PALACKY UNIVERSITY – FACULTY OF MEDICINE AND DENTISTRY

INSTITUTE OF DENTISTRY AND ORAL SCIENCES

DOCTORAL DISSERTATION

THE MARGINAL FIT OF LITHIUM DISILICATE CROWNS

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DECLARATION

I declare that I performed this dissertation independently under the supervision of my supervisor and that I stated all used literature and other sources.

Signature:

In Olomouc on

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1 ABSTRACT

1.1 Objectives

This in-vitro study aimed to compare the vertical marginal gap of lithium disilicate crowns (Press vs. CAD) and to compare the effect of different resin luting cements on this gap.

1.2 Methods

Twenty intact extracted lower third molars were collected before being disinfected in a 10% formaline solution for 7 days. Teeth were then inserted in acrylic bases and prepared to receive a ceramic crown. Next, teeth were digitally scanned using (CEREC omnicam, Sirona, Germany) for the milling of 20 e.max CAD crowns using blocks of (IPS e.max CAD, Ivoclar vivadent, Liechtenstein) and a milling machine (CEREC MC XL, Sirona, Germany). In addition, 20 impressions using additional silicone (Express heavybody + light body, 3M, USA) were made for the making of 20 e.max press crowns using ingots of (IPS e.max press, Ivoclar vivadent, Liechtenstein). As a result, 20 e.max press crowns and 20 e.max CAD crowns were fabricated. The marginal gap was measured using optical microscope at 200x magnification and an image analyzing program. The measurements were achieved on 25 points on the finishing line on each tooth. Statistical analysis was done using Willcoxon test to compare the mean marginal gap of e.max press and e.max CAD groups. In addition, Kruskal-Wallis test was used to demonstrate–differences between the values measured on the different teeth in each technique.

18 E.max press crowns were chosen randomly and divided into 3 groups (6 crowns in each group) and then cemented using 3 different resin luting cements (Harvard® flowable, Relyx ultimate®, Enamel® preheated composite). The marginal gap was measured before and after cementation. The measurements were achieved on 4 points on the finishing line on

each tooth. Statistical analysis was done using Kruskal-Wallis test to compare the mean marginal elevation between the three groups.

1.3 Results

The analysis showed statistically significant differences in the marginal gap between the two groups. The e.max press crowns had smaller marginal gaps than the e.max CAD crowns. The mean marginal gap of e.max press crowns was (37.75 ± 12.46 SD microns), while the mean marginal gap of e.max CAD crowns was (45.24 ± 12.34 SD microns). There were statistically significant differences in the marginal gaps between the different teeth studied in every technique (press or CAD).

The least amount of marginal elevation after cementation was with the Harvard® flowable cement with an average marginal elevation of (41.88 ± 11.38 SD microns). Relyx ultimate® cement elevated the margins with an average (45.17 ± 29.07 SD microns). The highest marginal elevation was in the Enamel® preheated composite group (116.13 ± 46.73 SD microns).

1.4 Significance

This research indicates that e.max lithium disilicate crowns fabricated with the press technique have measurably smaller marginal gaps when compared to those fabricated with CAD technique within in-vitro environments. However, the marginal gaps achieved by the crowns across all groups were within a clinically acceptable range. In addition, the final shape of preparation and intrapersonal variability might influence the marginal gap. Moreover, the marginal elevation of pressed crowns cemented with the preheated composite (Enamel®) exceeded the clinical acceptable range of marginal gaps. Thus, we do not recommend its use for the cementation of lithium disilicate crowns.

1.5 Keywords

Marginal fit, e.max, press, CAD, lithium disilicate, resin cement.

2 INTRODUCTION

2.1 Ceramics in dentistry

Ceramics are probably the oldest materials developed by man. Pieces of ceramics, dated 30,000 years BC, helped archaeologists study the behavior of our ancestors. In 1774, the French pharmacist, Alexis Duchateau, unsatisfied with his dentures in ivory, noticed that the ceramic utensils used in handling chemical formulations resisted abrasion caused by the products used, and maintained their color. He suggested that porcelain could be used as an alternative for the replacement of missing teeth.

Later, Duchateau, with the collaboration of a dentist named Nicholas Dubois De Chemant, managed to fabricate the first dental porcelain composition based on "green" traditional porcelain (50% kaolin clay - Al_2O_3 SiO_2 $2H_2O$, 25 % feldspar - K_2O Al_2O_3 $6SiO_2$ and 25% silica or quartz - SiO_2). However, the prostheses made with these materials did not gain popularity due to their high opacity. In 1838, Elias Wildman made porcelain that was more translucent, becoming closer to that of natural teeth. The reduction or complete removal of kaolin resulted in an increase in the amount of feldspar, and therefore greater light transmission and esthetics (1, 2).

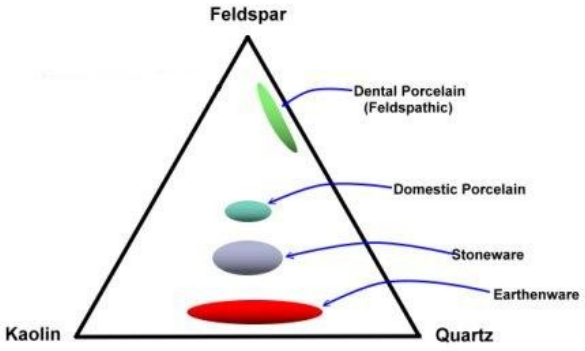


Figure 1: Shows the main components of a ceramic material (3)

While providing a high translucency, feldspathic porcelain showed high mechanical fragility, when used in the mouth. Extensive prostheses made from pure porcelain fractures easily due to the propagation of cracks or voids resulting from laboratory processing (4).

This clinical observation led to the introduction of metal infrastructures, associated with ceramics, in order to compensate for the low mechanical properties of the porcelain. This combination became known as "metalloceramic prosthesis", and represents a milestone in the technological progress of dental prostheses. From this point, dental porcelains could be used in extensive fixed prostheses (2).

The use of metalloceramic prostheses over the last 50 years has minimized the problem with porcelain fragility; however, its aesthetic side was not convincing due to the presence of metal.

The metal framework acts as a barrier in the way of light transmission, giving the prosthetic dental restoration an unaesthetic opaque aspect, with the presence of darkening at the cervical region of the restoration (5).

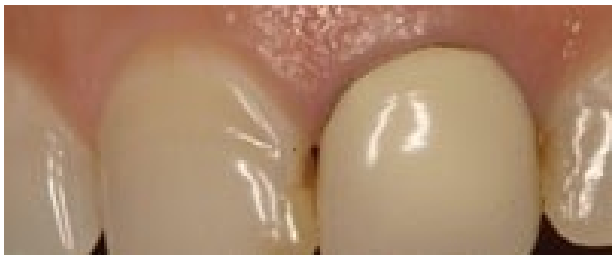


Figure 2: Shows the darkening of cervical margins around a metal-ceramic crown (6)

In the search for a material to replace the metal infrastructure of a metalloceramic prosthesis, McLean and Hughes introduced aluminum oxide (Al2O3) as a reinforcing phase in dental porcelain in 1965. The incorporation of strengthening components to the feldspathic glassy matrix enabled the manufacturing of ceramic infrastructures without metal, initiating an era of advances in the development of new ceramic systems and processes routinely used in current dental practices (1).

The first ceramic infrastructures made of alumina were obtained by a process known as infiltration slipcasting, where an infrastructure of high-density crystal is prepared with a small amount of glass. The ceramic powder reinforced with alumina is mixed with water and applied on a refractory die. Next, the alumina is sintered for 10 to 12hs at a temperature of 1140^{o}C. During sintering, the particles fuse and produce a crystalline structure which is opaque and porous. In a second stage, this structure is infiltrated by a thin layer of molten glass of low viscosity (lanthanum aluminosilicate). With an increase in temperature (1100^{o}C for 4 to 6 hours), the glass melts and penetrates the infrastructure, through capillary action, and creates a ceramic surface with a very low porosity and high mechanical properties. Three infiltrating systems (Vita Zahnfabrik, Germany) were developed for this technique of processing: reinforcing with alumina (70% to 85% aluminum oxide) and with magnesia (70% aluminum oxide and 30% magnesium oxide) or zirconia (67% aluminum oxide and 33% of tetragonal zirconium oxide). The flexural strength varies according to the type of reinforcement used: alumina (400MPa), magnesia (300MPa) and zirconia (750MPa). Depending on the strength achieved by the infiltration, the construction of fixed prostheses in areas of high masticatory forces might be indicated. However, both the high concentrations of alumina and zirconia shown in these ceramic systems result in poor optical qualities of the restoration, due to its high opacity (7, 8). Additionally, the porosity incorporated during the manufacturing of the infrastructure can affect the strength of these restorations (9).

Alumina coping

Galss application

Figure 3: Shows the process of slip-casting (In-ceram®- Vita)

Parallel to the introduction of infiltrated ceramics, glass-ceramics have been manufactured in the vacuum injection technique, similar to the traditional technique of metal casting. Two glass-ceramic compositions were introduced: leucite-based (IPS-Empress®, IvoclarVivadent, Liechtenstein) and lithium disilicate-based (IPS-Empress 2®, IvoclarVivadent, Liechtenstein). In the first material, leucite is responsible for strengthening the ceramic. Leucite results from the nucleation process with increasing temperature, giving a higher flexural strength when compared to feldspathic porcelain, but still not enough for extensive restorations. The great advantage of this glassy ceramic is that it exhibits high light transmission, due to its high content of amorphous glass, which allows the manufacturing of restorations with high esthetics.

In the second material, the crystals generated are elongated crystals of lithium disilicate measuring 0.5 to 5µm and lithium orthophosphate measuring 0.1 to 0.3µm. They are smaller than those of the leucite reinforced ceramics. The high content of crystalline lithium disilicate enhances the flexural strength of the material (350 MPa), allowing the design of fixed partial prostheses of up to three units (7). Later on, the same company of Empress 2, introduced IPS e.max lithium disilicate, as an improved hot-pressed ceramic material (10)

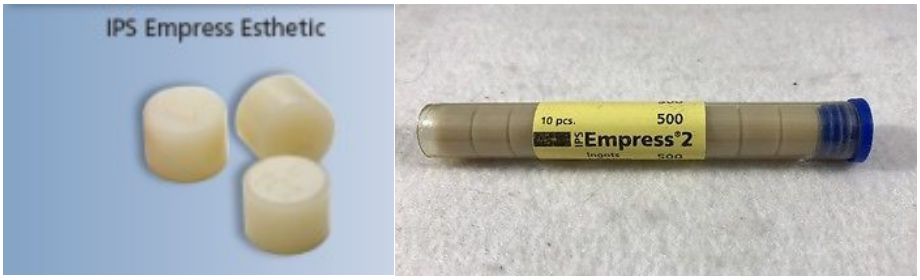


Figure 4: Shows ingots of Empress® (leucite-based) and Empress 2® (lithium disilicate-based)

The laboratory procedure for producing restorations using these materials involves the inclusion of waxed patterns in special rings with a refractory lining. The wax is burned out in a conventional furnace and then the rings are brought to injection furnace, where prefabricated ceramic ingots are melted and injected under heat (about 1150°C) and vacuum hydrostatic pressure (around 0.3 to 0.4 MPa). After the completion of the injection process, the molds are cooled to room temperature, and removal of the investment material is performed using jets of glass beads. The prosthesis of these systems can be obtained by two techniques: the restoration is cast in its final shape, and subsequently painted and glazed (monolithic restoration), or the ceramic infrastructure is obtained by injection, typically covered by a ceramic of a lower thermal expansion coefficient (layering technique-cut back) (2).

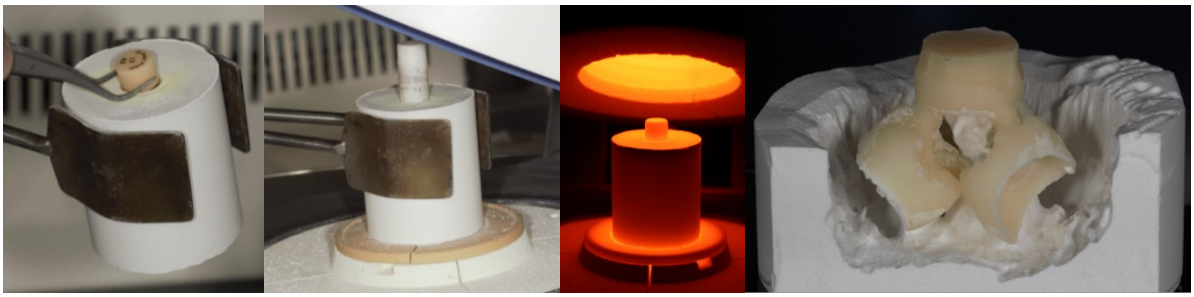


Figure 5: Shows the pressing technique

In handmade restorations, the possibility of errors is directly proportional to the number of variables involved (9). The automation and the ability to fabricate ceramic prostheses using a machine-readable technology, design (CAD) and manufacturing (CAM), results in the elimination of several clinical steps and a reduction of the variables involved in the production of the restoration. With the CAD/CAM technology, all ceramic prosthesis can be fabricated with an infrastructure of pure aluminum oxide (99.5%), which is crystalline, densely sintered and non-porous. Clinical procedures consist of obtaining an impression of the prepared area and preparing a die model. The die is positioned on the rotating platform of the scanner unit (CAD) and a probe with a spherical tip performs digital mapping of the die. The image obtained is sent to the system program, where the operator manipulates the generated image on the special software. The completed design of the digital infrastructure is sent via modem to a production station (PROCERA Sandvik®AB, Sweden or PROCERA® Fair Law, USA), where they industrially manufacture the piece requested (unit CAM) (11).

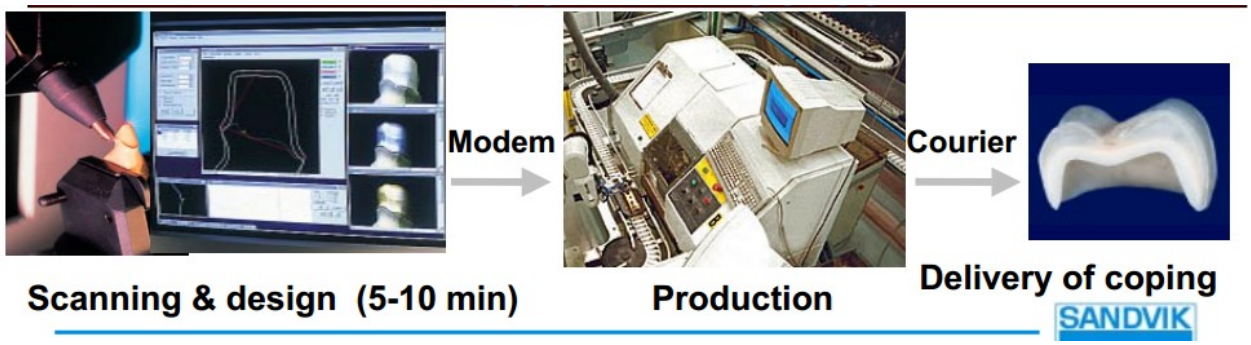


Figure 6: Shows the procera® system

Other systems use CAD/CAM technology for machining ceramic blocks with diamond burs and discs. The restoration is carved in blocks of ceramics of varying composition (feldspar, glassy, or alumina reinforced with zirconia, etc…). A CAD unit makes a digital reading of the

prepared tooth (intra-oral version - chair-side) or die gypsum (in-lab version), copying all of the details and transferring this information to a computer software where the digital design of the infrastructure is performed. The chosen ceramic block is attached to the CAM unit and a process of attrition (milling) takes place for about 10 to 30 minutes. The machining can be performed on pre-sintered or fully sintered blocks. The resulting pieces of pre-sintered blocks are shaped into a size 25 to 30% larger than desired (depending on the material batch) to compensate for the sintering shrinkage. Units from fully sintered blocks are milled in the ideal size, however, they suffer the stress of the milling process (12).

A B

Figure 7: Shows the two versions of CAD (Computer Aided Design) in dentistry (CEREC®, Sirona): Chair-side (A) and in-lab (B)

Structural ceramics based on zirconia (ZrO_2) are ceramics which have been well known in the health field by their biocompatibility, high mechanical properties and chemical stability (13). Their use in dentistry is relatively new, but zirconia has proven to be a promising material for making prosthetic infrastructures for crowns, bridges, abutments and implant prostheses (4). Although there are currently several kinds of ceramic systems based on zirconia, the 3Y-TPZ has been the most studied and used in dentistry (14). The polycrystal

tetragonal zirconia stabilized with yttria (3Y-TPZ) contains 3% yttria oxide (Y2O3) as a stabilizer and was first applied in the medical field of orthopedics (13). For dental applications, the 3Y-TPZ is synthesized in small grains (0.2 to 0.5 mm in diameter), which minimizes the growth of cracks (4). Pre-sintered blocks are milled with the aid of CAD/CAM, and the specimens are then sintered. This processing reduces the level of tension present in the material and prevents a tetragonal to monoclinic transformation (t → m), which leads to a final result virtually free of the monoclinic phase. The high fracture toughness exhibited by zirconia ceramics is attributed to their ability to transform from the tetragonal-to-monoclinic phase during crack propagation (15). The infrastructure obtained from these blocks is relatively stable, having a high crystalline structure and a flexural strength around 900 to 1200MPa. Fully sintered blocks are processed at a temperature between 1400 to 1500° C. This process causes the block to achieve a final density around 99% and high hardness (16).

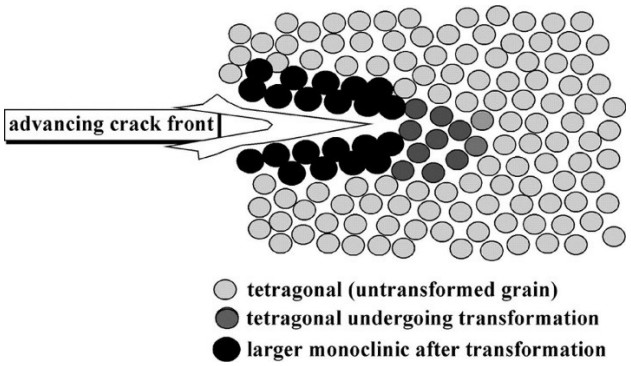
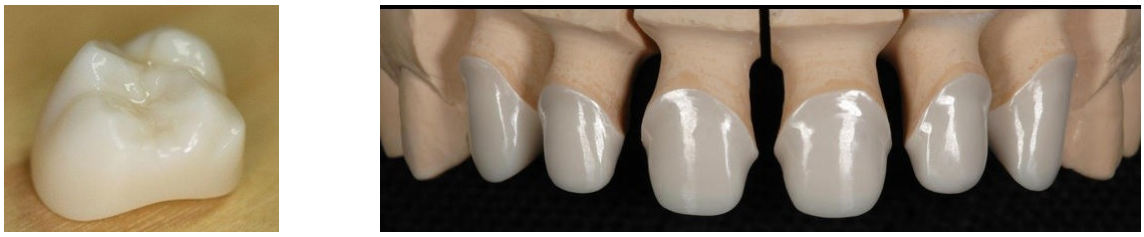


Figure 8: Shows the transformation phenomenon of zirconia from the tetragonal form into the monoclinic one to stop crack growth (17)

Zirconia ceramic was historically used as a prosthetic material to be veneered with ceramics, but it can also be used to manufacture monolithic restorations. It is available as a monochromatic uniform material, which, if needed, can be stained by infiltration. There is an increasing trend to use polychromatic CAD/CAM blocks and discs manufactured to imitate

the variation in color from dentin to enamel. In addition, these materials are manufactured with increasing translucency (18).



A B

Figure 9: Shows a monolithic zirconia crown (A) and a zirconia copings on which a glass-ceramic will be layered (B) (19, 20)

2.2 Classification of dental ceramics

In dental science, ceramics are considered as non-metallic, inorganic structures primarily containing oxygen with one or more metallic or semi-metallic elements. These include sodium, potassium, calcium, magnesium, aluminum, silicon, phosphorus, zirconium & titanium. Structurally, dental ceramics are composed of a crystal phase and a glass phase based on the silica structure, containing central Silica ion with surrounding Oxygen ions. Ceramics are nowadays widely used in dentistry due to their strength and esthetics (21).

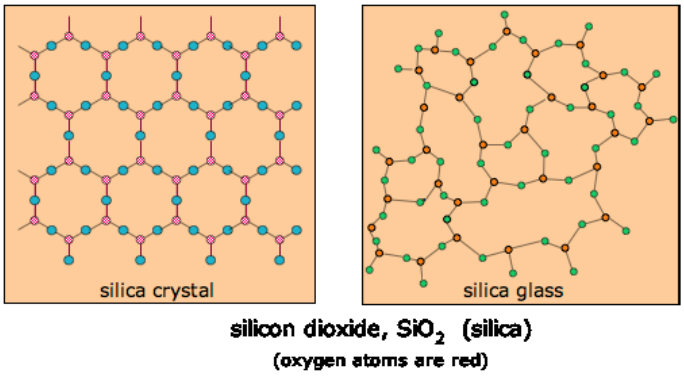


Figure 10: Shows the amorphous and crystalline silica (22)

There are many classification systems of dental ceramics. One important classification is based on the melting temperature of the ceramic material. The categories are describes as

- high-fusing (>1300°C)
- medium-fusing (1100-1300 °C)
- low-fusing (850-1100 °C)
- ultra-low-fusing (<850 °C) (23).

Gracis and colleagues classified dental ceramics into three groups:

1) Glass-matrix ceramics: Ceramics in this group contain a glass phase. Examples are feldspathic ceramics, and glass-infiltrated ceramics.
2) Polycrystalline ceramics: There is no glass phase in the ceramics of this group. Examples include alumina and zirconia.
3) Resin-matrix ceramics: Ceramics in this group contain organic matrix highly filled with ceramic particles. Examples are (Lava Ultimate®, 3M ESPE) and (Enamic®, Vita) (18).

Figure 11: Shows the composition of a resin-matrix ceramic (Enamic®, Vita): A: Ceramic network, B: Polymer network, C: Hybrid ceramic

Giordano and colleagues classified dental ceramics according to the processing technique as follows:

1) Powder/liquid glass-based ceramics: These are veneer materials often hand layered. They might be all glass or a mixture of glass and crystal components. These include veneers for all-ceramic and metal frameworks, and may also be used alone as anterior veneers. Typically, these materials are mixed by hand with deionised water or a special liquid supplied by the manufacturer. They are built up by hand and vibrated (condensed) to remove water and air. These are fired in a vacuum to help remove remaining air and improve the density of the veneer. Since these restorations are made by hand, there are often voids present in the fired material. This is inherent to the process and may be worse or better depending upon the skill of the technician, and the firing cycle. One sees frequently bubbles remaining in the hand-layered veneer material (24).
2) Pressable glass-based ceramics: Pressed ceramic restorations are fabricated using a method similar to injection moulding. Monochromatic ceramic ingots are heated to allow the material to flow under pressure into a mould formed using a conventional lost-wax technique. The restoration may be cast to its final contours and subsequently stained and glazed to provide an esthetic result. Alternatively, a coping may be moulded upon which porcelain is added to achieve the final shape and shade of the restoration. IPS Empress restorations and other materials are fabricated in this manner. The glass-ceramic IPS e.max is also fabricated this way. Pressables may be used for inlays, onlays, veneers and single-unit crowns (24).
3) CAD/CAM: These ceramics comes in a form of blocks, from which the framework or the full anatomic restoration is milled by a milling machine (24).

Figure 12: Shows the dental ceramic in the form of powder/liquid for the layering technique (IPS InLine®- Ivoclar Vivadent)

Figure 13: Shows the dental ceramic in the form of ingots for the press technique (IPS e.max press®- Ivoclar Vivadent)

Figure 14: Shows the dental ceramic in the form of block for the CAD/CAM technique (IPS e.max CAD®- Ivoclar Vivadent)

Kelly and Benetti made a useful classification of dental ceramics. There are three main classes:

1) Predominantly glassy ceramics: These ceramics are mainly composed of amorphous (without form) structure.
2) Particle-filled glasses: Filler particles are added to the glass composition to improve mechanical properties.
3) Polycrystalline ceramics: Ceramics in this group have no glassy phase. Atoms are densely packed to prevent crack propagation (25).

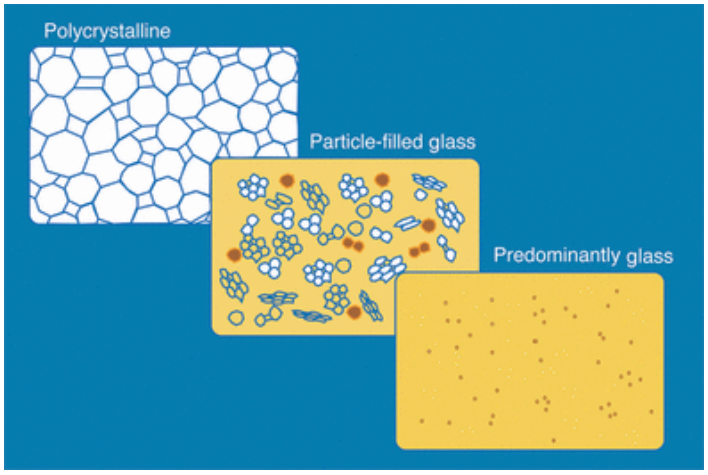


Figure 15: Shows the three groups of dental ceramics according to Kelly and Benetti (25)

2.3 Lithium disilicate

Lithium disilicate is a type of ceramic which consists of quartz, lithium dioxide, alumina, phosphor oxide, potassium oxide, and other components (10).

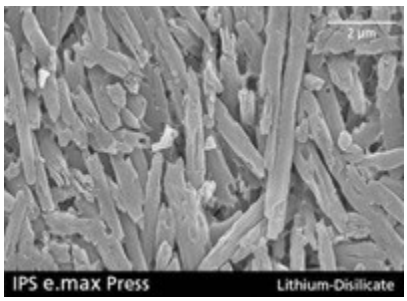


Figure 16: Shows the microscopic structure of lithium disilicate-based ceramic (10)

lithium disilicate-based restorations can be fabricated in the dental laboratories using the lost-wax technique. The Ivoclar-vivadent company introduced IPS Empress 2 in 1998. It was a lithium disilicate-based glass ceramic (SiO2-Li2O) using the hot pressing procedure with *in-vitro* mean fitting accuracy of posterior crowns amounted to less than 50 µm (26). The survival rate of this all-ceramic material was found to be 100% for posterior single crowns and 70% for 3-unit fixed partial dentures, in the anterior and premolar area, in a 5-year prospective clinical study (27).

IPS e.max lithium disilicate was introduced in 2005, as an improved hot-pressed ceramic material, in order to expand the range of indications of the previously used IPS Empress 2. The properties that the material possesses include high flexural strength (360 MPa to 440 MPa), high fracture toughness (2-3 MPa) and high thermal shock resistance due to the low thermal expansion (10). This material has lithium disilicate crystals (SiO2.Li2O) in a matrix of glass to minimize microcrack propagation (28).

Ingots of lithium disilicate (IPS e.max Press) are heat-pressed within a special furnace to follow the desired shape after the wax is burned out (29, 30). This technique involves less processing errors than conventional sintering and has better mechanical stability (31, 32).

Lithium disilicate is also available as blocks for chairside CAD/CAM systems (33). The machineable lithium disilicate (IPS e.max CAD) consists of 40% platelet-shaped lithium

metasilicate crystals embedded in a glassy phase which is produced after an "intermediate" crystallization process (blue, translucent state). The final crystallized state and desired tooth color is achieved during the post milling firing process in which lithium metasilicate transforms into lithium disilicate (10). Clinicians are able to fabricate restorations during a single visit by using intraoral digital impressions and in-office milling (34). Crowns must be afterwards heat-treated for the crystallization process to take place and to achieve definitive strength (10, 35).

Figure 17: Shows the two forms of lithium disilicate-based ceramics (ingots and blocks) (IPS e.max®, Ivoclar Vivadent)

The application of CAD/CAM systems in dentistry had initiated as early as 1970s by Duret and colleagues, but it was not until the 1980s when Mormann and colleagues developed the CEREC system, that they gained popularity (9, 36). Today, a rapidly increasing number of milling systems have established themselves on the dental market (36, 37). Some of them are:

- Cercon smart ceramics (DeguDent Frankfurt GmbH)
- CEREC (Sirona Dental Systems, LLC, Charlotte, NC, USA)
- DCS Dental (DSC Dental AG, Allschwil, Germany)
- E4D (D4D Technologies, Richardson, TX. USA)

- Etkon (etkon AG, Gräfelfingen, Germany)
- Hint Els DentaCAD systeme (Hint-Els GmbH)
- KaVo Everest (KaVo Dental GmbH, Biberach, DEU)
- LAVA (3M, St. Paul, MN, USA)
- Nobel Biocare Procera (Nobel Biocare, Yorda Linda, CA, USA)
- Wieland Zeno (Wieland Dental and Technik GmbH & Co. Pforzheim, DEU)
- ZirkonZahn (GmbH, Gais, Italy), and many more (36, 37).

Among the available CAD/CAM systems, the CEREC (*Chairside Economical Restoration of Esthetic Ceramics or Ceramic REConstruction*) system is commonly used, as it was the first to be commercially available. This system uses prefabricated high-quality ceramic blocks, resulting in biocompatible, esthetic, and durable restorations (38, 39). The CEREC system was developed by Dr. Werner M¨ormann and by an electrical engineer, Dr. Marco Brandestini, in 1980. The first inlay ceramic restoration was luted in 1985, using the CEREC system (Siemens, Bensheim, Germany) (40).

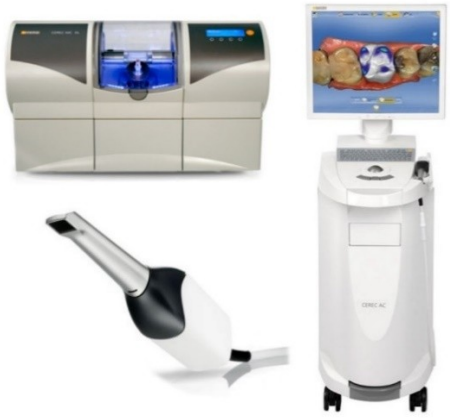


Figure 18: Shows the components of the CEREC system: Intraoral scanner, computer with a special software, and the milling machine (CEREC®, Sirona)

For CAD/ CAM systems, tooth preparation and cementation of the ceramic restoration can be performed during a single treatment session, eliminating the need for an interim crown. This is important because the contamination of dentin with provisional cements can impair the adhesion of the crown to the dentin surface (41).

2.4 Fixation of all-ceramic crowns

Different types of luting cements have been used for the fixation of all-ceramic crowns, and there are controversial opinions about which one is more appropriate (42, 43). When considering all-ceramic restorations, their mechanical properties can be improved by using resin cement. Therefore, this type of cement should be the preference when cementing such type of restorations (44, 45).

Resin cements may be classified according to their polymerization mode into chemical-cured, light-cured, and dual-cured. They can also be classified by their adhesive scheme: total-etch, self-etch, and self-adhesive (46). The self-adhesive resin cements may be also called universal cements or "all-in-one" (47).

Light-cure resin cements use photo-initiators, which are activated by light. The ability of light to penetrate all areas and activate the photo-initiators is very essential with this kind of cement. An advantage of light-curing cements is that there can be an increased working time compared to the other types. Therefore, the clinician is able to remove excess cement before curing (47). Another advantage of light-cure cements is their color stability compared to chemical-cure or dual-cure resin cements (48). Light-polymerized resins are recommended

when cementing ceramic restorations that are thin and relatively translucent, allowing the transmission of light to reach the resin cement (49).

Figure 19: Shows different examples of light-cure resin cements (Variolink Veneer®- Ivocalr Vivadent), (Relyx veneer®- 3M ESPE)

Dual-cure resin cements are capable of being cured by both chemicals and light. Self-cure initiators that can cure the cement are present. In addition, a curing light is used to activate the photo-initiators that are present in the cement (47). Dual-polymerized resin cements are indicated when the ceramic material is too thick or too opaque to allow transmission of light through it (50). Studies have shown that dual-cure resin cements still require light-curing to gain a high degree of polymerization (51, 52).

Figure 20: Shows different examples of dual-cure resin cements (NX3®- Kerr), (Relyx ultimate®- 3M ESPE)

Chemical-cure resin cements polymerize with a chemical reaction and can be also referred to as "self-curing." This means that two materials must be mixed together for the setting

reaction to start (47). These cements are especially useful in areas where light-curing alone is not possible. An example could be ceramic restorations that do not allow adequate polymerization of the resin cement from the curing unit (47).

Figure 21: Shows different examples of chemical-cure resin cements (C&B®- Synca), (M-Bond®- Tokuyama)

Total-etch resin cements use a 30% to 40% phosphoric acid to etch dentin and enamel. This etching procedure removes the smear layer, and opens dentinal tubules (53). After etching, the adhesive is applied to bond the cement to the tooth. These cements and the adhesives used with them could be light- or dual-cured (53). Total-etch resin cements have increased the bond strengths of resin cements and have markedly reduced microleakage (54). However, this multi-step application technique is complicated and thus might compromise bonding effectiveness due to a possible contamination (46).

Figure 22: Shows different examples of total-etch resin cements (Variolink II®- Ivoclar Vivadent), (Calibra®- Dentsply)

Self-Etch Resin Cements apply a self-etching primer to prepare the tooth surface, and mixed cement is then applied over the primer. Self-etching systems are popular among practitioners because of their ease of use, but they have demonstrated bond strength to enamel that is weaker than that of total-etch systems (55). Therefore, the total-etch, three-step adhesive system still sets the standard in terms of long-term predictability (56).

Figure 23: Shows different examples of self-etch resin cements (Linkmax®- GC), (Panavia F20®- Kuraray)

Self-Adhesive Resin Cements have been introduced as one-component "universal adhesive cements". These cements can bond in a single step to untreated tooth surface that has not been micro-abraded or pretreated with an etchant, primer, or bonding agent. These cements contain phosphoric acid, which is grafted within the resin. Once mixing is initiated, the phosphoric acid reacts with filler particles and dentin forming a bond (57). These cements bond better to dentin than to enamel (46). Enamel bonding is improved when an etchant and bonding agent are applied (58). This "selective-etch" technique uses an etchant or a self-etching primer before applying the self-adhesive resin cement. However, a lower bond strength to dentin was shown when the phosphoric acid pre-etch was applied to dentin (58). When tested without the pre-etch, self-adhesive resin cements have been shown to produce fairly strong bonds to dentin (59, 60). Pavan and colleagues found that dentin pretreatment with polyacrylic acid improved the bond strength of a slef-adhesive resin cement to dentin (61).

Figure 24: Shows different examples of self-adhesive resin cements (Relyx unicem 2®- 3M ESPE), (Maxcem Elite®, Kerr)

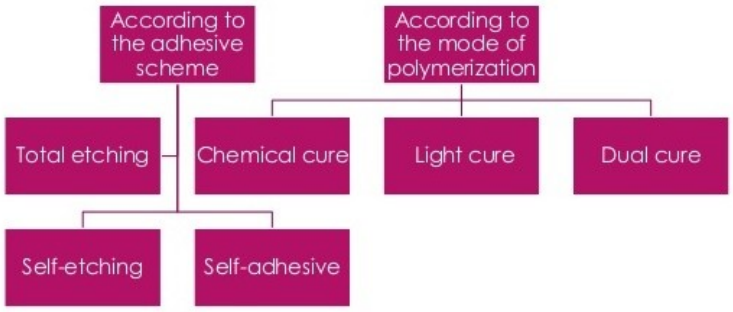


Figure 25: Shows the classification of resin cements

In general, flowable composites have a decreased filler concentration compared with restorative composites. Most flowable composites are filled between 41% and 53% by volume, which is dependent on the type and shape of the filler material. The amount of filler material can also be expressed by weight, which is usually higher (ie, 41% to 53% by volume would equal 56% to 70% by weight) (62). Weight is more commonly used by manufacturers because of the higher number. If the amount of filler content is increased, then the flow is minimized, which would decrease the polymerization shrinkage, but increase the difficulty in fully seating a restoration when used as a luting cement (63).

An ideal luting cement would have low polymerization shrinkage, high filler content for strength, and high flowability, allowing a restoration to be easily placed. When a composite resin has a greater filler volume, molecules have less space to compact, thereby decreasing

polymerization shrinkage (64). If the filler content of a flowable composite was in the range of a sculptable restorative composite (70% to 80%) and shared the same physical properties, it may be a desirable substitute for resin cement (63).

Flowable composites have been suggested for use as an alternative in cementing ceramic retsorations (48). Barceleiro et al found similar results when bonding feldspathic porcelain to bovine enamel using a dual-cure resin cement and a light-cure flowable composite. Their study suggested the use of flowable composites as a suitable alternative luting agent when bonding porcelain laminate veneers that were less than 2 mm in thickness (65). Prieto et al studied nanoleakage patterns of leucite-reinforced ceramic bonded to enamel using different resin systems and flowable composites. They concluded that the use of a two-step etch-and-rinse adhesive with a flowable composite as a luting agent created an adequate seal at the bond interface at the enamel (66).

Not all flowable composites are the same. There is a wide variety of flowable composites with a range of physical properties that include flow, flexural strength, modulus of elasticity, and radiopacity, as well as filler content (66). Flexural strengths have been reported to range between 66 MPa [67] and as high as 145 MPa (63).

Figure 26: Shows different examples of flowable resin composites (Filtec Z350®- 3M ESPE), (Tetric Evoflow®- Ivoclar Vivadent)

Preheating resin composites makes placement of restorations easier and improves monomer conversion (68) without promoting changes in the optical properties (69). Almeida et al

compared the optical properties of light-polymerizing cement (RelyX Veneer), flowable composite resin (Filtek Z350 Flow), or composite resin preheated for 30 minutes at 60°C (Filtek Z350 XT). They found that flowable and preheated composite resins had similar color stability to that of light-polymerizing resin-based cement (70).

In addition, preheating of composite resins may be an alternative way to increase the microshear bond strength of composites on dentin (71). Furthermore, Preheating hybrid composite decreases its viscosity and film thickness offering the clinician improved handling, enhanced composite adaptation to cavity walls together with an increased degree of polymerization and depth-of-cure (72-75). However, Preheating composite to relatively high temperatures (54 degrees C or 68 degrees C) to increase its flow and adaptation causes an increase in volumetric shrinkage (76). Moreover, preheated composite resin thickness is greater than that of veneer cements and flowable composite resins (77, 78).

Figure 27: Shows different examples of composite heaters (Ease it composite softener®- Ronvig), (Heatsync®- Bioclear matrix)

2.5 Marginal gap

The marginal gap is the perpendicular distance from the internal surface of the restoration to the finish line of the preparation (79). Horizontal discrepancies, such as crown overhangs, can be adjusted to some degree intraorally. However, a vertical MG can only be closed with

luting cement, which is prone to dissolution (80). For this reason, the vertical marginal gap has the most clinical relevance and should be regarded as the most critical in crown margin evaluation (81).

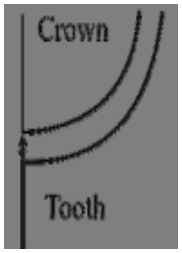


Figure 28: Shows the vertical marginal gap between the tooth and the crown (82)

Marginal fit is one of the basic factors in the success of restorations (83, 84). Poor marginal fit might lead to cement dissolution, marginal discoloration, microleakage, and secondary caries (80). Therefore, it is very important to minimize marginal gaps to decrease the incidence of associated complications.

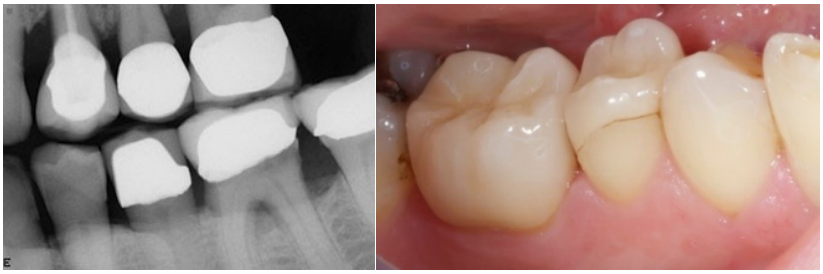


Figure 29: Shows the results of poor marginal fit (secondary caries, and marginal discoloration) (85)

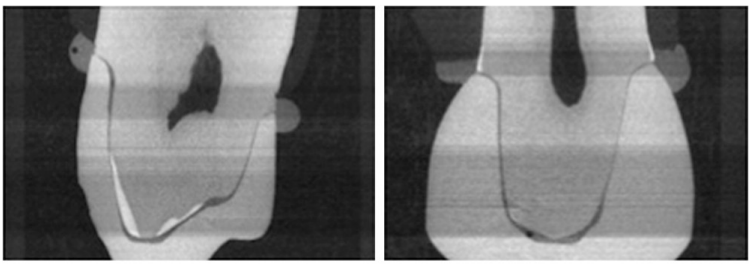
Review of the literature highlights the wide diversity of methodologies used to assess the level of adaptation of prostheses (86). Methods of evaluating marginal gaps might include:

1. Microphotography and light microscope (87) (88), laser microscope (89) or stereomicroscope (90, 91). Stereomicroscope techniques require a transverse section

of the crown and tooth to measure misfit, but this can cause deformations (92). Analysis involving a scanning electron microscope can be inaccurate if the angle of the specimen is not correct (93).

2. Measurement with the silicone replica of the misfit between the restoration and abutment. This replica is sectioned and evaluated under light or electronic microscopy (94, 95).
3. Measurement of the tooth–prosthetic interface after cementing dental prostheses. The spacer is evaluated with light or electronic microscopy after sectioning (96-99).
4. Measurement by a triple scan protocol with a noncontact scanner and specific software to perform a virtual 3D analysis. Optical digitalization allows for very precise detection and virtual reproduction of dental surface structures. The prepared tooth and the fabricated ceramics are digitized with a structure light scanner featuring a measurement-uncertainty of 4 microns. Color-coded difference images are used to examine the match of preparation and restorations (29). Modern computer-aided techniques can better evaluate the fit of the restoration, because they yield much more extensive and informative data in 3 dimensions (100).
5. Three dimensional analysis has also proven valid and reliable (101, 102). Another advantage of this method is that unlike other methods, this one requires neither fit-checker nor several dies, making it easier and more fail-safe. The different images facilitate direct visual feedback encompassing the entire restoration and make it possible to locate the more imprecise areas (103).
6. Measuring by micro-CT technology (104, 105). A technique that has been suggested by Pelekanos et al. was the computerized xray microtomography, where multiple projections of an object were taken as the source rotated around it (106). The projections were transferred to a computer and with special software; small slices of the object's internal structure could be added to the object's 3- D image. Advantages of this technique included the ability to produce images of the internal structure of

the specimen, in section form, while allowing for 3-D reconstruction, and the possibility of obtaining very proximate sections (106). This 3-dimensional, high resolution imaging system provides detailed cross-sectional information concerning the crown-to-die fit without damaging the specimen (107, 108). On the other hand, the disadvantages that this method presented included the difficulty to define the materials that have different coefficients of absorption in comparison with the optical or electron microscope, and the possible artifacts from refraction of the images from radiation (109). Moreover, the m-CT system is relatively expensive (110).



A B

Figure 30: Shows an example of different sections of micro-CT analysis of the marginal gaps of crowns (111)

There is no consensus yet regarding the clinically acceptable marginal gap (MG). The maximum value of MG for good clinical prognosis was determined to be 200 µm by Bjorn *et al (112)*.

McLean and von Fraunhofer examined more than 1,000 crowns after five years of clinical service and stated that marginal discrepancies less than 120 µm were clinically acceptable (113), but other authors show that a marginal gap ≤100 microns is ideal, below this threshold, it is easily possible to remove excess composite without tearing composite out of the gap (94, 114). Others consider clinically a marginal gap ≤75 microns acceptable (115). However, a marginal gap between 25 and 40 microns was considered by some researchers

to be a clinical goal (116), but additional studies showed that it is difficult clinically to achieve such marginal gaps (117).

Many factors can affect the accuracy of restorations, including the type of dental restoration, material properties, preparation design, scanning device accuracy, software design, spacer settings, and milling machine accuracy (88, 91, 118). Many studies evaluated the marginal fit of different restorations (87, 119-121). The results show great variations. Evaluating the marginal discrepancy depends on several factors: the measurement of cemented or non-cemented restorations, the type of abutment used for the measurements, the type of microscope, the enlargement factor used for the measurement location, and the quantity of single measurements (122).

Ueda and colleagues compared the marginal fit of frameworks from cobalt-chromium (CoCr) and zirconia (Z). The results showed better marginal fit of CoCr and zirconia frameworks after digital impressions (DI) compared to frameworks after conventional impressions. Further on, frameworks from group DI-CoCr showed a better marginal fit than ones from group DI-Z, despite being fabricated on the same datasets. The different fabrication mode of CoCr and zirconia might explain these differences. After milling, the semi-sintered zirconia blanks applied in the present study had to be sintered to achieve final density and maximum strength of the material. This sintering process involves a sintering shrinkage of about 20–30 %, which has to be compensated for in the milling procedure. The extent of the shrinkage applies an extra challenge to the software that has to accurately calculate the milling of a 20–30 % enlarged framework that will shrink precisely to the required dimension during sintering (123). This procedure could negatively influence the final dimension of the restoration (124). On the other hand, CoCr blanks are milled in their original size without a sintering process (125).

Almeida and colleagues evaluated the marginal fit of CAD/CAM-generated four-unit zirconia fixed dental prostheses made with digital and conventional impressions. They concluded that

frameworks fabricated from digital and conventional impressions showed clinically acceptable marginal fit with no statistically significant differences (126).

There are controversial opinions on the marginal fit of pressed and CAD restorations in the literature. Some authors claimed that the combination of polyvinyl siloxane (PVS) impression method and press fabrication technique produced the most accurate marginal fits (127). Moreover, one-step impression methods resulted in statistically significantly less marginal and internal discrepancy than the two-step impression method. One-step impressions are the method of choice to obtain the most authentic reproduction of supra- and subgingival preparations (128).

Others concluded that pressed ceramics have marginal accuracy comparable to that of metal restorations (129). Other studies have shown that milled ceramic restorations had inferior marginal fit compared to pressed restorations (83). The marginal inaccuracy of the early CAD/CAM restorations was attributed to the CAD/CAM system (low-resolution scanning and inadequate computing power) and not to the ceramic material itself (130).

Several studies have reported that the marginal fit of CAD/CAM restorations is dependent on different factors that include margin configuration and die space thickness (120, 131-133). Suggestions that scanning, software, and machining have a detrimental effect on the fit of CAD/CAM restorations have also been made (91, 134-137).

Software limitations in designing restorations and hardware limitations within scanning equipment and the milling machine are possible short- comings in the CAD/CAM technique. With the advancement of software programs, design algorithms, and milling units, the CAD/CAM accuracy has been improved. Moreover, the expertise with the Cerec device and the clinical skills of the operator during preparation also impact the outcome of CAD/CAM fabricated restoration (138).

Recent advances have occurred in CAD/CAM technologies that claim to produce more accurately fitting restorations (36). Guth et al reported that direct digitalization with the (Lava™ C.O.S) had the potential to improve the accuracy of fixed dental prostheses as compared to conventional impression making and indirect digitalization (139).

The conventional method requires the meticulous securing of a negative replica of the dentition with a stable recording medium, for example, an elastomeric impression material, to minimize errors in crown fabrication (140, 141). Transporting the impression to a commercial dental laboratory subjects an impression to significant variation in temperature, which has been shown to result in significant dimensional changes (142). Moreover, the length of time between securing an impression and the pouring of the stone cast, the ambient temperature, the surface wettability of the gypsum product, and disinfection may result in additional distortion (143, 144). The application of die spacer, the fabrication of a wax pattern of the intended crown, and the investment and casting or pressing process may also induce errors (145, 146). The impossibility of controlling all the variables, combined with a propensity for human error, can result in poor marginal fit and even misfit. The use of the digital method decreases the chances for error and should produce better fitting crowns (81).

Another important factor in the literature is the cementation of crowns before evaluating the marginal fit. Many authors analyzed cemented crowns (117, 122, 147). The marginal gap generally increases after luting (105, 119, 135, 148). It has been reported that the marginal gap increased by about 13 to 50um when the crown was luted with cement (122, 138, 148-151). Yuksel and Zaimoglu found that self-adhesive resin cement showed less microleakage than glass-ionomer cement (152). On the other hand, Quintas and colleagues found no significant differences in the marginal gap, when using different types of luting agent. The luting agents tested were zinc phosphate (SS White, Brazil), resin-modified glass ionomer

cement (Fuji Plus; GC America), and resin composite cement (Panavia F; J Morita USA) (135).

Ayad and colleagues found no significant differences between the marginal gaps when using zinc phosphate cement (Fleck's), glass ionomer cement (Ketac-Cem), and adhesive resin cement (Panavia 21) (153).

Celik and Gemalmaz Compared in-vitro the marginal integrity of ceramic and composite restorations luted with two different resin agents: (Variolink II) high viscosity and (Variolink Ultra) highly filled resin luting agent. No significant differences were recorded between the marginal gaps in relation to different types of luting agents (154).

Van Den Breemer and colleagues concluded that the use of highly viscous cement is recommended with large marginal gaps, while there is no advantage when using it for small marginal gaps (155).

Blalock and colleagues compared the film thickness of a variety of preheated commercial composite resins to those of flowable resins. No difference in thickness existed between composite resins preheated to 54 degrees C and 60 degrees C. However, room temperature and preheated conventional composite resin provided film thickness greater than that of flowable materials (77).

Sampaio and colleagues studied the film thickness of different luting agents. They concluded that veneer cements and flowable composite resins had significantly lower film thickness than the film thickness of direct restorative composite resins, preheated or not (78).

No cementation protocol for lithium disilicate restorations can be considered as superior in clinical performance according to the reviewed literature (155). Moreover, one can notice the different results regarding the effect of type of luting cement on the marginal gap after fixation. Furthermore, it is not clear if the restorations produced by the more advanced CAD–CAM systems show comparable adaptation level to the restorations produced by the dental

laboratory technician as the literature is usually limited to the comparison among different CAD–CAM systems (35, 117, 130, 131, 136, 156, 157) and only few studies have a control group (124, 158). Therefore, we conducted our study.

3 AIMS OF STUDY

The study had two aims:

1. Compare the marginal fit of e.max press and e.max CAD crowns.
2. Compare the marginal elevation of e.max press crowns after fixation using different resin luting cements.

4 MATERIALS AND METHODS

4.1 Sample preparation

Twenty intact extracted lower third molars were collected at the department of oral surgery- Faculty of medicine and dentistry- Palacky university. Teeth were then disinfected in a 10% formaline solution for 7 days (Histofor, Pro-charitu, Czech republic) (159). Afterwards, teeth were inserted in acrylic bases made from mixing acrylic powder and liquid (Dentalon, Heraeus Kulzer GmbH, Germany). Teeth were then prepared under magnification 4x (Univet, Italy) to receive a ceramic crown according to the following criteria: Chamfer finishing line 1mm, occlusal reduction 2mm, axial reduction 1.5mm.

Figure 31: Shows the loupes used for magnification during tooth preparation

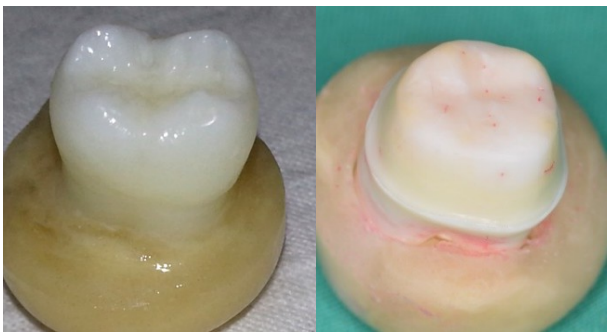


Figure 32: Shows an extracted tooth in the acrylic base before and after preparation

Next, teeth were digitally scanned using (CEREC omnicam, Sirona, Germany). Crowns were designed on the software (CEREC SW 4.4, Sirona, Germany), before milling 20 e.max CAD crowns from blocks (IPS e.max CAD, Ivoclar vivadent, Liechtenstein) by a milling machine (CEREC MC XL, Sirona, Germany), and then fully crystallized in a special furnace.

Figure 33: Shows defining the finishing line and insertion axis on the software

Figure 34: Shows crown design on the software

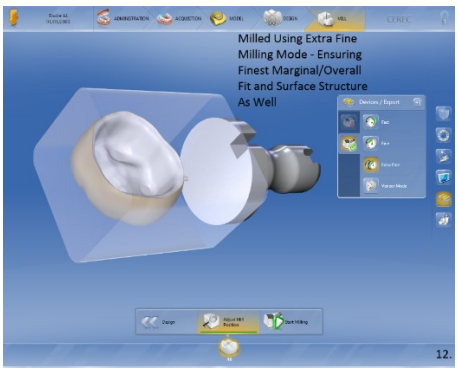


Figure 35: Shows complete fit of the crown in the ceramic block on the software

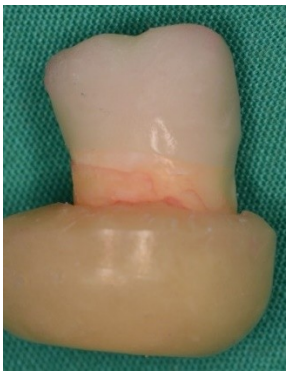


Figure 36: Shows an e.max CAD crown on a prepared tooth

20 impressions of the prepared teeth were made using additional silicone (Express heavybody + light body, 3M, USA). Stone models (Shera premium type IV, SHERA, Germany) were then fabricated, on which crowns were modulated from wax (Geo classic opak, Renfert, Germany). The wax crowns were attached to wax sprues and invested in flasks using an investment material (Pressvest speed, Ivoclar vivadent, Liechtenstein), before burning the wax out in a furnace. Afterwards, e.max press ingots (IPS e.max press, Ivoclar vivadent, Liechtenstein) were heat-pressed into the space created by the wax. The crowns were then removed from the flasks, sprues were cut, and the crowns were finished and polished.

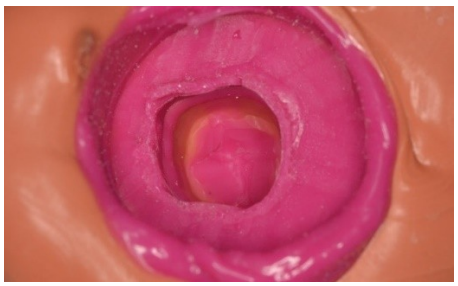


Figure 37: Shows an impression of the prepared tooth using additional silicone

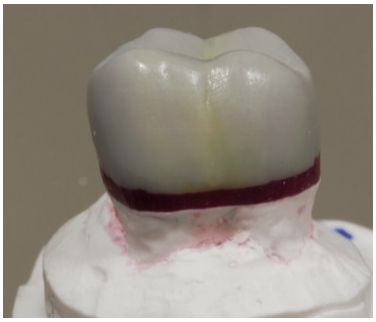


Figure 38: Shows the waxing of a crown on a stone model

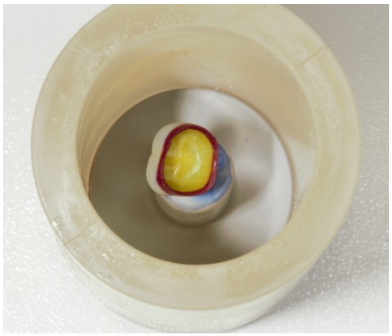


Figure 39: Shows the crown after waxing, attaching to a sprue, and insertion into a flask before investment

Figure 40: Shows the pressing of e.max press ingot into the space created in the investment material after wax burn out

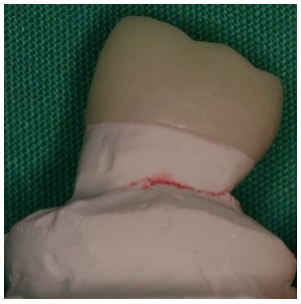


Figure 41: Shows an e.max press crown on a stone model

As a result, 20 e.max press crowns and 20 e.max CAD crowns were finally fabricated.

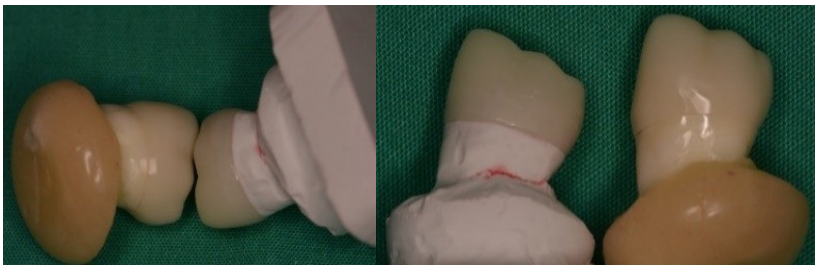


Figure 42: Shows an e.max CAD crown on a prepared tooth and an e.max press crown on a stone model

4.2 Measurement of the marginal gap

Measuring the marginal gap was done at the faculty of science - Palacky university using optical microscope at 200x magnification (Keyence VHX-5000, Japan) and a special image analyzing software attached to the microscope. The measurements were achieved on 25 points on the finishing line on each tooth. The mean marginal gap for every tooth was calculated from the 25 points measured on it. The mean marginal gap for each group (e.max press and e.max CAD) was then calculated. Statistical analysis was done using Willcoxon test to compare the mean marginal gap of e.max press and e.max CAD groups. In addition, Kruskal-Wallis test was used to show if there are statistically significant differences between the values measured on the different teeth for each technique.

Figure 43: Shows the microscope used for measuring the marginal gap

4.3 Fixation of crowns

18 out of the 20 E.max press crowns were chosen randomly and then divided into 3 groups (6 crowns in each group) according to the luting cement to be used. Group 1: Harvard® flowable cement. Group 2: Relyx ultimate® cement. Group 3: Enamel® preheated

composite. The intaglio surface of the crowns was treated before cementation similarly in all groups: Etching with hydrofluoric acid 9% (Porcelain etch®, Ultradent) for 20 seconds- rinsing with water and air- immersion in 96% alcohol (Ethanolum 96%, TAMDA a.s- Czech republic) in ultrasonic bath (ZZlinker, China) for 5 min before air drying - silane application on the etched surface with a microbrush (Ceramic silane®, Ultradent) - bond application with a microbrush (Optibond FL®, Kerr) in group 1 and 3, (Single bond® universal adhesive, 3M) in group 2.

Figure 44: Shows the hydrofluoric acid and silane used to prepare the ceramic surface

Figure 45: Shows the application of hydrofluoric acid, ultrasonic cleaning with alcohol, and silane application to prepare the ceramic surface

Figure 46: Shows the bonding agent (Optibond FL®, Kerr) used in group 1 and 3 and the bonding agent (single bond- 3M ESPE®) used in group 2

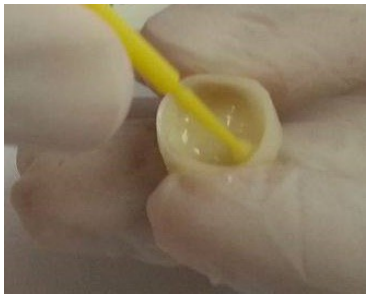


Figure 47: Shows the application of bonding agent (Optibond FL®, Kerr in group 1 and 3 and single bond® in group 2) to the ceramic surface

Teeth in group 1 were treated as follows: Etching enamel with phosphoric acid 37% (Total etch®, Ivoclar vivadent) for 30 seconds and dentin for 15 seconds- rinsing with water and air before air drying- primer (Optibond FL®, Kerr) application on dentin with a microbrush- Bond (Optibond FL®, Kerr) application on enamel and dentin with a microbrush- flowable composite (Harvard® dental international GmbH) application inside the crown- seating the crown on the tooth with finger pressure- cleaning the excess material with a microbrush before light curing for 60 seconds from all sides using a lamp (VALO® cordless, Ultradent).

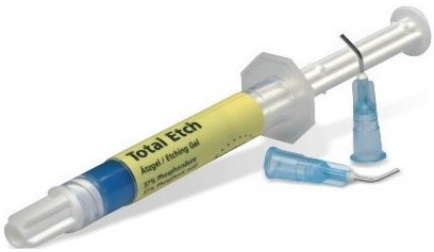


Figure 48: Shows the etching gel

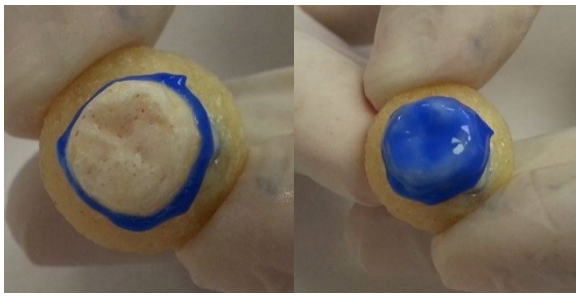


Figure 49: Shows the etching process of enamel and dentin

Figure 50: Shows the bonding agent (primer and bond) used in group 1

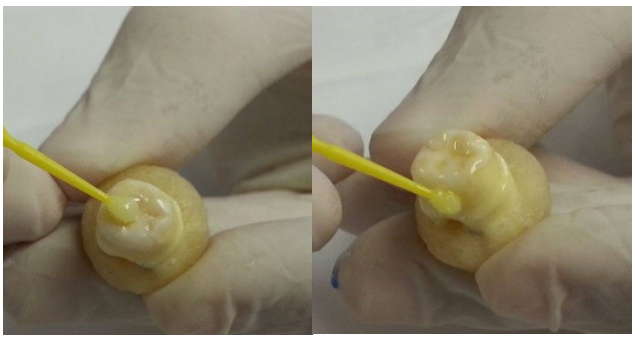


Figure 51: Shows the application of bonding agent (primer and bond)

Figure 52: Shows the flowable composite used in group 1

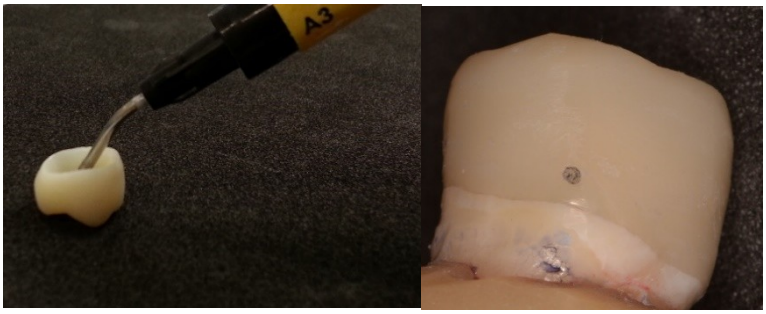


Figure 53: Shows the application of cement inside the crown and the crown after fixation on the prepared tooth

Figure 54: Shows the lamp used for light curing the cement after fixation

Teeth in group 2 were treated as follows: Etching only enamel with a phosphoric acid 37% (Total etch®, Ivoclar vivadent) for 30 seconds (selective etch)- rinsing with water and air before air drying- bond (Single bone®, 3M) application with a microbrush on dentin and enamel- mixing the cement (Relyx ultimate®, 3M) after delivery from the clicker- cement application inside the crown- seating the crown on the tooth with finger pressure- cleaning the excess material with a microbrush before light curing for 60 seconds from all sides using a lamp (VALO® cordless, Ultradent).

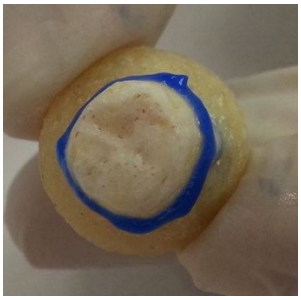


Figure 55: Shows the etching process of enamel

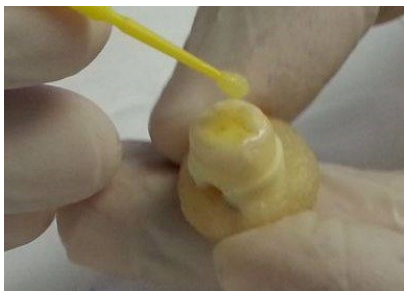


Figure 56: Shows the application of bonding agent (Single bond®, 3M)

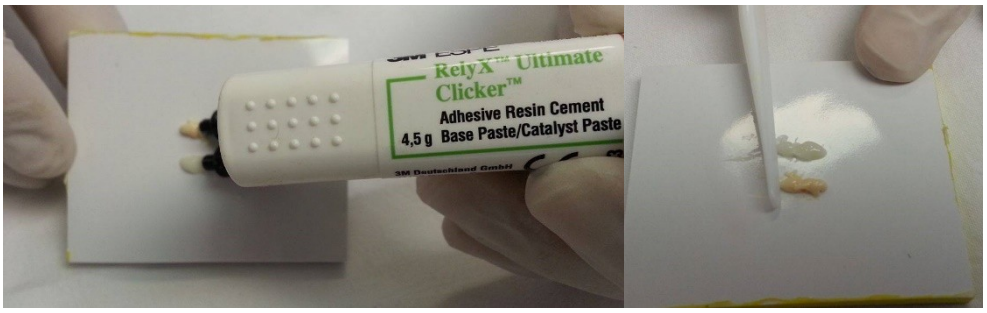


Figure 57: Shows the dual-cure resin cement and the mixing of the cement used in group 2

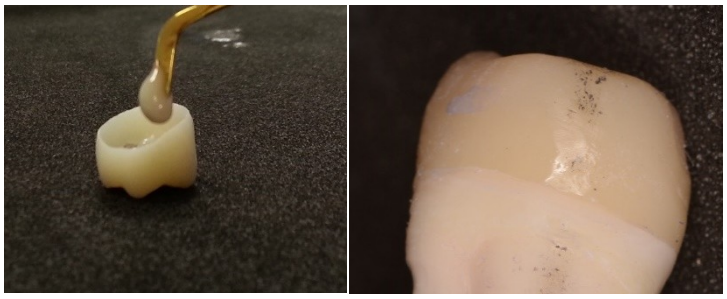


Figure 58: Shows the application of cement inside the crown and the crown after fixation on the prepared tooth

Teeth in group 3 were treated as follows: Etching enamel with phosphoric acid 37% (Total etch®, Ivoclar vivadent) for 30 seconds and dentin for 15 seconds- rinsing with water and air before air drying- primer (Optibond FL®, Kerr) application on dentin with a microbrush- Bond (Optibond FL®, Kerr) application on enamel and dentin with a microbrush - application of preheated composite (Enamel® plus HRi, Micerium SPA + heater ENA® heat, Micerium

SPA for 1 hour at temperature 55° C) inside the crown- seating the crown on the tooth with finger pressure- cleaning the excess material with a microbrush before light curing for 60 seconds from all sides using a lamp (VALO® cordless, Ultradent).

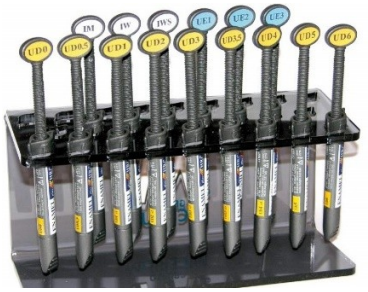


Figure 59: Shows the resin composite used in group 3

Figure 60: Shows the resin composite heater used in group 3

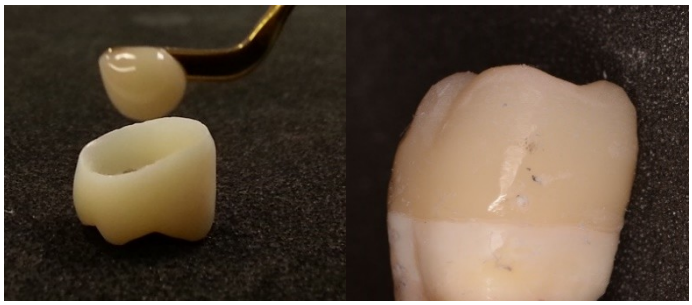


Figure 61: Shows the application of cement inside the crown and the crown after fixation on the prepared tooth

4.4 Measurement of the marginal gap after fixation

Measurements were performed at the faculty of science- Palacky university using optical microscope at 200x magnification (Keyence VHX-5000, Japan) and a special image analyzing software attached to the microscope. Four points were chosen on every tooth (mesial, distal, buccal, lingual). At each point, two dots were drilled: One dot was drilled on the tooth directly below the finishing line, and the other dot was drilled on each crown of the 18 e.max press chosen just close to its margin. Measuring the marginal gap between the two dots was done before fixation and after fixation, and the difference between the two measurements was considered as the marginal elevation. The measurements were achieved on the four points on each tooth. The mean marginal elevation for every tooth was calculated from the 4 points on it.

The mean marginal elevation was calculated for every group (Harvard® flowable, Relyx ultimate®, Enamel® preheated composite). Statistical analysis was done using Kruskal-Wallis test to compare the mean marginal elevation between the three groups.

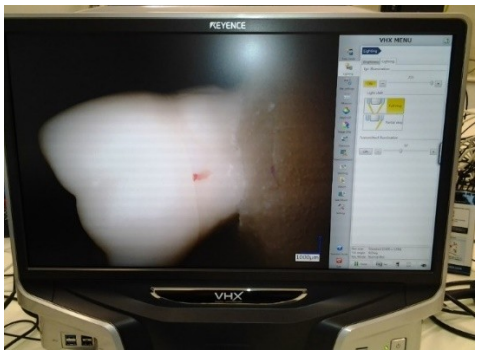


Figure 62: Shows the software used for measuring the marginal gap before and after fixation

5 RESULTS

5.1 Results of marginal gaps before fixation

Shapiro-Wilk normality test showed that data do not have normal distribution. Therefore, the comparison was performed by non-parametric Wilcoxon test. This test showed that e.max press crowns had statistically significantly lower values of marginal gaps compared to e.max CAD crowns (P-value 0.006). The mean marginal gap of e.max press crowns was (37.75 ± 12.46 SD microns), while the mean marginal gap of e.max CAD crowns was (45.24 ± 12.34 SD microns). Distribution of data is shown in a box chart. The horizontal line in the box represents the median value (figure 63). The minimum, maximum, and mean marginal gaps are shown in table 1. Kruskal-Wallis test showed that the values measured on the different teeth had statistically significant differences in each technique (press and CAD) ($p < 0.0001$). Box charts show the distribution of values for every tooth in each technique (figures 65,66).

CAD					Press					p
Median	Min	Max	Mean	SD	Median	Min	Max	Mean	SD	
44,00	26,88	70,24	45,24	12,34	31,46	26,52	66,44	37,75	12,46	0,006

Table 1: Shows the minimum, maximum, and mean marginal gaps of e.max CAD and e.max press crowns

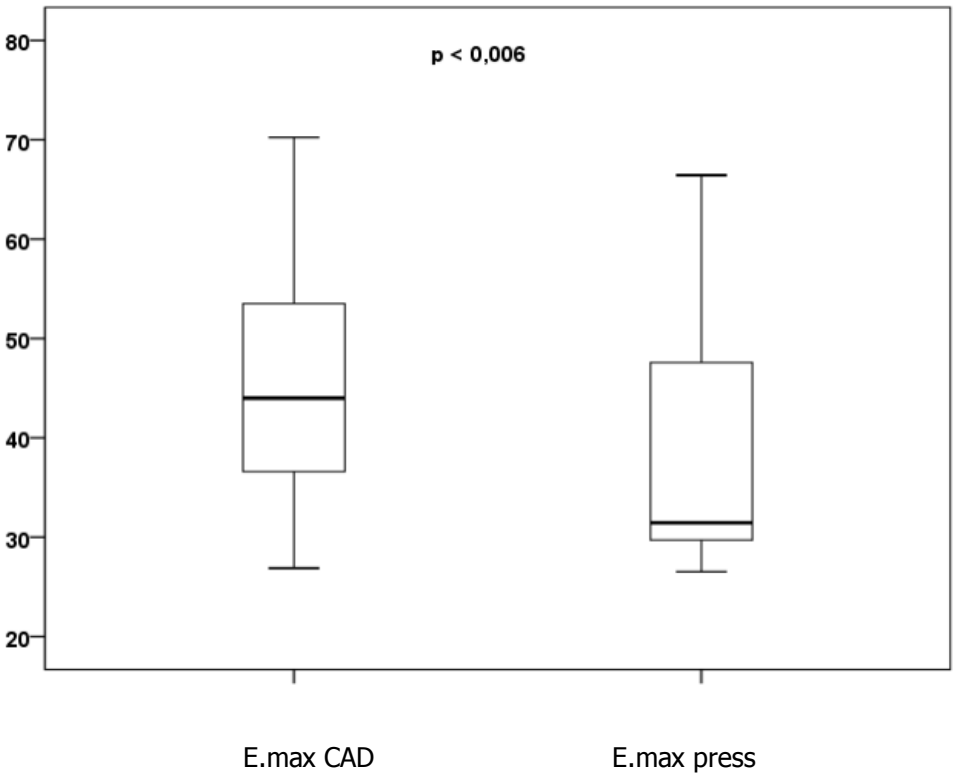


Figure 63: Shows distribution of data in a box chart. The horizontal line in the box represents the median value

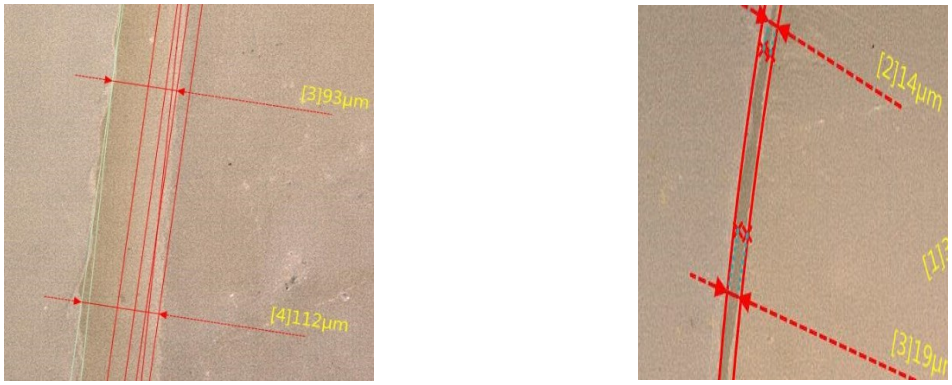
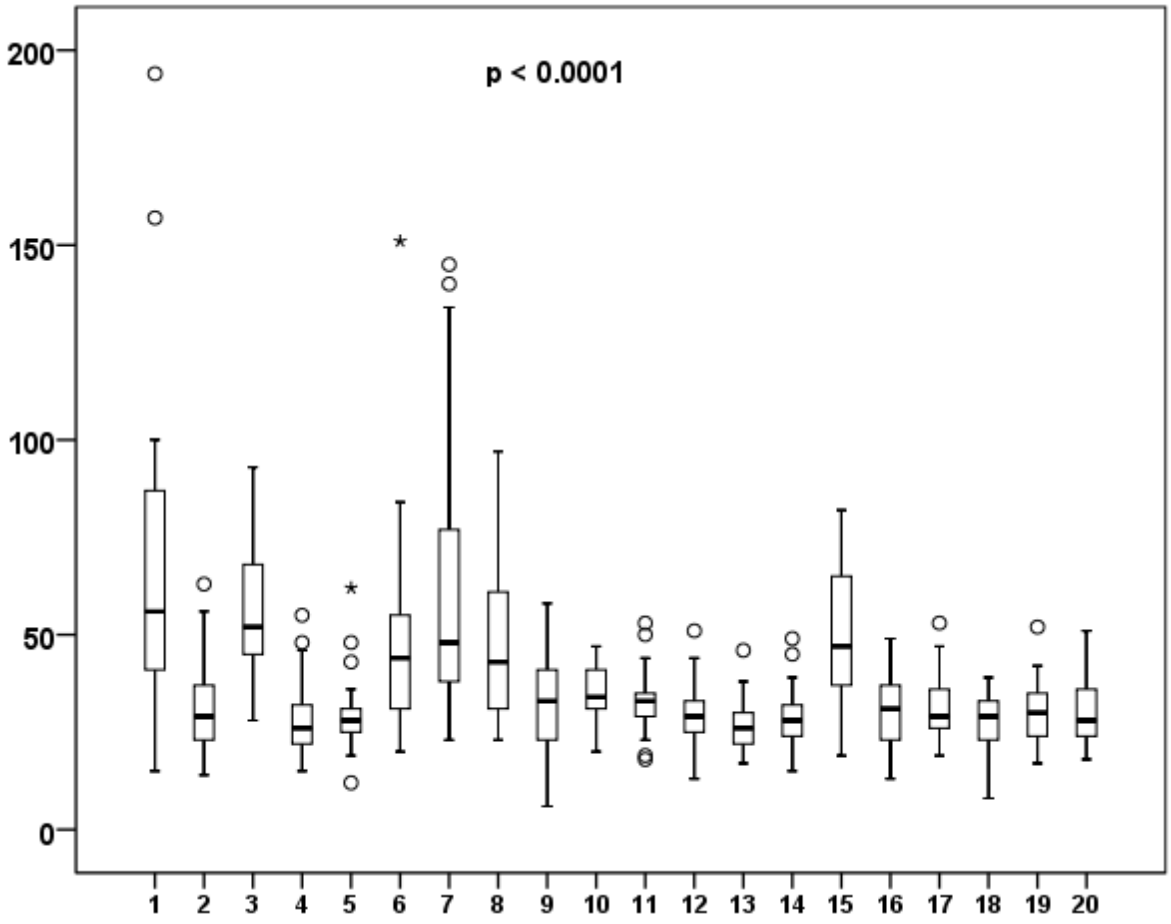


Figure 64: Shows an example of the measurements done on an e.max CAD and e.max press crown



E.max press

Figure 65: Shows distribution of data for each tooth with the press technique in a box chart. The horizontal line in the box represents the median value in microns

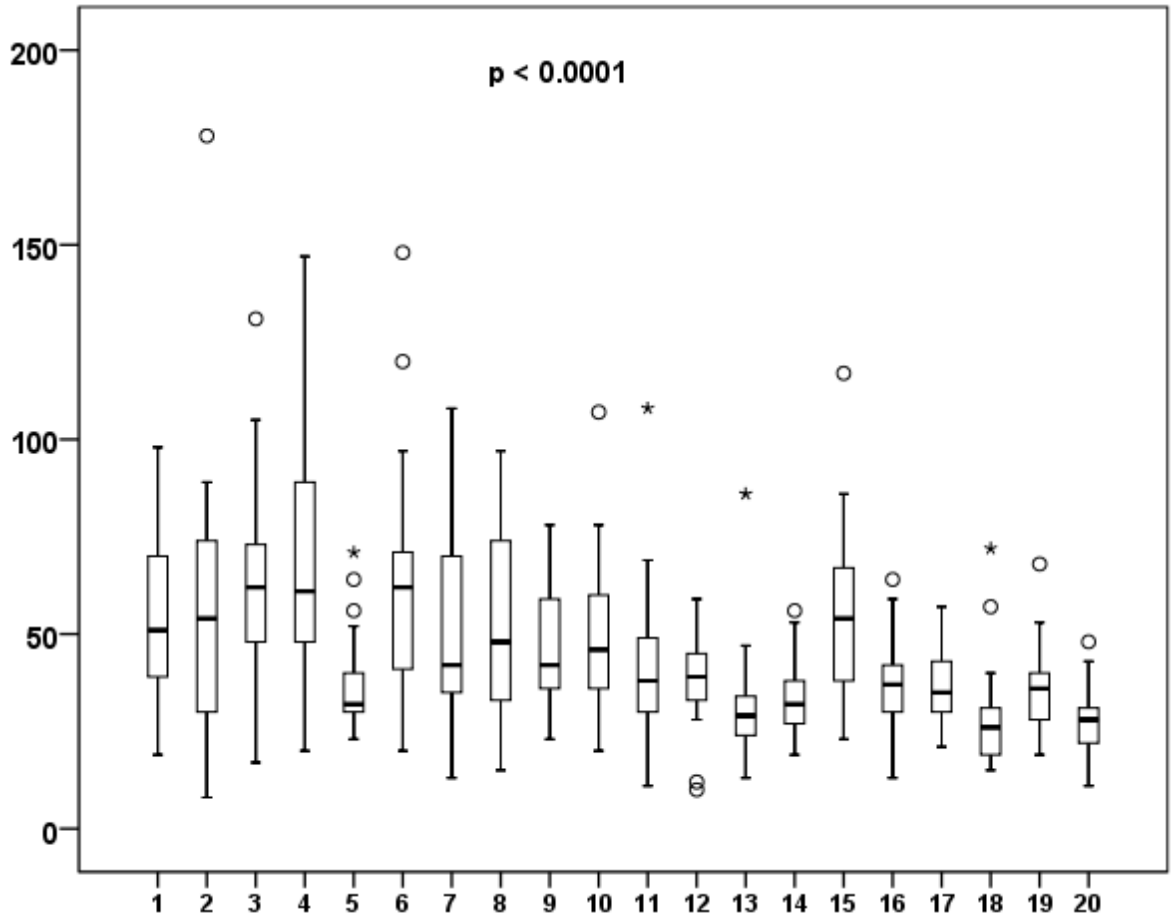


Figure 66: Shows distribution of data for each tooth with the CAD technique in a box chart. The horizontal line in the box represents the median value in microns

5.2 Results of marginal gaps after fixation

The comparison was performed by non-parametric Kruskal-Wallis test. This test was chosen because of the small sample sizes. The test showed statistically significant differences between groups ($p = 0.019$). Subsequently, post hoc tests of multiple comparisons were performed. These tests demonstrated that the preheated composite Enamel® had a

significantly higher value than Harvard® flowable (p = 0.031). No significant difference were found between Harvard® and Relyx ultimate® cement (p = 1.000) nor between Relyx ultimate® and Enamel® (p = 0.075). The mean marginal elevation was as follows: Group1 (mean: 41.88, SD: 11.38), group2 (mean: 45.17, SD: 29.07), and group3 (mean: 116.13, SD: 46.73).

VAR00001	Mean	Std. Deviation	Minimum	Maximum	Median
Harvard®	41,88	11,38	30,00	59,50	40,13
Relyx®	45,17	29,07	21,25	99,50	39,75
Enamel®	116,13	46,73	44,50	186,25	123,50
Total	67,72	46,60	21,25	186,25	47,38

Table 2: Shows the results of marginal elevation of the different resin cements used

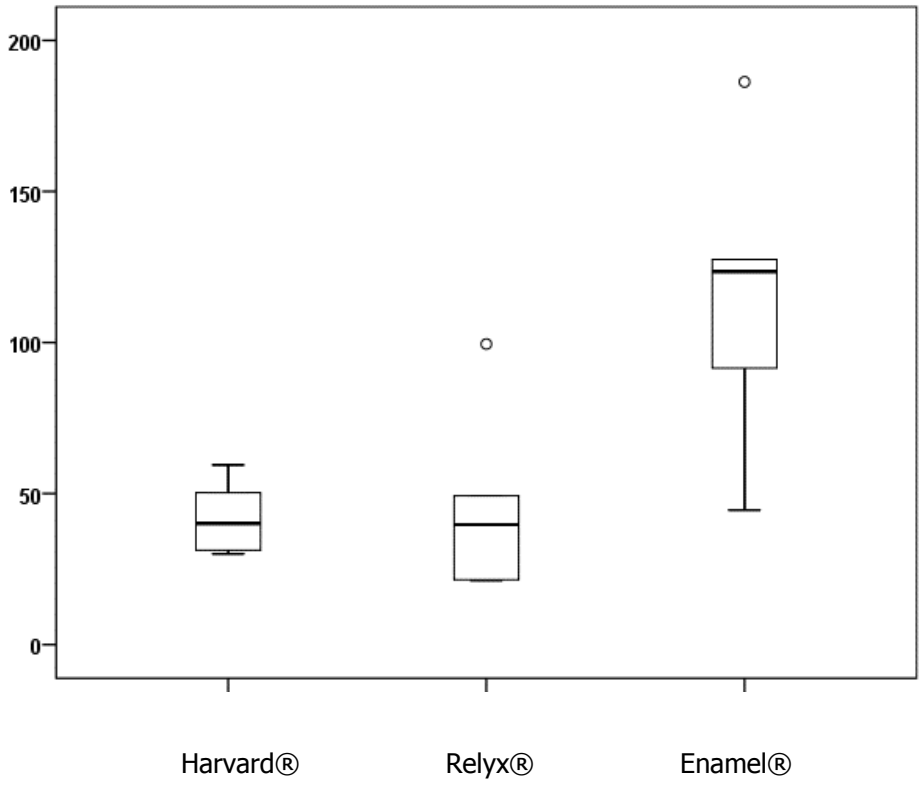
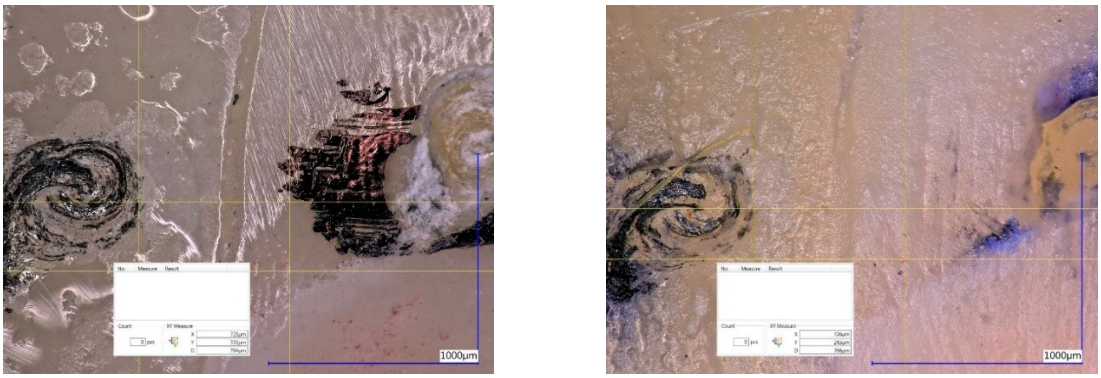
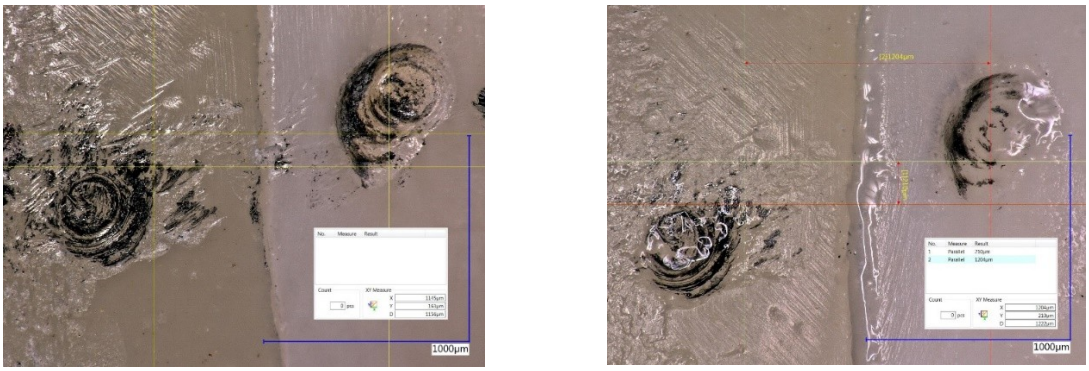


Figure 67: Shows distribution of data in a box chart. The horizontal line in the box represents the median value



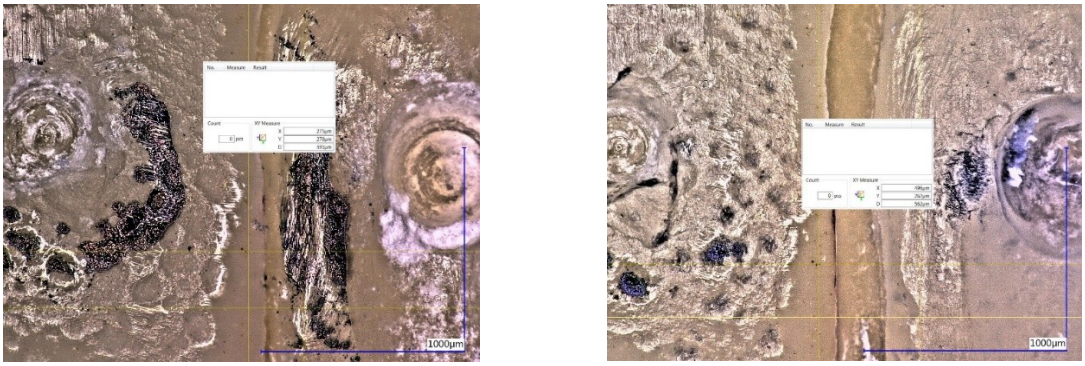
A B

Figure 68: Shows the marginal gap (A) before and (B) after cementation with Harvard® flowable composite



A B

Figure 69: Shows the marginal gap (A) before and (B) after cementation with Relyx ultimate®



A B

Figure 70: Shows the marginal gap (A) before and (B) after cementation with Enamel® preheated composite

6 DISCUSSION

The results of our study showed statistically significant differences between the marginal fit of e.max CAD and e.max press crowns. The mean marginal gap was 37.75 microns in the e.max press group, while it was 45.24 microns in the e.max CAD group.

Guess and colleagues (138) compared the marginal fit of e.max CAD (CEREC 3D InLab) and e.max press onlays. Marginal gaps were measured using a stereomicroscope at 200x magnification (Zeiss Axioskop Zeiss, Oberkochen, Germany), a 3 CCD-colour videocamera (Sony 3CCD, Sony, Koln, Germany), and image analysis software (cell Imaging Software for Life Sciences Microscopy, Olympus Soft Imaging Solutions, Munster, Germany). The mean marginal gap for the e.max CAD group was 50.09 microns before cementation. The mean marginal gap for the e.max press group was 45.51 microns before cementation. The difference in the mean marginal gap was not significant between the two groups before cementation (P-value 0.29). The results are not in agreement with our study. This could be attributed to the different type of restorations used in their study (onlays) and in our study (crowns), different milling machine and software used in their study (CEREC inlab 3D, software V3.01, Sirona, Germany) while in our study (CEREC MC XL, software SW 4.4, Sirona, Germany), or the different type of microscope used (stereomicroscope), while in our study (optical microscope).

Ng and colleagues (81) compared the marginal gaps of e.max CAD (LAVA C.O.S. scanning unit) and e.max press crowns. The marginal gap was measured at 40x magnification before cementation with a digital camera (5D Mark II 21-mp; Canon) mounted on a stereomicroscope (Edmund E-Zoom; Edmund Optics Inc) and a program for photos calibration and measurements (Image J 1.32; U.S. National Institutes of Health). The mean marginal gap was significantly higher for the e.max Press group (74 microns) than for the

E.max CAD group (48 microns). The results do not agree with our study. This might be due to the different scanning unit used in their study (LAVA™ C.O.S) while in our study (CEREC omnicam, Sirona, Germany), different milling machine (DMG, Mori seiki) while in our study (CEREC MC XL, Sirona, Germany), different magnification used (40x) while in our study (200x), or the use of a different type of microscope.

Mously and colleagues (160) assessed the marginal fit of e.max CAD (E4D scanner) and e.max press crowns. Four groups were studied: Group 1: e.max CAD with a 30 micron spacer, group 2: e.max CAD with a 60 micron spacer, group 3: e.max CAD with a 100 micron spacer, group 4: e.max press. The marginal gap was evaluated with microcomputed tomography, micro-XCT (mCT 40; Scanco Medical) and a software for analyzing images (Image J software -National Institutes of Health). The median marginal gap was: Group 1: 55.18 (50.70-76.25) microns, group 2: 49.35 (32.30- 56.10) microns, group 3: 46.65 (30.55-58.15) microns, group 4: 30.80 (24.35- 41.75) microns. The marginal gap was significantly lower in the e.max press group than the e.max CAD groups (P-value = 0.005) (160). In contrast with the results reported by Ng and colleagues, this study concluded that the marginal gaps of the e.max CAD specimens were significantly higher than the e.max press specimens. This might be due to the differences in the CAD systems used in these studies, E4D system in the study of Mously and colleagues and LAVA C.O.S. system in the study of Ng and colleagues. The results of this study are in agreement with our study.

Neves and colleagues (161) compared the marginal fit of e.max CAD and e.max press crowns. Three groups were assessed: Group 1 (e.max CAD CEREC 3D bluecam scanner), group 2 (e.max CAD E4D laser scanner), group 3 (e.max Press). The marginal gap was measured by a processing software (v1.12.0.0; Sky-Scan) after micro CT scanning. The mean marginal gap was 39.2 ± 8.7 SD microns for group 1, 66.9 ± 31.9 SD microns for group 2, and 36.8 ± 13.9 SD microns for group 3. E.max Lithium disilicate crowns fabricated with either the - heat-press technique or Cerec 3D Bluecam scanner CAD/CAM - achieved

significantly smaller marginal gaps than crowns fabricated with the -CAD/CAM E4D Laser scanner- (P-value 0.046) (161). The results compare favourably with the CAD E4D results of Mously and colleagues. They show that the e.max press technique has better results than the E4D, and that different CAD techniques such as the CEREC 3D bluecam scanner or alternative technologies used by other authors may produce excellent outcomes for CAD/CAM fabricated prostheses.

Anadioti and colleagues (127) compared the marginal fit of e.max CAD and e.max press crowns in combination with conventional (PVS) and optical impressions (Lava™ C.O.S). The study was divided into 4 groups: Group 1 (PVS + Press), group 2 (PVS + CAD), group 3 (Optical + Press), group 4 (Optical + CAD). The marginal fit was assessed in 2 dimensions and 3 dimensions on a computer software (Geomagic Qualify 2012, Research Triangle Park, NC) after the sample was digitized by a laser scanner (Laser Design Inc, GKS, Minneapolis, MN). The mean marginal gap was:

Group 1: 2D measurement (40 ± 9 SD microns), 3D measurement (48 ± 9 SD microns),

Group 2: 2D measurement (76 ± 23 SD microns), 3D measurement (88 ± 24 SD microns),

Group 3: 2D measurement (75 ± 15 SD microns), 3D measurement (89 ± 20 SD microns),

Group 4: 2D measurement (74 ± 26 SD microns), 3D measurement (84 ± 21 SD microns).

The smallest marginal gap was found in the first group (Conventional impression + e.max press) 3D (48microns) and 2D (40 microns), which was significantly smaller than in the other groups (P-value <0.0001) (127). These results are in agreement with our study. In addition, the results agree with the results of Mously and colleagues, which also showed that the e.max press restorations achieved by silicon impressions had small marginal gaps.

The results of our study showed that the mean marginal gap of e.max crowns fabricated with the CAD technique was significantly higher than the mean marginal gap of e.max

crowns fabricated with the press technique. This could be attributed to the limitations within the CAD system, including the different steps in the process of crown fabrication (scanning, design, milling, etc...). However, the results of marginal gaps of the current study and the previously mentioned studies comparing the CAD technique with the press technique, regardless of the statistical significance of the differences or insignificance, are still far from perfect when considering the marginal gap from the molecular and bacterial level. Therefore, more advances are required to improve both techniques (press and CAD) to be able to achieve much smaller marginal gaps. The question then arises: Will the technology be able to achieve such a goal? Is it possible to see such developments in the near horizon?

Despite the fact, that the study was achieved on the same type of teeth (intact lower third molars) and the same preparation protocol was followed on every tooth, the marginal gaps were statistically significantly different between the different teeth in each technique (press and CAD). This could be explained by that the teeth in this study were prepared by an individual and not a machine, making it difficult to absolutely achieve the same preparation on all teeth. Thus, the final shape of preparation could differ between different teeth and in turn might influence the fit of crowns.

Regarding the cementation of crowns, many authors found an increase in the marginal gap after fixation (105, 119, 135). Moreover, adhesive cementation causes a significant increase of the marginal discrepancies of restorations (149). Our results showed similar results with an increase in the marginal gap in all cases with all the resin luting cements used.

In most studies in the literature, the marginal gap elevation after fixation ranged between 13 to 50 microns (122, 138, 148-151). Guess and colleagues had a mean elevation of the marginal gaps around 17 microns for the e.max press restorations after fixation with resin luting cement (Variolink II) (138). Borges and colleagues had a mean elevation of the marginal gaps around 37 microns after fixation of e.max press crowns with resin cement (Variolink II) (151). Sakrana examined the fit of two types of all-ceramic single crowns and

indirect composite resin full coverage crowns before and after cementation with self-adhesive resin cement. She found an increase in the marginal gap after fixation of 24-40 microns (148).

Stappert and colleagues had an elevation of the marginal gaps of e.max press restorations from 20-50 microns after fixation with a resin luting cement (Variolink II) (150).

In our study, we had an elevation of the marginal gaps with Harvard® flowable composite (mean 41.88 microns, SD 11.38), Relyx ultimate® (mean 45.17 microns, SD 29.07), and Enamel® preheated composite (mean 116.13 microns, SD 46.73). The results demonstrated that the preheated composite Enamel® had a significantly higher value of marginal elevation than Harvard® flowable ($p = 0.031$). Our results agree with the study of Sampaio and colleagues, where they found that preheated restorative composite (68^{o} C) makes higher film thickness (300 microns) compared to flowable resins (150 microns) (78). Our results agree as well with Blalock and colleagues who found an average film thickness of flowable resin composites (35 microns) and preheated resin composites at 54^{o} C (140 microns) (77).

The non-significance in the statistical differences between group 2 (Relyx ultimate®) and group 3 (Enamel® preheated composite) could be attributed to the small size of the samples (6 teeth in every group). However, it is clear from the results that Enamel® preheated composite had the highest amount of marginal elevation in comparison with the other used resin luting agents. This could be related to the consistency of this material and the difficulty in fully seating the restoration and pushing the excess cement out during fixation. The results of our study show that Enamel® preheated composite caused an extremely high marginal elevation, pushing the results too high out of the range of marginal elevation of the previous studies. Therefore, we do not recommend its use for crown fixation and we recommend the use of more flowable resin cements. Thus, the practitioner has better ability to seat the restoration with minimum elevation of the margins during fixation.

The results of this study are limited by some aspects of its methodology. The study was achieved on only e.max crowns. Thus, the results cannot be applied to other types of restorations or other restorative materials. The measurements were done using an optical microscope, due to the availability of this microscope at Palacky university and the low expenses related to its use. However, the optical microscope is reliable and high magnification 200x was used for greater accuracy. The authors acknowledge the limitations, but also espouse the contribution that this study has made to the knowledge base in this growing field.

Despite the drawbacks found in our study, there were also positive sides which give this study its importance. The sample size in the first part of study was sufficiently large to avoid type II errors, and allow confidence in the significant results reported. The study was conducted on extracted human teeth and this allowed the behavior of the teeth under experimental investigations to be as similar as possible to the intraoral environment. The marginal gap was measured at different locations for each restoration in this study, minimizing measurement error and allowing the circumferential fit of the restoration to be estimated with the highest accuracy.

This study provides information about the dimensions of vertical marginal gaps that can be achieved under experimental conditions in-vitro with e.max lithium disilicate. However, these in-vitro measurements do not necessarily reflect clinical environment. Each in-vitro study may differ considerably from everyday clinical practice. Differences might include (the existence of soft tissues and saliva make intraoral tooth preparation and impression making much more complicated than in-vitro ones, and other related factors), which means that the results have decreased external validity. Despite this limitation, the information reported provides researchers with an important starting point to guide hypotheses for future clinical research. Further studies are required in three separate domains: (1) to determine whether these marginal gaps can be achieved in a clinical environment; (2) the consequences of such

marginal gaps on the longevity of restorations; and (3) to study marginal gaps across different restorative materials and different luting agents.

7 CONCLUSION

Within the limitations of this study, we conclude that,

- The e.max press crowns had statistically significantly smaller marginal gaps than the e.max CAD crowns. However, the mean marginal gap of all e.max lithium disilicate crowns appraised in this study, regardless of technique, was within the clinically acceptable range.

- The final shape of preparation and intrapersonal variability might influence the marginal gap.

- The cementation process increased the marginal gap for the three luting cements evaluated. However, preheated composite (Enamel®) had measurably higher marginal gaps than flowable composite (Harvard®) and dual-cure resin cement (Relyx ultimate®).

8 LIST OF FIGURES

9 LIST OF TABLES

10 ACKNOWLEDGMENT

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Iam thankful to my home country Syria and i hope that peace will spread in every part of it soon. Iam also thankful to Czech republic which became my second home.

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