powder condensation, pressing, slip casting, and CAD/CAM milling of ceramics.[55]

Powder Condensation

Powder condensation is considered to be the gold standard method of fabricating all-ceramic crowns.[56] Moist porcelain powder is applied to build up the crown and then additional humidity is eliminated to condense the powder particles. Then the porcelain is fired under a vacuum; however, a large amount of residual porosity is found. Although all-ceramic crowns fabricated by this method have low strength, they are more esthetic than crowns made by the other techniques because of their greater translucency. [28,56]

Heat Press Technique

The lost wax technique is used to produce all-ceramic crowns by the heat press technique. It consists of heating pressable ceramics ingots to a high temperature, at which they turn out to be extremely viscous liquid and then are pressed gradually into the formed lost wax mold. All-ceramic crowns fabricated by this technique have reduced porosity and good accuracy of fit. [56]All pressable ceramic materials are offered in the form of ingots. The first generation of the heat-pressed ceramics was composed of 35-45% leucite by volume as crystalline phase while the second generation comprised approximately 65% lithium disilicate by volume as the main crystalline phase. [28]

Slip Cast Technique

A slurry of ceramic powder particles suspended in fluid is called a slip. Forming a negative replica and then introducing the slip into the replica accomplishes this technique, which produces ceramic that is porous and weak. [28,56] The use of this technique is limited because it requires complicated steps to accomplish precise adaptation and may end up with internal flaws that deteriorate the material. [57,58]

Computer-Aided Design/Computer-Aided Manufacturing Systems

Computer-Aided Design and Computer-Aided Manufacturing (CAD/CAM) systems computerized the construction procedure of dental prostheses. [59] They comprise mainly a milling machine, information acquisitions unit, and planning software. [59]

The prepared tooth along with surrounding tissues are caught and converted by an optical scanner into digital information. [59] The prepared tooth design can be directly obtained intra-orally by a chair-side optical scanner or indirectly by scanning the impression or the cast by a laboratory scanner. [59] Then the information is transmitted to the planning software to be prepared and introduced as a 3D picture of the anticipated restoration. [59] Finally, the prosthesis is created by using a milling machine. [59]

CAD/CAM systems can be categorized into three types based on their location [59]: centralized CAD/CAM, laboratory CAD/CAM, and chairside CAD/CAM. When the dental practitioner scans the patient's prepared tooth, plans and designs and then mills the prosthesis in the dental clinic, it is named a chairside CAD/CAM system. [59] When these steps take place in a dental lab after receiving a cast or a routine impression from the dentist, it is called the laboratory CAD/CAM system, and for the centralized CAD/CAM system, data are gathered and handled either in the lab or in the dental office and then the data are sent to a milling center. [59]

The U.S. market has four intraoral scanner systems: Lava C.O.S. System (3M ESPE, MN), CEREC Bluecam System (Sirona Dental System, NY), E4D System (D4D Technologies, Richardson, TX), and iTero System (Align Technology, CA). Beuer et al. reported a 90% success rate for all-ceramic inlays fabricated by CAD/CAM technology after 10 years and 85% after 12. [59] Roggendorf et al. reported an 86.9% survival rate for bonded CAD/CAM prosthesis after seven years. [60]

Classification of Dental Ceramics

Kelly et al. divided dental ceramics into polycrystalline ceramics, particle-filled glasses and predominantly glassy materials. [61]

Polycrystalline Ceramics

This type of ceramics does not have any glass components. It is difficult to make a crack through polycrystalline ceramics as all of the atoms are tightly packed. Therefore, one advantage of polycrystalline ceramics is that it is much stronger than glassy ceramics. [61]

Particle-Filled Glasses

To regulate optical properties such as opacity, color, and opalescence and to improve mechanical properties, crystalline filler particles are added to the structure. Leucite is the first filler to be used in dental ceramics and was added to produce porcelains that could be safely fired onto metal substructures.[63]

Predominantly Glassy Ceramics

The best dental ceramics simulate the optical characteristics of dentine and enamel. [61] Feldspar is a type of mineral from which glasses in dental ceramics are derived. [61] This provides glasses with stability against crystallization and a wide range of firing. [61]

Current Ceramic Materials

Glass Ceramics

Lithium-disilicate glass ceramic, *IPS Empress 2* (Ivoclar Vivadent AG, Liechtenstein) is produced by the lost-wax technique followed with a heat-pressing procedure. [62] Leucite-reinforced glass ceramics, *IPS Empress,* (Ivoclar Vivadent AG, Liechtenstein) is used to fabricate single unit anterior restorations due to its limited strength. The flexural strength of the IPS Empress 2 has improved by three times compared to the IPS Empress. [63]

Nakamura et al. and Holand et al. both reported that it can be used for anterior 3-unit fixed partial dentures. [63,64]

Compared to IPS Empress 2, *IPS e.max Press,* which is also a lithium-disilicate (Ivoclar Vivadent AG, Liechtenstein), is an enhanced ceramic material that has improved translucency and physical properties. [65] Leucite-reinforced ceramic, *IPS ProCAD* (Ivoclar Vivadent AG, Liechtenstein), is comparable to IPS Empress, although particle sizes are different. *Vita TriLuxe Bloc* is a multicolored block (VITA Zahnfabrik, Bad Säckingen, Germany) intended to simulate natural teeth optical properties and to pass the esthetic limitations of conventional ceramic blocks.[66]

Zirconia-Based Ceramics

This polymorphic material melts at 2680°C. When this takes place, the cubic structure converts into the tetragonal phase.[67,68] The tetragonal-to-monoclinic phase conversion takes place at below 1170°C and is accompanied by a 3%-5% volume expansion that causes great interior strains. To stabilize pure zirconia and to control the volume expansion, Yttrium oxide is added.[66]

Alumina-Based Ceramics

The first metal-free system available for single-unit prosthesis and 3-unit anterior fixed partial dentures was *In-Ceram Alumina* (VITA Zahnfabrik, Bad Säckingen, Germany).[66] Feldspathic porcelain is used to veneer the *In-Ceram Alumina* coping.[69] Since In-Ceram Alumina is an opaque material, *In-Ceram Spinell* (VITA Zahnfabrik, Bad Säckingen, Germany) was invented to manage the esthetic limitations of In-Ceram Alumina. Alumina and magnesia were added to In-Ceram Spinell to achieve better translucency; however, In-Ceram Alumina is superior in terms of flexural-strength.[66] Procera ceramic blocks

(Nobel Biocare AB) were created with 99.9% pure aluminum oxide.[66] Procera has the greatest strength among the materials that are based on alumina and its strength is inferior just to zirconia.[66]

CAD/CAM Glass Ceramics

Dental ceramic is mainly based on silicon, Si, and usually in the form of silicon dioxide, SiO_2, or various silicates.[70] Ceramic restorations can be produced by either CAD/CAM or traditional laboratory methods.[71,72] Time-consumption, technique sensitivity and unpredictability are some disadvantages of the conventional methods [71] while CAD/CAM can reduce the production time of strong ceramics such as InCeram™ by up to 90%.[66]

CAD/CAM with Leucite-Reinforced Ceramics

This is a leucite-reinforced ceramic, which means that it is similar in structure to the Empress™ (Ivoclar-Vivadent). Denissen et al reported a 100% survival rate after 24 months.[73] Empress™ CAD (Ivoclar-Vivadent) was introduced in 2006 and contains 45% leucite with flexural strength of about 160 MPa.[66] Single tooth restorations can be fabricated by Empress™ CAD and is offered as polychromatic (Empress™ CAD Multi) blocks, low translucency (Empress™ CAD LT) and high-translucency (Empress™ CAD HT). After milling, the restoration can be stained and glazed.[66]

CAD/CAM-Compatible Feldspathic Ceramics

In 1985, a feldspathic ceramic block was utilized to fabricate the first CAD/CAM inlay.[66] The success rate of these CAD/CAM inlays was evaluated and found to be 90.4%.[66] On the other hand, a much higher breakage rate of up to 36% after two years was reported by Christensen et al.[74]

In 1991, Vita[tm] Mark II (Vita Zahnfabrik, Bad Sackingen, Germany) announced and revealed improved mechanical characteristics with flexural strength from 100 MPa to 160 MPa after being glazed.[66] Vita[tm] Mark II blocks' composition is like the feldspathic ceramic yet is fabricated in an alternate procedure.[66] Vita[tm] Mark II is monochromatic and, in any case, is accessible in different shades. The more up-to-date Vitablocs[TM] have many shade layers and exhibit an incline of translucency and shading.[66]

CAD/CAM and Glass Infiltrated Alumina and Zirconia Ceramics

The Vita[tm] InCeram group of ceramics consists of glass-infiltrated ceramics. The flexural strength for InCeram[tm] Alumina, Spinell, and Zirconia were 450–600 MPa, 350 MPa, and 700 MPa, respectively, according to Giordano et al.[75] The five-year survival rate of CAD/CAM IInCeram[tm] Spinell has been reported to range from 91.7% to 100%, while it was 92% for CAD/CAM InCeram[tm] Alumina.[66] Ho GW et al. reported that acid etchants have no advantageous effects on aluminum trioxide and glass ionomer cement has been suggested for luting;[76] however, air abrasion with 50 um aluminum trioxide[77,78] and a silane coupling agent[78] have been suggested as effective.[79,80] The bonding of InCeram[tm] Zirconia could be significantly increased if the surface is to be treated with tribochemical silica coating and a silane coupling agent.[66]

CAD/CAM Milling Lithium Disilicate Reinforced Ceramics

Lithium disilicate, Li2SiO5, ceramic has flexural strength ranging from 350 MPa to 450 MPa.[66] The chair-side monolithic restorative material, e.max CAD (Ivoclar-Vivadent), was introduced in 2006 and is available in different shades as well as translucencies and is supplied in a pre-crystallized blue state.[66] After being milled, the restoration is re-crystallized in a chair-side ceramic oven at 850 C. During this heat treatment, the metasilicates are dissolved, lithium disilicate crystallizes, and the ceramic is glazed at the same time.[66] The block also changes from blue to the chosen shade and translucency. The survival rate of single crowns after two years was shown to be between 97.4% and 100%.[81,82]

Aim of the Study

The aim of this study was to evaluate and compare microleakage of CAD/CAM crowns made out of nano ceramics (CERASMART, GC, Tokyo, Japan) and lithium disilicate ceramics (IPS e.max, Ivoclar Vivadent AG, Liechtenstein) on extracted teeth after thermocycling testing.

Variables Tested

1- Percentage of Microleakage

2- Microleakage on an ordinal scale from 0-3 in which:

   0 = no evidence of microleakage.

   1 = evidence of microleakage at the margin only.

   2= evidence of microleakage approaching the axial wall.

   3= evidence of microleakage at the occlusal surface.

Hypothesis

It was hypothesized that lithium disilicate crowns would have lower microleakage values when compared to nano ceramic ones.

Clinical Significance

Results of this study might help dental practitioners differentiate the performance of the existing IPS e.Max restorative material and the relatively new material, CERASMART, which could affect their decision on which material would be more appropriate to use.

Research Design

Power Calculation:

The software nQuery Advisor (version 7.0) was used for the power calculation. With the assumption of a mean (SD) percent microleakage of 1.11 (0.19) for IPS e.Max and 2.80 (0.18) for Nano Ceramics, [83] a sample size of n=15 per group was satisfactory to obtain a Type I error rate of 5% and a power greater than 99%.

Inclusion Criteria

- Freshly extracted sound human third molars.

Exclusion Criteria

- Defected teeth (caries, abrasion, erosion, cracks).
- Endodontically treated teeth.

Materials and Methods

Thirty recently extracted non-defective human third molar teeth were used for this study. Tufts University School of Dental Medicine's Department of Oral and Maxillofacial Surgery provided these teeth. The teeth were accumulated in a deidentified manner. Then the teeth were put in a container with an aqueous solution of 0.5% sodium hypochlorite (Bleach, Olinchloralkali, Cleveland, Tennessee). The teeth that were chosen for this study did not have any developmental defects, cracks, restorations, or caries. Stains and surface debris, if any, were removed from teeth surfaces using an ultrasonic scaler (Cavetron SPS, Dentsply, York, PA) and subsequently kept in faucet water to prevent teeth dehydration at room temperature within the timeline of the study.

To achieve adequate retention, notches were made on the roots of all of the teeth and then they were fixed vertically with the cemento-enamel junction at 1.0 mm higher that the top of a mounting template (Figure 1.A and 1.B). Orthodontics acrylic resin (Caulk, DENTSPLY, York, PA) was used to fill the mounting templates (Ultradent Product Co., South Jordan, UT) to lock the extracted teeth. The occlusal surface of each sample after mounting was cut flat using a cutting saw (11-4254-blade, Isomet; Buhler Ltd, Evanston, IL) and kept 5.0 mm atop the upper surface of the acrylic resin. A high-speed hand piece (Midwest Dentsply, Des Plaines, IL) was connected to a surveyor (Degussa F1;

DeguDent, Hanau, Germany) so that a rotary bur (450K Max; Brasseler, Savannah, GA) was arranged at a three-degree point from the vertical axis of the tooth to have a total convergence angle of 12 degrees (Figure 2). Parker reported that an ultimate total convergence angle is not steady and that angle ranges from three to 24 degrees.[84]

A custom jig (Figures 3.A and 3.B) was used to secure the mounted teeth vertically and held immovably in the surveyor base. Lab putty polysiloxane (Coltene/Whaledent, Switzerland) was used to fabricate the jig. The surveyor base was changed to be parallel to the floor. Axial cutting was accomplished by turning the mounted sample against the turning bur (Figure 4). The diamond bur made a shoulder finish line design for an ideal preparation to be interpreted by the CEREC CAD/CAM machine.[85]

The axial length was cut to 4.0 mm. Then, the axial surfaces were reduced 1.5 mm in depth followed by 1 mm reduction, at least, proximally by utilizing copious water irrigation. This preparation design was made according to the manufacturer's recommendations.[85] A fresh diamond bur was used for each sample preparation. At that point, the coarse diamond bur was switched to a fine diamond bur (KD7W6 Brasseler, Savannah, GA) fitted in the hand piece to smooth the surface of the sample. When completing teeth preparation, the specimens were allocated randomly into two groups (group 1 and group 2), after having done block randomization on tooth size, by utilizing the statistical software package R (version 3.1.2); see Figure 5.

The teeth were scanned using the CAD/CAM machine (CEREC, Bluecam, Bensheim, Germany) (Figure 6). To accomplish a high-determination picture, the scanner used optical imaging of the tooth from various headings (Figure 7). The crown was intended to have a wall thickness of 2.0 mm in the contact area, 1.0 mm at the apical area, and 1.5 mm in alternate regions. All crowns were designed to have a cement thickness of 60 µm beginning 1.0 mm beyond the margin. At that point, the crowns were milled out (Figure 8) from lithium disilicate block (IPS e.Max CAD, Ivoclar Vivadent AG, Liechtenstein) and nano ceramic blocks (CERASMART, GC, Tokyo, Japan) using the CEREC milling machine (Bluecam, Bensheim, Germany) (Figure 9). Every specimen was assigned a number after the milling was completed.

A prophy brush having a flour of pumice and water was used to clean the samples. After that, samples were washed and left physiologically damp. Every crown was put on the related sample and one administrator closely assessed marginal fit visually and by using an explorer (Figure 10). A few changes were made to the intaglio surfaces of the crowns when needed to enhance the seating of the crown on the prepared teeth. This was achieved by delicately grinding the inner surface of the crown with a small round rotary cutting bur (6801;

Brasseler, Savannah, GA). At that point, the internal surfaces of all crowns were acid etched with 9.6% hydrofluoric acid (The Micro Dose, Premier, Plymouth Meeting, PA) for 20 seconds (Figure 11), cleaned and dried with a three-way syringe. A silane coupling agent (The Micro Dose, Premier, Plymouth Meeting, PA) was then applied for one minute (Figure 12) and then dried. After that, the enamel margins of all prepared teeth were treated with 37% phosphoric acid (Scotchbond, 3M ESPE, St. Paul, MN) (Figure 13) for 15 seconds and then cleaned with air and water. Then, the base and catalyst of RelyX Ultimate (3M ESPE, St. Paul, MN) (Figure 14) resin cement was blended according to the manufacturer's guidelines. Every crown's intaglio surface was painted with the resin cement and at first positioned with solid finger pressure. The combined teeth and crowns were then set in a loading machine (Instron, Model 5566; Canton, Mass) (Figure 15) and each one was exposed to a seating power of 50 N for every specimen for the predefined setting time of five minutes to take into account room temperature polymerization.

The margins were cleaned of any excess cement and then the samples were kept in faucet water for seven days at 37ºC before thermocycling testing. Following this accommodation stage, the samples were thermally cycled between water temperatures of 5ºC and 55ºC for 10,000 cycles with a 15-

second settle time at every temperature. After that, all crowns were submerged into a 50% wt silver nitrate solution (Salt Lake Metals, Salt Lake, UT) for one day (Figure 16), followed by a photo-developing solution (Carestream Dental, Atlanta, GA) for eight hours (Figure 17). Samples were rinsed for a minute under running water after which they were surrounded by orthodontics acrylic resin (Caulk, DENTSPLY, York, PA). Specimens were segmented buccolingually (Figure 18) utilizing a 0.5 mm thickness and an eight-inch diameter wheel (Isomet 1000, Buehler, IL, USA) (Figure 19). A stereomicroscope (SZX16, Olympus, Pennsylvania) with 10 magnifications was used to evaluate the specimens (Figure 20), and they were scored by the average percentage of color infiltration along the dentinal walls of each sample (Figure 21). One administrator did all the steps at the Gavel Research Center at Tufts University School of Dental Medicine.

Statistical Analyses

The percentage on the microleakage scale was calculated based on the buccal and lingual surfaces, and this percentage was used in the statistical analysis. For the ordinal microleakage scale, results of the buccal and lingual surfaces were kept separate, and both were included in the statistical analysis. Descriptive statistics (counts and percentages for categorical variables, medians and inter-quartile ranges for continuous variables) were computed. For the percentage microleakage scale, statistical significance between groups was assessed by the Mann-Whitney U test since the data were not normally distributed. For the ordinal microleakage scale, statistical significance between groups was assessed by generalized estimating equations (GEE). SPSS version 22 and SAS 9.4 were used in the analysis and p-values of less than 0.05 were considered statistically significant.

Results

For the continuous (percentage) data, results for both lithium disilicate and nano ceramic were not normally distributed. The nano ceramic group showed lower median microleakage at 5.9% (IQR=20.7) than the lithium disilicate group, which showed a median microleakage of 7.4% (IQR=13.9). (Figure 22) The Mann-Whitney U test revealed no statistically significant difference between the groups ($p = 0.806$). For the ordinal data, Figure 23 shows the frequency distribution for each group. Both groups showed a similar percentage of 0 values, the lithium disilicate group showed a higher percentage of 1 values, while the nano ceramic group showed a higher percentage of 2 values. The GEE analysis revealed no statistically significant difference between the groups ($p = 0.605$).

Discussion

Different authors have used a number of methods to evaluate marginal fit and marginal microleakage of fixed dental restorations. One of these methods requires the restoration being directly viewed and evaluated on a die.[86] Another one, which is a commonly used method, is the dye penetration method combined with cross-sectional cuts of the cemented restoration. This allows the sliced sections to be viewed and evaluated under the microscope.[87] Other methods include chemical tracers, radioactive tracers, impression replicas, air pressure, bacteria, artificial caries, electrical conductivity, neutron activation analysis, and clinical exams.[86,88]

In this study, dye penetration was accomplished by immersing the samples in a 50% wt silver nitrate (AgNO3) solution for one day followed by eight hours in a photo-developing solution.[89] Other studies used different solutions for this purpose. Kassem et al.[90] utilized 0.5% red fuchsin aqueous solution dye for one day, Ghazy et al.[91] utilized 2.0% red fuchsin aqueous solution dye for one day while El-Damanhoury et al.[83] used a 5% methylene-blue dye solution for one day.

This study has evaluated the microleakage of lithium disilicate and nano ceramic restorative materials that were cemented with RelyX Ultimate resin cement in teeth that were prepared to receive CAD/CAM-generated full-coverage crowns. Although Reich et al. [29] reported that the values of cement's film thickness in crowns produced by the milling machines is higher than crowns that were fabricated with other techniques, this study was not aimed at comparing the microleakage of crowns fabricated by different techniques. Moreover, the cement's film thickness and the selection of resin cement might be other variables influencing the degree of microleakage. This study was not aimed to compare the performance of different resin cements and their effects on marginal microleakage. Trajtenberg et al. [92] reported that there was statistically significant difference among RelyX Unicem, Panavia F 2.0, and Multilink resin cements in terms of marginal microleakage of all-ceramic crowns.

The reasons for choosing IPS e.max, CERASMART, and RelyX Ultimate materials in this study were 1) IPS e.max is a popular all-ceramic restorative material widely used by dental practitioners nowadays; 2) CERASMART is a new nano-ceramic restorative material that was introduced to the market with no known literature discussing its microleakage; 3) the tooth preparation is relatively easy when full-coverage CAD/CAM restoration is planned, thus practitioner inconsistency is somewhat reduced; 4) CAD/CAM CEREC machines are popular among dental practitioners; and 5) RelyX Ultimate adhesive resin cement is a common cement due its ease of use and handling.

The use of self-etch cements on enamel margins is still controversial.[93] Hara et. al[94] compared the enamel shear bond strength of a self-etch adhesive system, a one-bottle adhesive system, and a multiple-bottle adhesive system. The enamel shear bond strength of the self-adhesive system was inferior to the one-bottle adhesive and the multiple-bottle adhesive systems. However, Hannig et al.[95] compared the enamel shear bond strength of self-adhesive systems and multiple-bottle adhesive systems; they reported no statistically significant differences among the tested groups. In our study, RelyX Ultimate Adhesive Resin Cement with a selective-etch approach was used, as it is one of the recommendations by the manufacturer.[96]

This study hypothesized that lithium disilicate crowns would exhibit less microleakage than nano-ceramic ones; however, no statistically significant differences between the groups were observed. For the percentage data, the nano ceramic group showed a lower median microleakage, 5.9%, than the lithium disilicate group, 7.4%. For the ordinal data, eight samples out of 30 (26.7%) exhibited a score of 0, 14 samples (46.7%) exhibited a score of 1, and eight samples (26.7%) exhibited a score of 2 among the lithium disilicate group, while for the nano-ceramic group, nine samples (30.0%) exhibited a score of 0, eight samples (26.7%) exhibited a score of 1, and 13 samples (43.3%) exhibited a score of 2.

The results of our study are in agreement with Ghazy et al. , Kassem et al. , and Kandil , but not with El-Damanhoury et al.. Both Ghazy et al. [91] and Kassem et al. [90] reported no statistically significant differences in microleakage scores between Vita Mark-II crowns and Paradigm MZ-100 crowns. Kassem did both thermocycling and chewing load testing for the subjects, while Ghazy did only thermocycling testing. Kandil [97] reported no statistically significant difference in microleakage scores between Lava Ultimate composite crowns and IPS e.max CAD ceramic crowns. The difference between his and our study is that not only thermocycling testing was done but chewing load testing was also done, which we did not do. El-Damanhoury et al. [83] reported a statistically significant difference in microleakage values among Lava Ultimate crowns, e.max CAD crowns, and CEREC blocks crowns. The authors utilized both thermocycling and a compressive load testing in this study.

This study is an in-vitro one. Definitive conclusions should be made after conducting an in-vivo study as there are many variables, such as the presence of enzymes and saliva and pH changes intra-orally that might affect the score of microleakage. So the nature of the study is considered as one of its limitations. Another limitation is the use of natural extracted teeth. Natural teeth, especially third molars, vary in shapes and sizes, thus affecting their standardization. This explains why block randomization was used to randomly assign the samples into the groups (Figure 24). One more limitation to this study is the lack of a chewing load testing. Intra-orally, the teeth are subjected to occlusal and lateral forces that could be simulated by the chewing load testing. The resin cement used in this study would also be a limitation as different resin cements have dissimilar chemical and mechanical properties that might affect the score of microleakage.

Conclusion

Within the limitations of this study, there was no proven evidence of a statistical difference when comparing microleakage of lithium disilicate and nano-ceramic materials.

References

1. Douglas RD, Przybylska M. Predicting porcelain thickness required for dental shade matches. *J Prosthet Dent*. 1999;82(2):143-149.

2. Holloway JA, Miller RB. The effect of core translucency on the aesthetics of all-ceramic restorations. *Pract Periodontics Aesthet Dent*. 1997;9(5):567-74; quiz 576.

3. Deany IL. Recent advances in ceramics for dentistry. *Crit Rev Oral Biol Med*. 1996;7(2):134-143.

4. Ghazy M, El-Mowafy O, Roperto R. Microleakage of porcelain and composite machined crowns cemented with self-adhesive or conventional resin cement. *J Prosthodont*. 2010;19(7):523-530.

5. Tsitrou EA, Northeast SE, van Noort R. Evaluation of the marginal fit of three margin designs of resin composite crowns using CAD/CAM. *J Dent*. 2007;35(1):68-73.

6. Fasbinder DJ. Clinical performance of chairside CAD/CAM restorations. *J Am Dent Assoc*. 2006;137 Suppl:22S-31S.

7. Oden A, Andersson M, Krystek-Ondracek I, Magnusson D. Five-year clinical evaluation of procera AllCeram crowns. *J Prosthet Dent*. 1998;80(4):450-456.

8. Pelekanos S, Koumanou M, Koutayas SO, Zinelis S, Eliades G. Micro-CT evaluation of the marginal fit of different in-ceram alumina copings. *Eur J Esthet Dent*. 2009;4(3):278-292.

9. Souza RO, Ozcan M, Pavanelli CA, et al. Marginal and internal discrepancies related to margin design of ceramic crowns fabricated by a CAD/CAM system. *J Prosthodont*. 2012;21(2):94-100.

10. Nakamura T, Dei N, Kojima T, Wakabayashi K. Marginal and internal fit of cerec 3 CAD/CAM all-ceramic crowns. *Int J Prosthodont*. 2003;16(3):244-248.

11. Holmes JR, Bayne SC, Holland GA, Sulik WD. Considerations in measurement of marginal fit. *J Prosthet Dent*. 1989;62(4):405-408.

12. Beuer F, Schweiger J, Edelhoff D. Digital dentistry: An overview of recent developments for CAD/CAM generated restorations. *Br Dent J*. 2008;204(9):505-511.

13. Schaefer O, Watts DC, Sigusch BW, Kuepper H, Guentsch A. Marginal and internal fit of pressed lithium disilicate partial crowns in vitro: A three-dimensional analysis of accuracy and reproducibility. *Dent Mater*. 2012;28(3):320-326.

14. Andriani W,Jr, Suzuki M, Bonfante EA, Carvalho RM, Silva NR, Coelho PG. Mechanical testing of indirect composite materials directly applied on implant abutments. *J Adhes Dent*. 2010;12(4):311-317.

15. Magne P, Boff LL, Oderich E, Cardoso AC. Computer-aided-design/computer-assisted-manufactured adhesive restoration of molars with a compromised cusp: Effect of fiber-reinforced immediate dentin sealing and cusp overlap on fatigue strength. *J Esthet Restor Dent*. 2012;24(2):135-146.

16. Chen C, Trindade FZ, de Jager N, Kleverlaan CJ, Feilzer AJ. The fracture resistance of a CAD/CAM resin nano ceramic (RNC) and a CAD ceramic at different thicknesses. *Dent Mater*. 2014;30(9):954-962.

17. Hill EE. Dental cements for definitive luting: A review and practical clinical considerations. *Dent Clin North Am*. 2007;51(3):643-58, vi.

18. Lu C, Wang R, Mao S, Arola D, Zhang D. Reduction of load-bearing capacity of all-ceramic crowns due to cement aging. *J Mech Behav Biomed Mater*. 2013;17:56-65.

19. Ortengren U, Elgh U, Spasenoska V, Milleding P, Haasum J, Karlsson S. Water sorption and flexural properties of a composite resin cement. *Int J Prosthodont*. 2000;13(2):141-147.

20. Thompson VP, Rekow DE. Dental ceramics and the molar crown testing ground. *J Appl Oral Sci*. 2004;12(spe):26-36.

21. Felton DA, Kanoy BE, Bayne SC, Wirthman GP. Effect of in vivo crown margin discrepancies on periodontal health. *J Prosthet Dent*. 1991;65(3):357-364.

22. Tan PL, Gratton DG, Diaz-Arnold AM, Holmes DC. An in vitro comparison of vertical marginal gaps of CAD/CAM titanium and conventional cast restorations. *J Prosthodont*. 2008;17(5):378-383.

23. Boening KW, Wolf BH, Schmidt AE, Kastner K, Walter MH. Clinical fit of procera AllCeram crowns. *J Prosthet Dent*. 2000;84(4):419-424.

24. Magne P, Boff LL, Oderich E, Cardoso AC. Computer-aided-design/computer-assisted-manufactured adhesive restoration of molars with a compromised cusp: Effect of fiber-reinforced immediate dentin sealing and cusp overlap on fatigue strength. *J Esthet Restor Dent*. 2012;24(2):135-146.

25. Tsitrou E, Helvatjoglou-Antoniades M, Pahinis K, van Noort R. Fracture strength of minimally prepared resin bonded CEREC inlays. *Oper Dent*. 2009;34(5):537-543.

26. McLean JW, von Fraunhofer JA. The estimation of cement film thickness by an in vivo technique. *Br Dent J*. 1971;131(3):107-111.

27. Renne W, McGill ST, Forshee KV, DeFee MR, Mennito AS. Predicting marginal fit of CAD/CAM crowns based on the presence or absence of common preparation errors. *J Prosthet Dent*. 2012;108(5):310-315.

28. Mously HA, Finkelman M, Zandparsa R, Hirayama H. Marginal and internal adaptation of ceramic crown restorations fabricated with CAD/CAM technology and the heat-press technique. *J Prosthet Dent*. 2014;112(2):249-256.

29. Reich S, Uhlen S, Gozdowski S, Lohbauer U. Measurement of cement thickness under lithium disilicate crowns using an impression material technique. *Clin Oral Investig*. 2011;15(4):521-526.

30. Mou SH, Chai T, Wang JS, Shiau YY. Influence of different convergence angles and tooth preparation heights on the internal adaptation of cerec crowns. *J Prosthet Dent*. 2002;87(3):248-255.

31. Liu B, Lu C, Wu Y, Zhang X, Arola D, Zhang D. The effects of adhesive type and thickness on stress distribution in molars restored with all-ceramic crowns. *J Prosthodont*. 2011;20(1):35-44.

32. Schmid-Schwap M, Graf A, Preinerstorfer A, Watts DC, Piehslinger E, Schedle A. Microleakage after thermocycling of cemented crowns--a meta-analysis. *Dent Mater*. 2011;27(9):855-869.

33. Nawafleh NA, Mack F, Evans J, Mackay J, Hatamleh MM. Accuracy and reliability of methods to measure marginal adaptation of crowns and FDPs: A literature review. *J Prosthodont*. 2013;22(5):419-428.

34. Larson TD. The clinical significance and management of microleakage. part two. *Northwest Dent*. 2005;84(2):15-19.

35. Retief DH, Mandras RS, Russell CM. Shear bond strength required to prevent microleakage of the dentin/restoration interface. *Am J Dent*. 1994;7(1):44-46.

36. Dhima M, Carr AB, Salinas TJ, Lohse C, Berglund L, Nan KA. Evaluation of fracture resistance in aqueous environment under dynamic loading of lithium disilicate restorative systems for posterior applications. part 2. *J Prosthodont*. 2014;23(5):353-357.

37. Nugen C. *A new in vitro method for the study of microleakage of dental restorative materials.* [M.S in Dentistry]. Australia: The University of Adelaide; 2007.

38. Amaral FL, Colucci V, Palma-Dibb RG, Corona SA. Assessment of in vitro methods used to promote adhesive interface degradation: A critical review. *J Esthet Restor Dent*. 2007;19(6):340-53; discussion 354.

39. Gale MS, Darvell BW. Thermal cycling procedures for laboratory testing of dental restorations. *J Dent*. 1999;27(2):89-99.

40. Kohorst P, Dittmer MP, Borchers L, Stiesch-Scholz M. Influence of cyclic fatigue in water on the load-bearing capacity of dental bridges made of zirconia. *Acta Biomater*. 2008;4(5):1440-1447.

41. Kassem AS, Atta O, El-Mowafy O. Fatigue resistance and microleakage of CAD/CAM ceramic and composite molar crowns. *J Prosthodont*. 2012;21(1):28-32.

42. Seydler B, Rues S, Muller D, Schmitter M. In vitro fracture load of monolithic lithium disilicate ceramic molar crowns with different wall thicknesses. *Clin Oral Investig*. 2014;18(4):1165-1171.

43. Kelly JR, Benetti P. Ceramic materials in dentistry: Historical evolution and current practice. *Aust Dent J*. 2011;56 Suppl 1:84-96.

44. van Noort R, Barbour ME. *Introduction to dental materials.* 4th ed. Edinburgh ; New York: Mosby Elsevier; 2013:246.

45. Stamatacos C, Simon JF. Cementation of indirect restorations: An overview of resin cements. *Compend Contin Educ Dent*. 2013;34(1):42-4, 46.

46. Ferracane JL, Stansbury JW, Burke FJ. Self-adhesive resin cements - chemistry, properties and clinical considerations. *J Oral Rehabil*. 2011;38(4):295-314.

47. Attar N, Tam LE, McComb D. Mechanical and physical properties of contemporary dental luting agents. *J Prosthet Dent*. 2003;89(2):127-134.

48. Hill EE. Dental cements for definitive luting: A review and practical clinical considerations. *Dent Clin North Am*. 2007;51(3):643-58, vi.

49. Hikita K, Van Meerbeek B, De Munck J, et al. Bonding effectiveness of adhesive luting agents to enamel and dentin. *Dent Mater*. 2007;23(1):71-80.

50. Hattar S, Hatamleh MM, Sawair F, Al-Rabab'ah M. Bond strength of self-adhesive resin cements to tooth structure. *Saudi Dent J*. 2015;27(2):70-74.

51. Behr M, Rosentritt M, Regnet T, Lang R, Handel G. Marginal adaptation in dentin of a self-adhesive universal resin cement compared with well-tried systems. *Dent Mater*. 2004;20(2):191-197.

52. Capa N, Ozkurt Z, Canpolat C, Kazazoglu E. Shear bond strength of luting agents to fixed prosthodontic restorative core materials. *Aust Dent J*. 2009;54(4):334-340.

53. RelyX ultimate [package insert]. . January,2014;3M Deutschland GmbH(Neuss, Germany).

54. Burgess JO. Materials you cannot work without. . 2013;28(4):94-106.

55. Dundar M, Gungor MA, Cal E. Multidisciplinary approach to restoring anterior maxillary partial edentulous area using an IPS empress 2 fixed partial denture: A clinical report. *J Prosthet Dent*. 2003;89(4):327-330.

56. Griggs JA. Recent advances in materials for all-ceramic restorations. *Dent Clin North Am*. 2007;51(3):713-27, viii.

57. Pallis K, Griggs JA, Woody RD, Guillen GE, Miller AW. Fracture resistance of three all-ceramic restorative systems for posterior applications. *J Prosthet Dent*. 2004;91(6):561-569.

58. Yeo IS, Yang JH, Lee JB. In vitro marginal fit of three all-ceramic crown systems. *J Prosthet Dent*. 2003;90(5):459-464.

59. Beuer F, Schweiger J, Edelhoff D. Digital dentistry: An overview of recent developments for CAD/CAM generated restorations. *Br Dent J*. 2008;204(9):505-511.

60. Roggendorf MJ, Kunzi B, Ebert J, Roggendorf HC, Frankenberger R, Reich SM. Seven-year clinical performance of CEREC-2 all-ceramic CAD/CAM restorations placed within deeply destroyed teeth. *Clin Oral Investig*. 2012;16(5):1413-1424.

61. Kelly JR. Dental ceramics: Current thinking and trends. *Dent Clin North Am*. 2004;48(2):viii, 513-30.

62. Conrad HJ, Seong WJ, Pesun IJ. Current ceramic materials and systems with clinical recommendations: A systematic review. *J Prosthet Dent*. 2007;98(5):389-404.

63. Holand W, Schweiger M, Frank M, Rheinberger V. A comparison of the microstructure and properties of the IPS empress 2 and the IPS empress glass-ceramics. *J Biomed Mater Res*. 2000;53(4):297-303.

64. Nakamura T, Ohyama T, Imanishi A, Nakamura T, Ishigaki S. Fracture resistance of pressable glass-ceramic fixed partial dentures. *J Oral Rehabil*. 2002;29(10):951-955.

65. Stappert CF, Att W, Gerds T, Strub JR. Fracture resistance of different partial-coverage ceramic molar restorations: An in vitro investigation. *J Am Dent Assoc*. 2006;137(4):514-522.

66. Li RW, Chow TW, Matinlinna JP. Ceramic dental biomaterials and CAD/CAM technology: State of the art. *J Prosthodont Res*. 2014;58(4):208-216.

67. Etman MK, Woolford MJ. Three-year clinical evaluation of two ceramic crown systems: A preliminary study. *J Prosthet Dent*. 2010;103(2):80-90.

68. Stappert CF, Denner N, Gerds T, Strub JR. Marginal adaptation of different types of all-ceramic partial coverage restorations after exposure to an artificial mouth. *Br Dent J*. 2005;199(12):779-83; discussion 777.

69. Haselton DR, Diaz-Arnold AM, Hillis SL. Clinical assessment of high-strength all-ceramic crowns. *J Prosthet Dent*. 2000;83(4):396-401.

70. Kelly JR, Benetti P. Ceramic materials in dentistry: Historical evolution and current practice. *Aust Dent J*. 2011;56 Suppl 1:84-96.

71. Miyazaki T, Nakamura T, Matsumura H, Ban S, Kobayashi T. Current status of zirconia restoration. *J Prosthodont Res*. 2013;57(4):236-261.

72. Takaba M, Tanaka S, Ishiura Y, Baba K. Implant-supported fixed dental prostheses with CAD/CAM-fabricated porcelain crown and zirconia-based framework. *J Prosthodont*. 2013;22(5):402-407.

73. Denissen HW, El-Zohairy AA, van Waas MA, Feilzer AJ. Porcelain-veneered computer-generated partial crowns. *Quintessence Int*. 2002;33(10):723-730.

74. R.P. Christensen, A.D. Galan, T.A. Mosher. Clinical status of eleven CAD/CAM materials after one to twelve years of service. . 2006.

75. Giordano R, McLaren EA. Ceramics overview: Classification by microstructure and processing methods. *Compend Contin Educ Dent*. 2010;31(9):682-4, 686, 688 passim; quiz 698, 700.

76. G.W. Ho JPM. Insights on porcelain as a dental material. part II: Chemical surface treatments. *Silicon*. (2011) 3:117–123.

77. Matinlinna JP, Vallittu PK. Bonding of resin composites to etchable ceramic surfaces - an insight review of the chemical aspects on surface conditioning. *J Oral Rehabil*. 2007;34(8):622-630.

78. Lung CY, Matinlinna JP. Aspects of silane coupling agents and surface conditioning in dentistry: An overview. *Dent Mater*. 2012;28(5):467-477.

79. Awliya W, Oden A, Yaman P, Dennison JB, Razzoog ME. Shear bond strength of a resin cement to densely sintered high-purity alumina with various surface conditions. *Acta Odontol Scand*. 1998;56(1):9-13.

80. Kern M, Thompson VP. Sandblasting and silica coating of a glass-infiltrated alumina ceramic: Volume loss, morphology, and changes in the surface composition. *J Prosthet Dent*. 1994;71(5):453-461.

81. Fasbinder DJ, Dennison JB, Heys D, Neiva G. A clinical evaluation of chairside lithium disilicate CAD/CAM crowns: A two-year report. *J Am Dent Assoc*. 2010;141 Suppl 2:10S-4S.

82. Reich S, Fischer S, Sobotta B, Klapper HU, Gozdowski S. A preliminary study on the short-term efficacy of chairside computer-aided design/computer-assisted manufacturing- generated posterior lithium disilicate crowns. *Int J Prosthodont*. 2010;23(3):214-216.

83. El-Damanhoury HM, Haj-Ali RN, Platt JA. Fracture resistance and microleakage of endocrowns utilizing three CAD-CAM blocks. *Oper Dent*. 2015;40(2):201-210.

84. Parker MH. Resistance form in tooth preparation. *Dent Clin North Am*. 2004;48(2):v-vi, 387-96.

85. Ivoclar Vivadent. All-ceramic chaiside preparation guide for IPS e.max. http://www.ultimate-dl.com/images/emax.pdf.

86. Balkaya MC, Cinar A, Pamuk S. Influence of firing cycles on the margin distortion of 3 all-ceramic crown systems. *J Prosthet Dent*. 2005;93(4):346-355.

87. Ferrari M, Dagostin A, Fabianelli A. Marginal integrity of ceramic inlays luted with a self-curing resin system. *Dent Mater*. 2003;19(4):270-276.

88. Alani AH, Toh CG. Detection of microleakage around dental restorations: A review. *Oper Dent*. 1997;22(4):173-185.

89. Amin RA, Mandour MH, Abd El-Ghany OS. Fracture strength and nanoleakage of weakened roots reconstructed using relined glass fiber-reinforced dowels combined with a novel prefabricated core system. *J Prosthodont*. 2014;23(6):484-494.

90. Kassem AS, Atta O, El-Mowafy O. Combined effects of thermocycling and load-cycling on microleakage of computer-aided design/computer-assisted manufacture molar crowns. *Int J Prosthodont*. 2011;24(4):376-378.

91. Ghazy M, El-Mowafy O, Roperto R. Microleakage of porcelain and composite machined crowns cemented with self-adhesive or conventional resin cement. *J Prosthodont*. 2010;19(7):523-530.

92. Trajtenberg CP, Caram SJ, Kiat-amnuay S. Microleakage of all-ceramic crowns using self-etching resin luting agents. *Oper Dent*. 2008;33(4):392-399.

93. Pashley DH, Tay FR. Aggressiveness of contemporary self-etching adhesives. part II: Etching effects on unground enamel. *Dent Mater*. 2001;17(5):430-444.

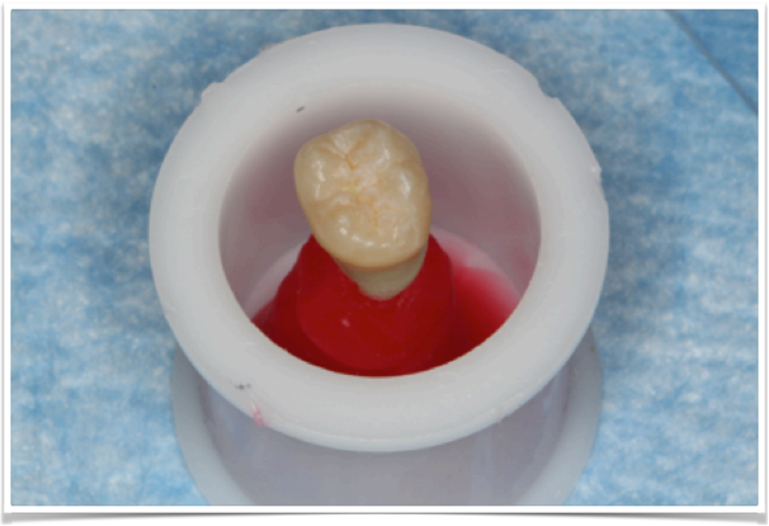
94. Hara AT, Amaral CM, Pimenta LA, Sinhoreti MA. Shear bond strength of hydrophilic adhesive systems to enamel. *Am J Dent*. 1999;12(4):181-184.

95. Hannig M, Reinhardt KJ, Bott B. Self-etching primer vs phosphoric acid: An alternative concept for composite-to-enamel bonding. *Oper Dent*. 1999;24(3):172-180.

96. 3M ESPE. RelyX™ ultimate adhesive resin cement. http://multimedia.3m.com/mws/media/783784O/relyx-ultimate-adhesive-resin-cement.pdf.

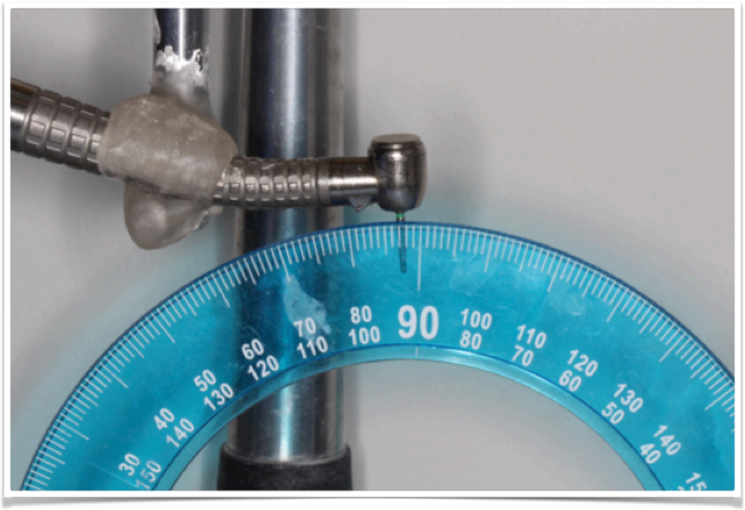
97. Kandil M. Tspace Repository. Toronto, CN: University of Toronto;2015. https://tspace.library.utoronto.ca/bitstream/1807/69310/3/Kandil_Mohamed_M_201506_PhD_thesis.pdf

Appendix: Figures



(Figure 1.A): A sample fixed vertically inside the mounting template.

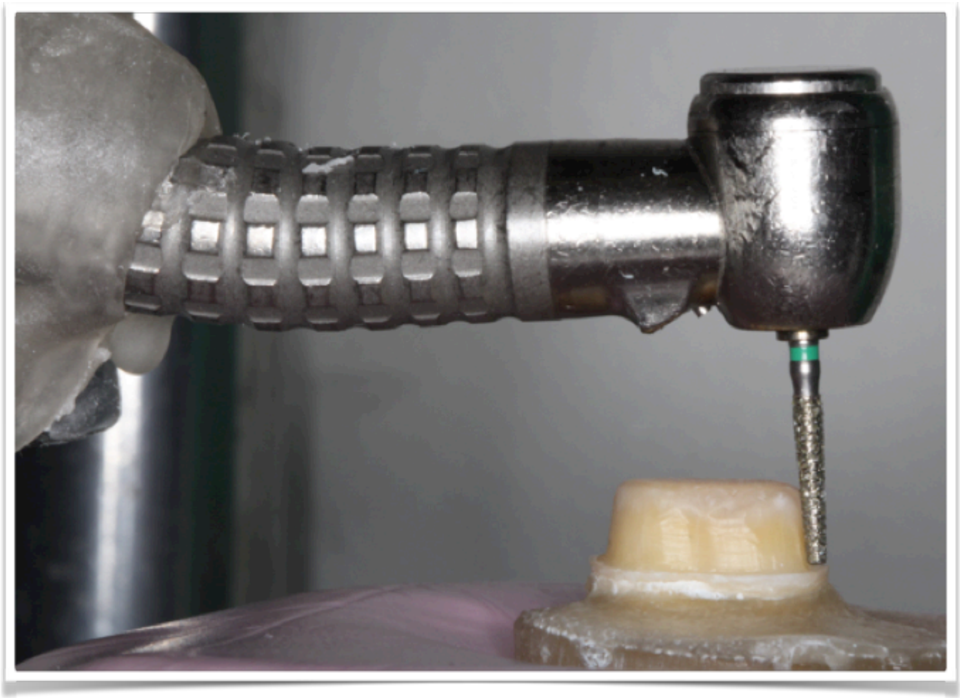
(Figure 1.B): A sample fixed vertically inside the mounting template with the CEJ being 1.0 mm higher than the top of a mounting template.



(Figure 2): A high-speed hand piece connected to a surveyor at a three-degree point from the vertical axis of the tooth.

(Figure 3.A): A surveyor table positioned parallel to the floor

(Figure 3.B): A custom jig on the surveyor table held immovably in the surveyor base



(Figure 4): Axial tooth reduction

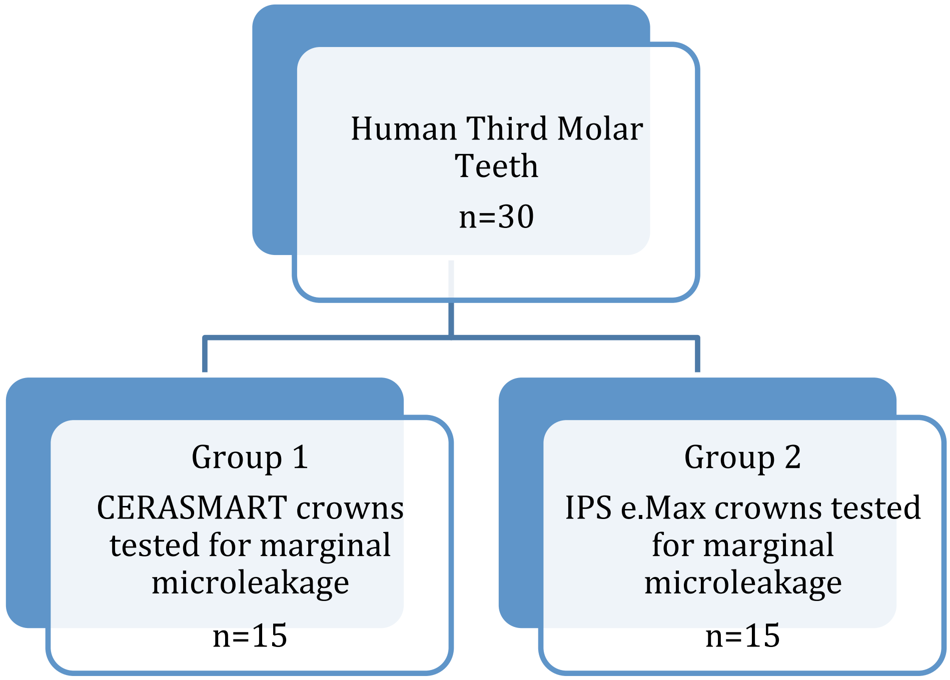


Figure 5: Groups of the study

Figure 6: CEREC scanning machine

Figure 7: A scanned sample

Figure 8: Milled IPS e.max crown

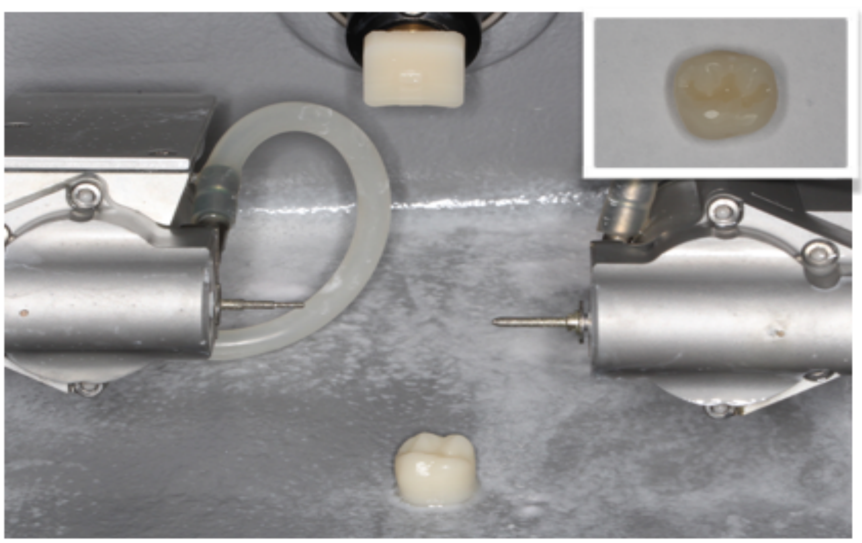


Figure 9: Milled CERASMART crown

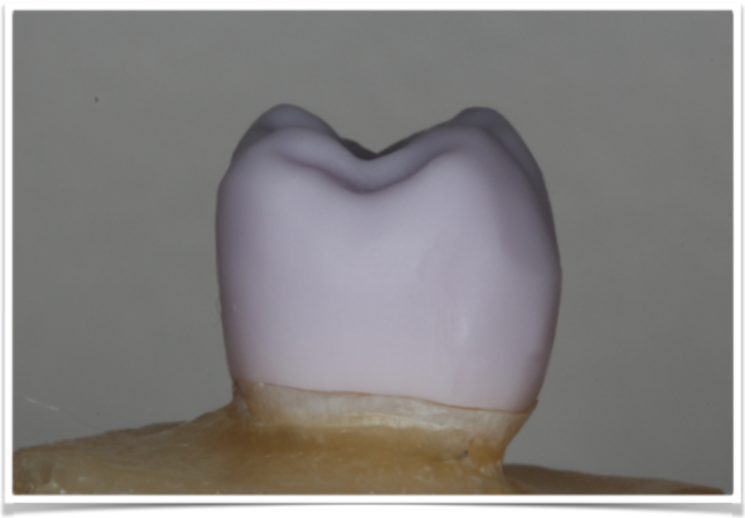


Figure 10: Assessing marginal fit

Figure 11: Hydrofluoric acid to etch the intaglio surface of the crown.

Figure 12: A silane coupling agent applied on the intaglio surface of the crown.

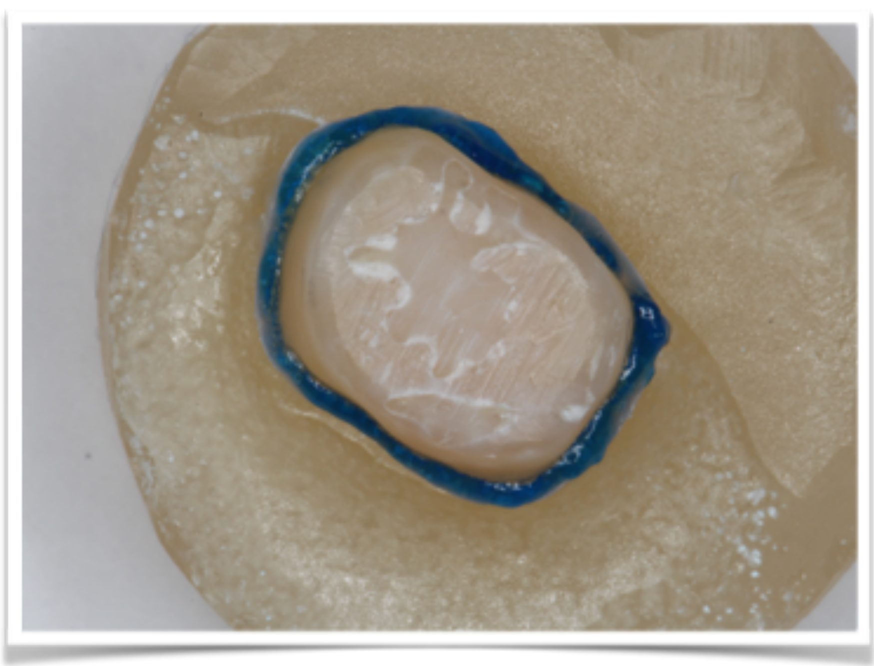


Figure 13: A sample with selective etch approach

Figure 14: RelyX ultimate adhesive cement

Figure 15: A sample in an Instron

Figure 16: Silver Nitrate

Figure 17: Photo-developing solution

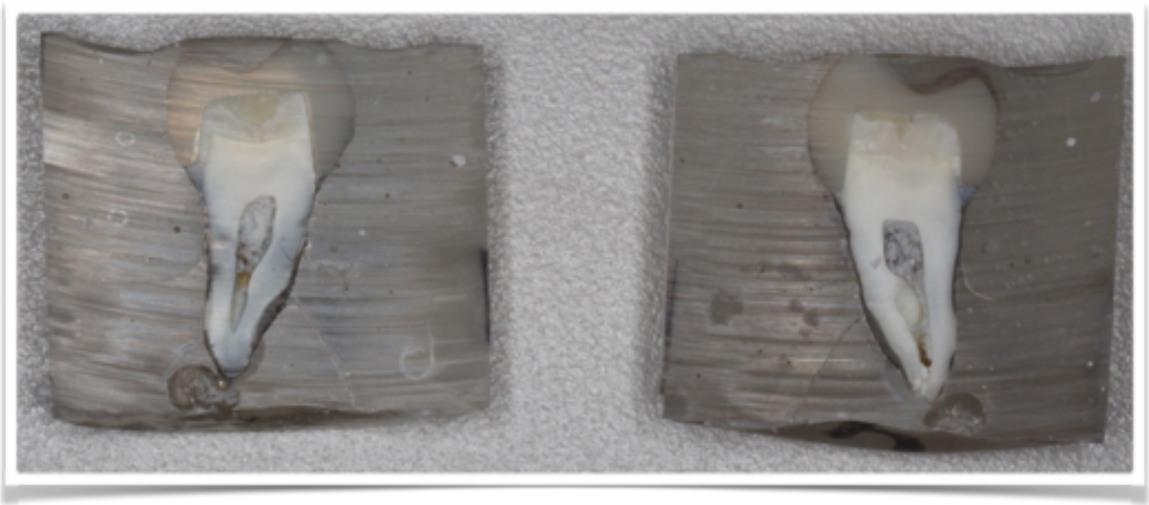


Figure 18: A sample segmented buccolingually

Figure 19: Samples sectioning machine

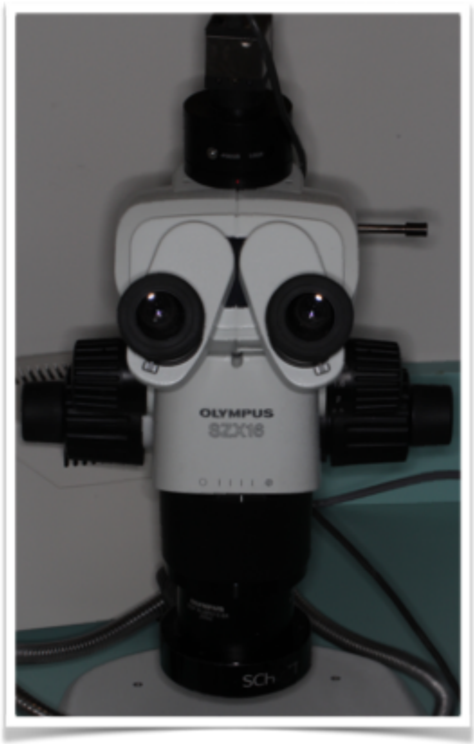


Figure 20: A stereomicroscope

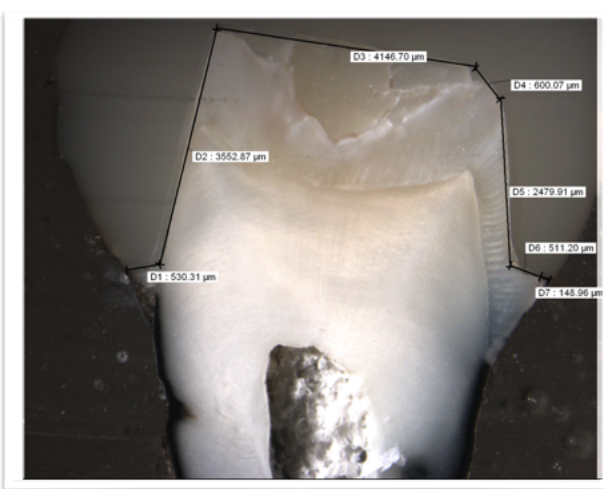


Figure 21: A sample under the microscope showing dye penetration

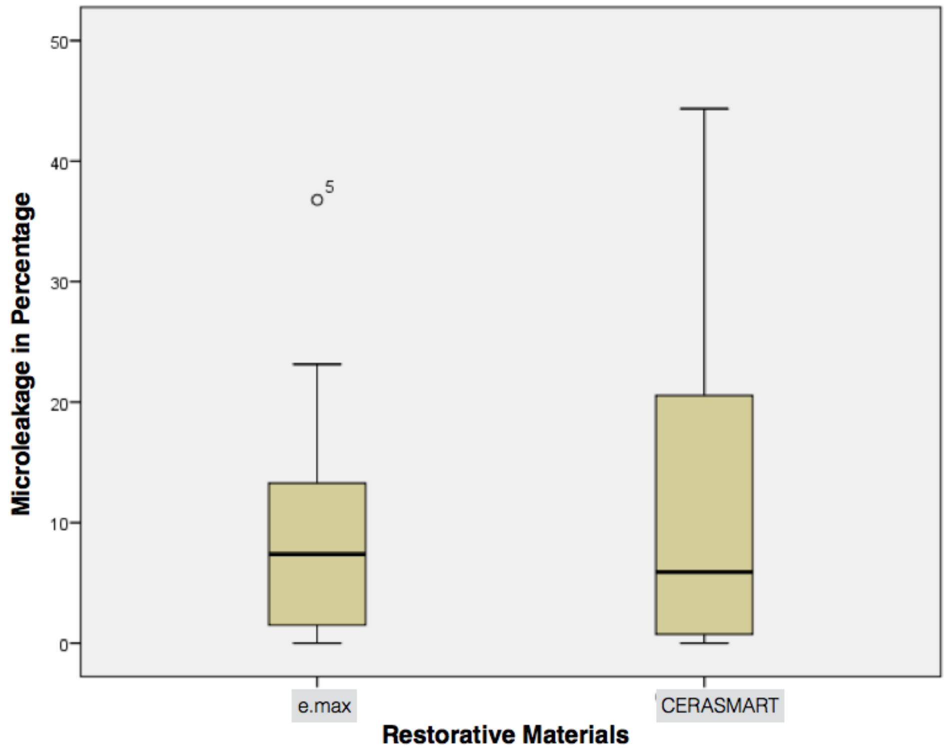


Figure 22: Side-by-side boxplots representing the percentage of microleakage in each group for the continuous data

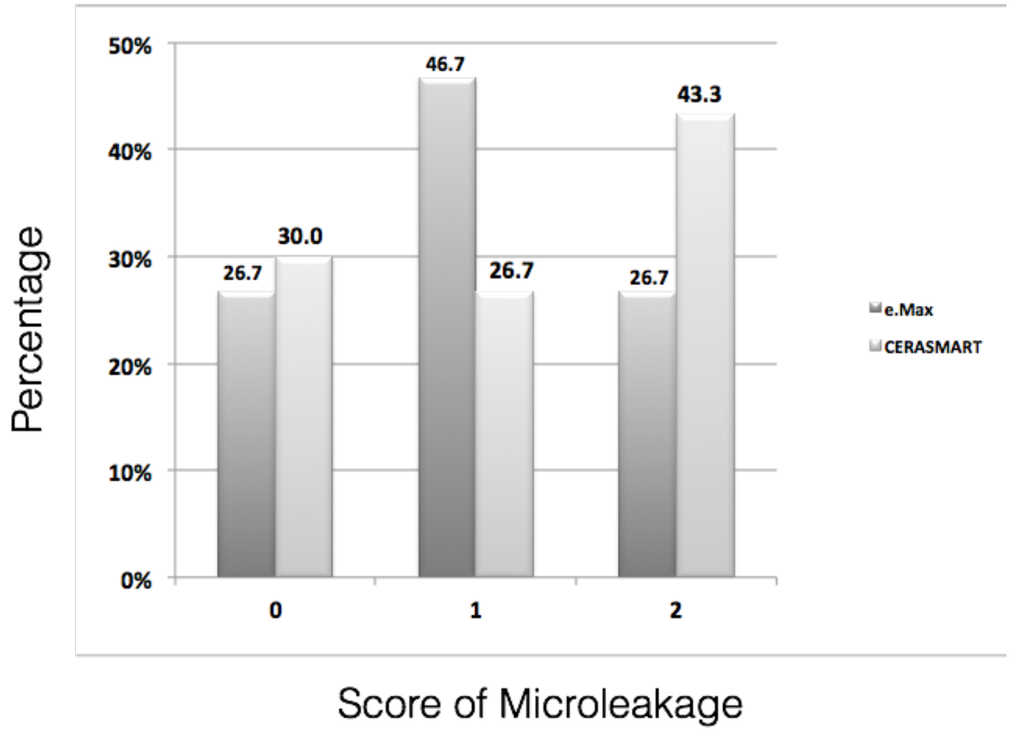


Figure 23: Bar chart representing the frequency distribution of microleakage in each group on an ordinal scale

Figure 24: A sample being measured by electric ruler for block randomization