EFFECT OF FIRING ON THE MARGINAL FIT OF HEAT-PRESSED LITHIUM DISILICATE VENEERS: AN IN-VITRO STUDY

A Thesis

by

PANAGIOTIS GAKIS

Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Chair of Committee,	William W. Nagy
Committee Members,	Elias Kontogiorgos
	John T. Goodman
	Jorge Gonzalez
Head of Department,	Larry L. Bellinger

May 2018

Major Subject: Oral Biology

ABSTRACT

The purpose of this in vitro study was to evaluate and compare the marginal fit of heat-pressed lithium disilicate veneers fabricated with the “staining”, or “cut-back” technique, using 3D analysis. Two groups of ten specimens were fabricated and each group differed in core thickness and the fabrication process. Group S was a full contour veneer, with one glaze firing. Group CB had a “cut-buck” core of 0.6mm on the cervical and middle third and 0.5mm on the incisal areas, with three firings (wash, incisal and glaze firing). Marginal fit was evaluated at two stages; first after the copings were pressed (baseline) and second after the fabrication of the veneers.

The wax copings were processed and pressed with IPS e.max lithium disilicate LT, and the overall marginal fit, along with measurements from the cervical, mesial, distal and incisal areas were obtained using the virtual replica technique.

The Shapiro-Wilk test was used to evaluate normality. A student T-test (α=.05) was used to evaluate differences between and within the groups in the four locations; cervical, mesial, distal and incisal. A statistically significant difference was found for the incisal area of the CB group (p=0.04). In all other areas of measurements, no statistically significant differences were found. The overall marginal fit of group S and CB was 61.5 µm (8.4) and 67.5 µm (9.7) respectively. The increase of marginal discrepancy on the incisal of CB group was attributed to the porcelain application.

The results suggest that heat-pressed lithium disilicate veneers fabricated either with the “staining” or with the “cut-back” technique produce marginal discrepancies within the clinical acceptable standard.

DEDICATION

To my parents, Pantelis and Olga, and my siblings, Nikos and Irini, for their constant support and love.

To my professors in Dental school and graduate studies in Texas A & M college of dentistry, who provide me with the motivation and inspiration.

ACKNOWLEDGEMENTS

I would like to thank my Thesis Committee Members; Dr. William Nagy, Dr. John T. Goodman, Dr. Elias Kontogiorgos, and Dr. Jorge Gonzalez. I thank each of you for your time and dedication.

To my mentor, Dr. William W. Nagy, I sincerely thank you for investing so much into the success of your students. Thank you.

Dr. Stephanie Zeller for her constant help, assistance and guidance with the Geomagic software.

A special thank you to my co-residents past and present.

CONTRIBUTORS AND FUNDING SOURCES

Contributors

This work was supervised by a thesis committee consisting of Drs William W. Nagy [advisor], John T. Goodman and Elias Kontogiorgos of the Department of Restorative sciences and Dr Jorge Gonzalez of the Department of Oral and Maxillofacial Surgery.

The data analyzed for Section 2 was provided by Dr Elias Kontogiorgos.

Funding Sources

Graduate study was supported by a research grant from Texas A&M University and the Stanley Tylman Grant from the American Academy of Fixed Prosthodontics.

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION AND LITERATURE REVIEW

An increasing number of patients are seeking dental treatment to enhance their smile by restoring unaesthetic anterior teeth. Porcelain laminate veneers are a predictable and conservative option, with high rates of long-term success (95.6% at 10 years)[1], that can improve tooth shade, shape, or position and require a small amount of tooth structure to be sacrificed[2].

Porcelain veneers were first introduced in 1938 by Dr. Charles Pincus[3] who described a technique in which porcelain veneers where temporarily retained in the mouth of actors with the use of denture adhesive. As soon as the filming was finished the veneers were removed.

In the late’s 40’s Oskar Hagger developed the first bonding system based on the glycerophosphoric acid dimethacrylate for enamel and dentin bonding[4]. Buanocore was the first in 1955 that described the etching of the enamel with phosphoric acid[5] a technique still in use today. In 1983 Simonsen and Calamia[6] introduced a special acid- etching procedures that improved the long-term retention of porcelain veneer and renewed the interest in ceramic veneers.

Early ceramic veneers were fabricated with low fusing feldspathic porcelain using a refractory die or a platinum foil technique. The combination of ceramic and platinum foil was first used by Land, in 1886. However, Horn described the use of platinum foil to fabricate veneers in 1983. Interestingly, the American dental technician, Daniel Materdomini, was the true inventor of the modern platinum foil ceramic veneer[7].

In the refractory die technique, the technician apply porcelain directly to the die, which becomes the firing tray. Hunt claimed that this technique can produce less wrapage and distortion.

Heat-pressable ceramics were developed to decrease inhomogeneities and porosities that usually occurred during conventional sintering[8]. IPS e.max, introduced in 2005 by Ivoclar Vivadent and it is the successor to Empress 2. E.max consists of lithium disilicate crystals (SiO2-Li2O) which are embedded into a matrix of glass to minimize microcrack propagation[9], thereby improving mechanical stability[10]. Lithium disilicate is a glassy ceramic that consists of quartz, lithium dioxide, phosphor oxide, alumina, potassium oxide and other components. The material has high flexural strength that can exceed 360 MPa[11]. The lost-wax technique can be used to fabricate heat-pressable lithium disilicate restorations. Ingots of lithium disilicate are pressed under heat to mold the final restoration in a porcelain furnace, designed for these types of restorations. This technique presents less processing errors compared to conventional sintering and improve mechanical stability[12].

Two techniques have been described using heat-pressed ceramics for the fabrication of ceramic crowns[13]; the "staining technique" and a "layering technique". In the "layering technique", a wax pattern coping is fabricated, and feldspathic porcelain is added to obtain the definitive shape and shade. According to the manufacturer, three minimum firings are required: wash, incisal, and glazing/charcterization firing. For the "staining technique" the wax pattern coping is pressed and subjected to only one firing, a glazing/characterization firing.

According to Holmes[14], the marginal fit of any dental restoration is essential to its long-term success. It is a fact that most luting agents are soluble in saliva and any discrepancy in the margins can potentially cause periodontal problems, caries, and discoloration due to the accumulation of bacteria. Goodacre et al. in a literature review found that the most common complications associated with conventional fixed partial dentures were caries, which accounted for 18% of abutments and 0.4% for single crowns[15]. Orstavik evaluated the attachment of Streptococcus sanguis to dental crown cements under in vitro conditions. He was able to demonstrate that cements do in fact serve as a suitable substrate for bacterial adhesion[16]. According to Fradeani[17], the main reason for categorizing a porcelain veneer as Beta, according to the modified US Public Health Service Criteria, was marginal discoloration, followed by contours, and marginal integrity. As a result, marginal fidelity is paramount for the long term prognosis of the restorations and the maintenance of dental and periodontal health.

Despite the high importance of marginal fidelity, there is no consensus on margin opening or misfit that is considered clinical acceptable. "Misfit" is the terminology that Holmes used to describe the "fit" of dental restorations[14]. In other words, "misfit" is the angular combination of the marginal gap and the extension error, overextension, or underextension, which results in the absolute marginal discrepancy. Several authors have attempted to establish criteria for what is the clinical acceptable margin opening. The American Dental Association (ADA) specification No. 8 indicates that the thickness of luting cement for a dental crown should be between 25-40 μm depending on the type of luting agent. [18]. Despite the fact that marginal openings in these range are considered as a clinical goal, they are seldom achieved in any clinical scenario[19]. Christensen evaluated the fit of of gold inlays in an in-vitro study with a group of dentists and he calculated that an acceptable gingival margin was 34 to 119 μm. Moreover, he concluded that the values for gingival margins were greater because they were more difficult to be evaluated. Ceramic marginal fit is a hot topic and fit values range (in μm) from 50-300 μm for all-ceramic restorations[21,22]. McLean and Von Fraunhofer established the clinical acceptable criteria of ≤120 μm and is the one used for most studies. These criteria were established in 1971, after they examined 1,000 crowns for a 5-year period and they concluded that margin openings less than 120 μm will be more likely to be successful[23]. Holmes, in an early study, measured the marginal fit of castable ceramics, Dicor, and compared it to that of type III gold crowns. The mean values of absolute marginal discrepancy for all locations ranged from 35 to 73 µm for the Dicor crowns [24]. As a result, this study provided a more acceptable standard by which more modern all-ceramic materials could be compared. However, there is no current consensus.

Several studies on feldspathic porcelain laminate veneers fabricated with either the refractory die technique or the platinum foil technique demonstrated a tendency to open margins at the cervico-proximal corners. These openings were two to four times larger than at the mid-labial position[25-27].

Sorensen in an in vitro study compared porcelain laminate veneers fabricated either with the refractory die technique or the platinum foil technique[25]. He found that the mean vertical discrepancy was 187 µm for the platinum foil technique and 242 µm for the refractory. Secondly, he found that openings on the interproximal areas where 2-3 times greater than the facial areas. He attributed this to the shrinkage of porcelain towards the greatest bulk of material.

Another study by Sim et al. compared the fit of porcelain veneers fabricated with the platinum foil technique, refractory die technique and cast ceramic technique[26]. They found similar trends when compared to Sorensen study, with the interproximal openings to be four times greater than the facial margins. However, the standard deviation was quite high, challenging the standardization of their techniques.

Three studies, two in-vivo and one in-vitro investigated heat-pressed lithium disilicate veneers.

Jha et al. in an in vivo study, compared the marginal fidelity and surface roughness of porcelain veneers fabricated by refractory die and pressing techniques[28]. After cementation, they used direct view with an optical microscope to evaluate the marginal gaps. Interestingly, they were unable to provide a value of misfit due to the nature of the research. They categorized their results as visible or no visible gap at 7 days and 3 months. They found no statistically significant difference between the groups.

In another in vitro study, Aboushelib et al. compared marginal fidelity and internal fit of heat-pressed and CAD/CAM lithium disilicate veneers[29]. They found that machinable ceramic veneers had a significantly higher marginal openings compared to pressable ceramic veneers. The horizontal and vertical misfit of the pressable ceramics were 105 µm and 242 µm respectively.

In the most recent in vivo study, Yuse et al. compared the marginal and internal adaptation of heat-pressed and CAD/CAM lithium disilicate laminate veneers[30]. They used a silicon replica technique for their measurements and their results were similar to Aboushelib's study. The marginal gap of heat-pressed lithium disilicate veneers was 295 µm.

Finally, it is unknown if firing affects the marginal fit of lithium disilicate veneers. One study by Cho et al. was evaluated whether multiple firings affected marginal integrity of pressable ceramic single crowns[13]. They concluded that the marginal gap increased during veneer application and decreased during the characterization and glazing firing cycle. The total marginal fit change after 5 firings was 0.33 µm for IPS e.max Press.

According to Groten et al. fifty measurements along the margin of a crown are required for a better representation of the marginal misfit[31]. This quantifiable number was the first to be reported as a minimum requirement.

There are many different ways to evaluate the marginal fit of crowns. However, they can be divided in two groups: 1. Invasive or destructive methods such as cross sectioning 2. Non invasive techniques or non destructive methods such as direct viewing, replica techniques, prolifometry, qualitative techniques, micro-CT scans.

In another classification, Sorensen classifies the measurement methods for marginal and internal misfit of restorations into 4 groups: 1. Direct view 2. Cross sectional 3. Impression technique 4. Visual examination[32]. Visual examination with an explorer is not a very common method due to inability to evaluate vertical discrepancies and subgingival margins[33]. According to Nawafleh[34], the direct view technique is used more often in the literature (47.5%), followed by cross-sectioning method (23.5%), and impression replica technique (20.2%).

The direct technique is less expensive and less time-consuming than other techniques and reduces the chance of error accumulation, as it eliminates steps that can produce errors such as cementing. A disadvantage of this method is that it cannot be used for an in vivo study. Moreover, magnification can make margins appear rounded and make difficult to accurately find areas of measurement.

The impression replica technique is a non destructive method to evaluate marginal discrepancies[34]. Two different techniques have been described. One uses a replica of the space between the die and the crown[35]. This is achieved by filling the intaglio of the restoration with light body polyvinyl siloxane impression material. After setting of the material, the restoration is removed and heavy body silicone is used to stabilize the light body silicone. Then the system of heavy and light body is removed and it is sectioned in different areas. Another technique utilizes an impression of the marginal areas with the crown placed on the abutment[36]. This technique has several drawbacks, such as difficulty in discriminating the margins of the restoration and the finishing lines of the tooth preparation; and it is technique sensitive due to the fact that tearing of the elastomeric film upon removal from the restoration can occur[33] or sectioning of the specimen in an oblique plane[37]. Finally, only few measurements are possible.

The cross-sectioning method allows for direct measurement of the cement thickness and marginal gap in the vertical and horizontal planes, minimizing software or repositioning errors[38]. It also permits a better evaluation of the marginal openings adjacent to the connector in FDP specimens. However, this method is a destructive method and does not allow the re-use of the same specimens after different manufacturing stages[39]. Moreover, a limited number of measurements can be obtained that does not represent the entire misfit space[40].

Profilometry is an accurate method that was used by Mitchell et al. but images in cases of vertical over-extension, resulting in false interpretation[41].

The micro -CT scan is a non-destructive method providing images of the intaglio surface of a specinmen, in section form, and at the same time allows for a 3-D reconstruction in each selected position. However, it has a low capacity of discrimination when compared with an optical or electron microscope (1.8 μm for microtomography and 0.3 μm and 0.25 nm for optical and electron microscope re- spectively). In addition, considering that the images result from radiation, there may be artifacts from refraction[42]. The more materials with different coefficients of absorption that exist, the more difficult it is to clearly define the lines between those materials using x-rays.

3-D analysis of marginal fit is a fairly new non-destructive technique that it has been introduced to evaluate marginal and internal fit of restorations. Luthardt used a modified replica technique to evaluate internal fit by digitizing the dies and the replica film[44]. In 2011, Holst used a triple scan protocol and come to the conclusion that the triple scan was a reliable method[45]. Anadioti et al used the same triple scan protocol proposed by Holst to evaluate the 2D and 3D marginal fit of pressed and CAD/CAM generated lithium disilicate crowns fabricated by conventional and digital impressions[43]. They found no statistical significant differences between 2D and 3D measurements and concluded that their method was reliable. In 2016, Lee proposed a modified technique for the replica film technique, similar to the one described by Luthardt[38]. He digitized the die and replica film and using the Geomagic control software he evaluated marginal discrepancies.

The aim of this study is to evaluate and compare the marginal fit of heat-pressed lithium disilicate veneers (E-max) fabricated with the two commonly used techniques: “staining” and “Cut-back”, using 3D analysis. The first null hypothesis is that there is no difference in marginal fit of heat-pressed porcelain veneers fabricated with the “staining” and “cut-back” technique. The second null hypothesis is that firing does not affect the marginal fit of lithium disilicate veneers fabricated with these two techniques.

2. MATERIALS AND METHODS

Twenty samples were used in this study. Samples were divided in two groups: ten in "cut-back" group (CB) and ten in "staining" group (S). Due to the fact that the measuring procedure was non-destructive, the ten specimens that were fabricated initially for each group, were used for evaluating the marginal fidelity after the different firing procedures. The two groups differed in core thickness and firing techniques. One group was a monolithic veneer, fabricated with the "staining" technique. The second group was a layered veneer, fabricated with the "cut-back" technique. After pressing, cores were placed on the master die and marginal gaps were measured using a 3-D impression replica technique. Then the same cores were used for porcelain application. Marginal gaps were evaluated again with the same technique. Measurements were made on the cervical, mesial, distal and incisal areas.

2.1 Master Die Fabrication

An ivorine maxillary central incisor (Viade Products Inc., Camarillo, CA) #9 was selected for the master die and a silicon pattern matrix was fabricated prior to the preparation of the tooth. The tooth was prepared for a lithium disilicate labial veneer, according to Ivoclar IPS e.max recommendations, with no sharp angles or edges and a chamfer finishing line (Figure 1).

Figure 1: Preparation of master ivorine tooth.

A laminate veneer preparation kit was used (K0162, Brasseler USA, Savannah, GA). A uniform reduction of 1.5 mm at the incisal third and facial reduction of 0.6mm in the cervical and in the middle third and 0.7mm in the incisal third was completed. The master die was duplicated with high-heat epoxy resin (Viade 9 Products Inc., Camarillo, CA) to minimize chances of damaging it during measuring procedures. Twenty custom trays were fabricated by using light cure material (Triad® TruTray™ VLC Custom Tray Material, Clear - Dentsply Intl) (Figure 2).

Figure 2: Custom tray fabrication.

An impression was made of the master die with heavy and light body VPS material (Aquasil Ultra). The impression was poured with type IV die stone (Resin rock, Whip mix). The master cast was based using a pin system (Axiopin) and a special stone for basing (Flowstone, Whip mix) (Figure 3).

Figure 3: Master cast fabrication with type IV dental stone.

2.2 Veneer Fabrication

2.2.1 Cut-back technique

The master die was coated with two layers of a newly opened die spacer to 1mm away from the margins (Tru-fit, Taub). Die hardener was applied on the die to increase wear resistance and decrease abrasion (Stone Die & Plaster Hardener -Taub). The master die was dipped in a wax dipping pot (Renfert) to create a wax coping with even thickness and minimum shrinkage. A full-contour wax-up was fabricated by using the full-contour silicon matrix (Figure 4).

Figure 4: Full contour wax-up for the “staining” group.

A cut-back of the incisal and middle third, created a coping with dimensions of 0.6mm circular and 0.5mm in the incisal third, meeting the minimum requirements as proposed by the manufacturer (Figure 5).

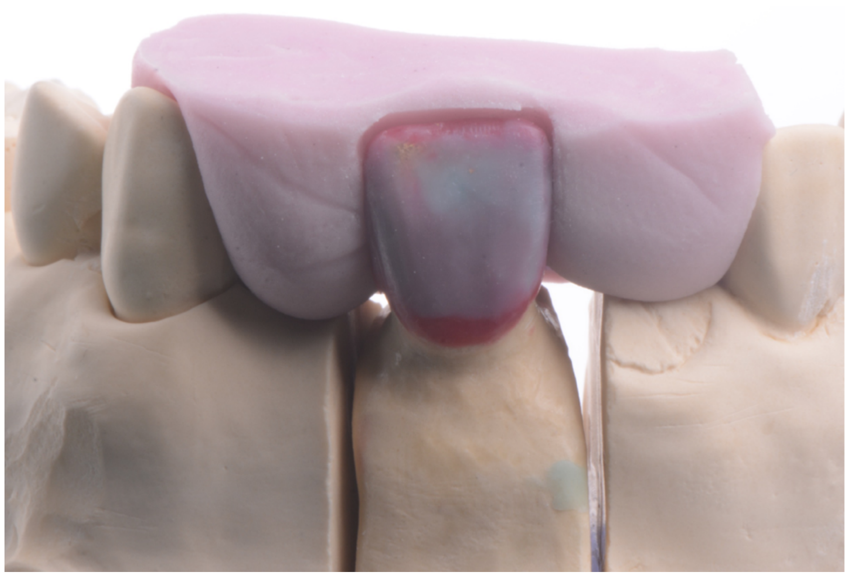

Figure 5: Coping for the “Cut-back” group.

A silicone putty cut-back matrix ensured adequate reduction. Each wax coping was sprued with an individual 4-mm long, 10-gauge wax sprue. Two copings were invested together per 100-gram investment ring (IPS Silicone Ring). Care was taken to ensure that each sprue was attached at a 45° angle to the base of the investment ring (Figure 6).

Figure 6: Sprue attached at a 45° angle to the base of the investment ring

Sprued copings were invested with a phosphate- bonded investment (IPS PressVEST Speed, Ivoclar Vivadent) (Figure 7).

Figure 7: Investment of wax copings with a phosphate- bonded investment

Following a 45-minute set time, the investment was removed from the plastic ring and placed in the preheated furnace (Apollo II Whip Mix, Louisville, KY) for an additional 45 minutes at 1562°F. After completion of the preheating cycle, one high-translucency IPS e.max Press ingot was inserted into the investment followed by placement of a disposable plunger. The loaded investment was immediately placed in the center of the hot press furnace (Vario Press 300 Zubler USA Inc., Irving, TX) and the press program recommended by the manufacturer was selected. Following pressing and cooling, veneers were divested using polishing beads at 60 psi for gross removal of investment material and 25 psi for fine removal of investment material directed 20 mm from the target (Figure 8).

Figure 8: Pressed IPS e.max copings immediately following divestment.

The pressed restorations were immersed in 0.5% hydrofluoric acid (Invex Liquid, Ivoclar Vivadent) to remove the reaction layer and ultrasonically cleaned for 20min. Sprues were removed with an aluminum- oxide separating disc (Keystone Industries, Gibbstown, NJ) with irrigation. Each veneer was fitted to its respective master die. Complete seating of the restoration onto the master die was confirmed visually with 2.5x magnification and with an explorer tip (EXPL-5/6, Brasseler USA, Savannah, GA). Due to the fact that measuring technique was non-destructive, the same cores were used to apply porcelain. The veneers were blasted with Al_2O_3 at 15 psi pressure. Surface was thoroughly cleaned with a steam jet and subsequently dried. A feldspathic ceramic matched to the system (IPS e.max Ceram; Ivoclar Vivadent) was used to complete the incisal veneer morphology (Figure 9).

Figure 9: Pressed IPS e.max veneer at the “cut-back” group following the three firings

Three firings were conducted; wash firing, incisal firing, and stain/glaze firing following manufacturer instructions (Table 1). The amount of porcelain applied was standardized by using a porcelain sampler (Smile line, Switzerland).

Table 1. Firing parameters for IPS e-max Press-Cut-back Technique

	Stand-by temperature	Closing time	Heating Rate	Firing temperature	Holding Time	Vacuum 1	Vacuum 2
Wash	403 ^{o}C	4:00 min	50 ^{o}C /min	750 ^{o}C	1:00 min	450 ^{o}C	749 ^{o}C
Incisal	403 ^{o}C	4:00 min	50 ^{o}C /min	750 ^{o}C	1:00 min	450 ^{o}C	749 ^{o}C
Galze	403 ^{o}C	6:00 min	60 ^{o}C /min	725 ^{o}C	1:00 min	450 ^{o}C	724 ^{o}C

2.2.2. Staining Technique

The same procedures were followed for the staining technique with the following modifications. The silicon matrix was used to fabricate full contours veneers that were pressed with the same ingots (Figure10). The difference with the “cut-back” group was that the glaze firing was conducted with different firing parameters (Table 2), as suggested from the manufacturer.

Figure 10: Pressed IPS e.max veneer at the "staining" group following glaze/staining firing.

Table 2. Firing parameters for IPS e-max Press-Staining Technique

IPS e.max Ceram	Stand-by temperature	Closing time	Heating Rate	Firing temperature	Holding Time	Vacuum 1	Vacuum 2
Glaze/stain firing	403 ^{o}C	6:00 min	60 ^{o}C /min	770 ^{o}C	1:00-2:00 min	450 ^{o}C	769 ^{o}C

2.3 Measuring Marginal Gap

Geomagic control software (3D systems) was used to evaluate marginal fit. The master dies were scanned with a laboratory scanner (3shape D900) and an STL files was produced. Each veneer was placed in its respective die and the space between the die and the veneers was replicated with low viscosity polyvinil siloxane (Aquasil Ultra) (Figure 11).

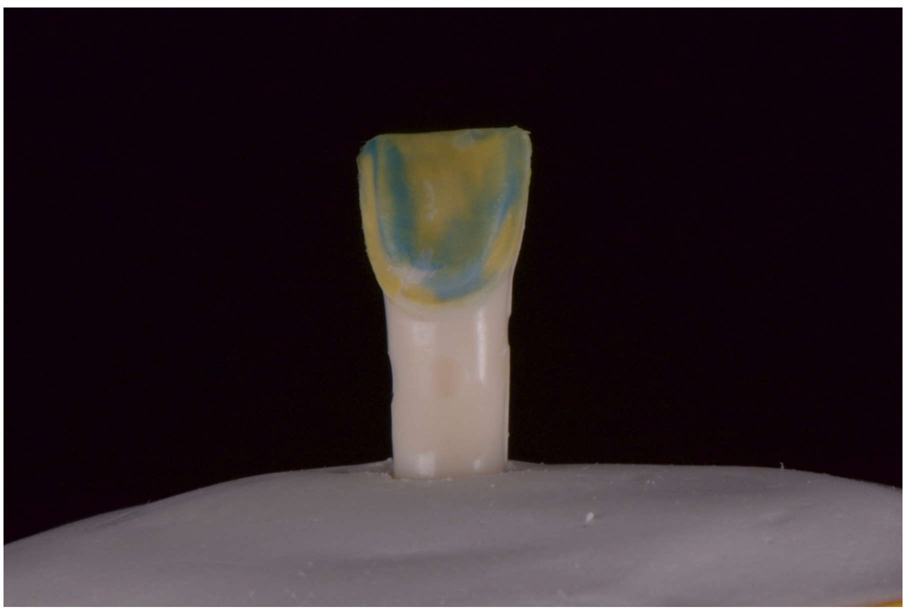

Figure 11: Impression replica

The replica then was scanned with the same lab scanner and a new STL file was generated. The two STL files were uploaded to the Geomagic software. The virtual dies with and without the impression replica were superimposed. First, a separate data set in STL format was generated from point clouds for the replica die specimen, containing 200,000 points (Figure 12)

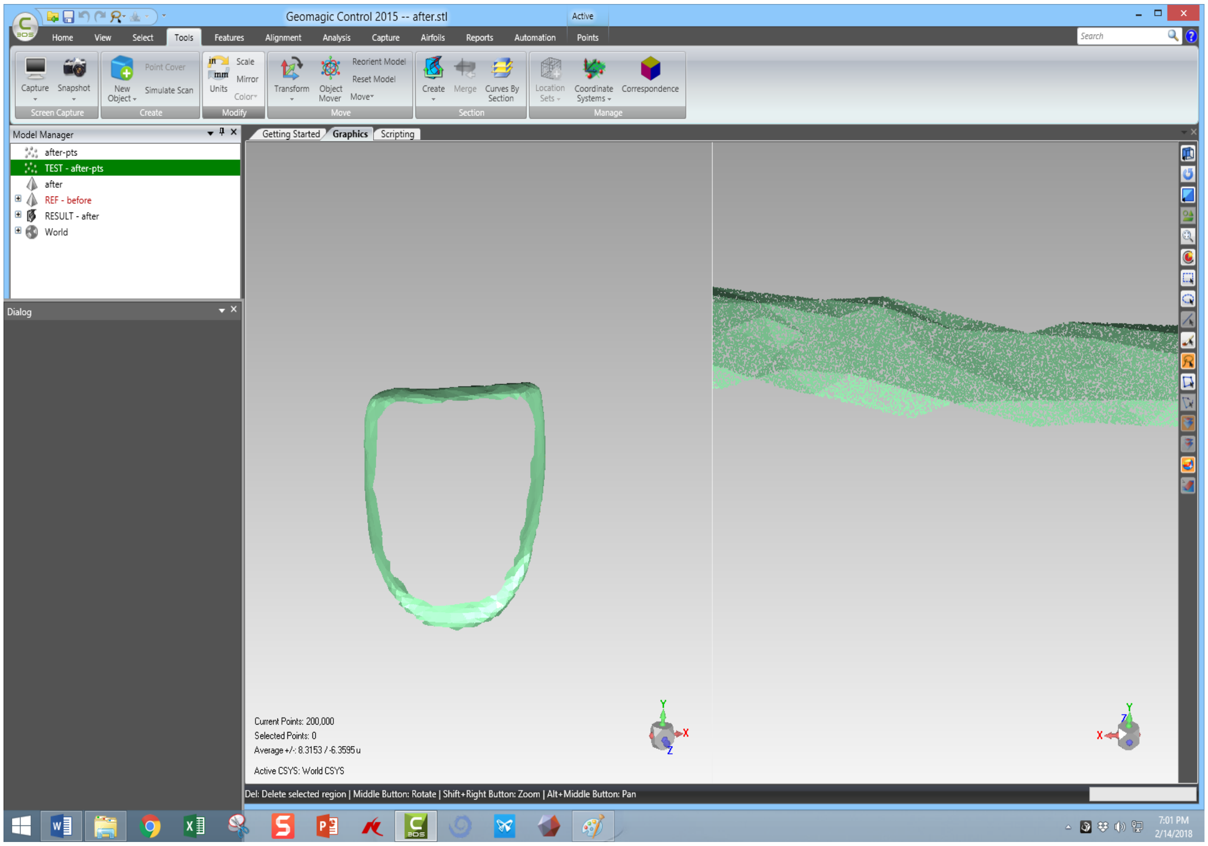

Figure 12: Convert STL file to point cloud.

Then, the die with and without replica were manually aligned using N-points alignment. Finally, a “best fit” alignment was used twice with zero tolerance. 3-D analysis was conducted to evaluate possible errors during alignment (Figure 13).

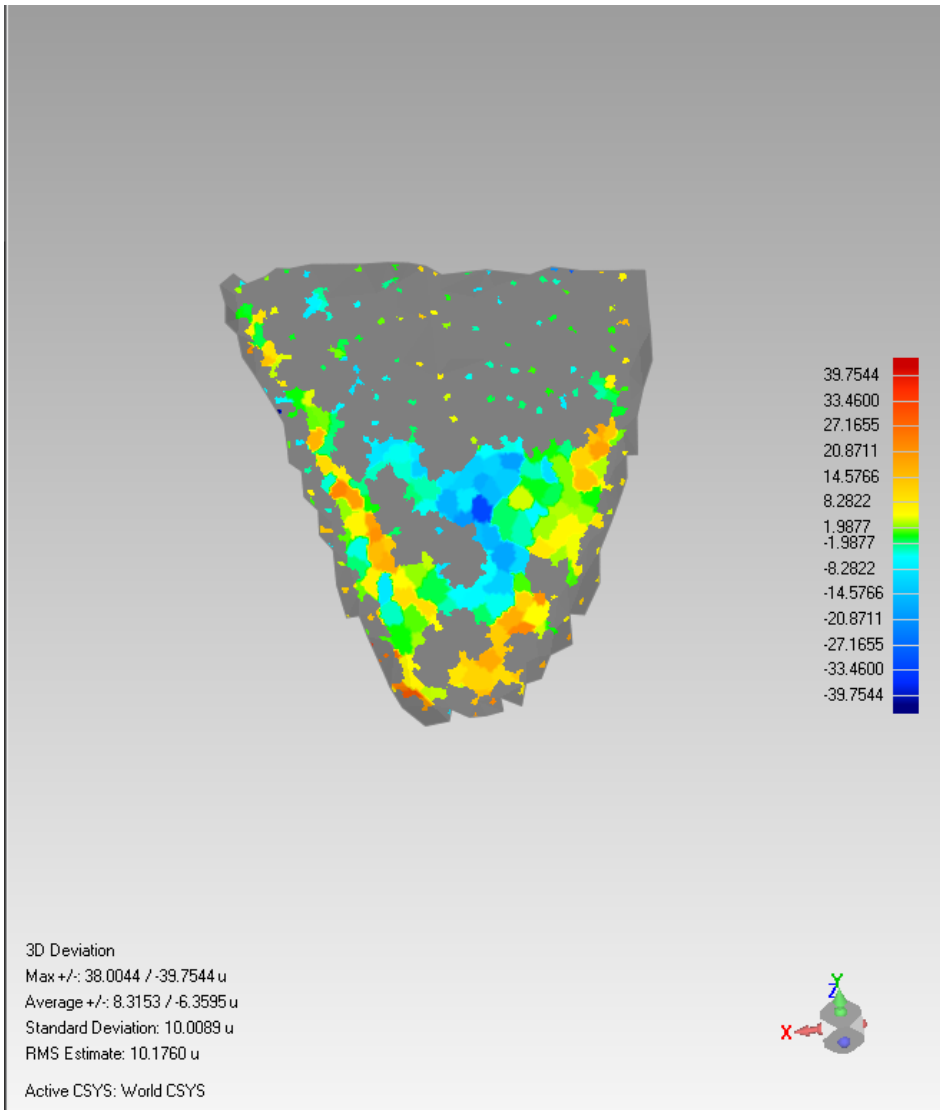

Figure 13: Evaluation of the alignment between the two STL files at the Geomagic software.

When differences were less than 10 μm, alignment could be considered accurate. The overall margin of the veneer was calculated, by using Geomagic Studio 2012 software. Internal areas were deleted and the area above the margin with 0.5mm incisal-gingival width circumferentially was selected. Three values by area (cervical, mesial, distal and incisal) were obtained (Figure 14).

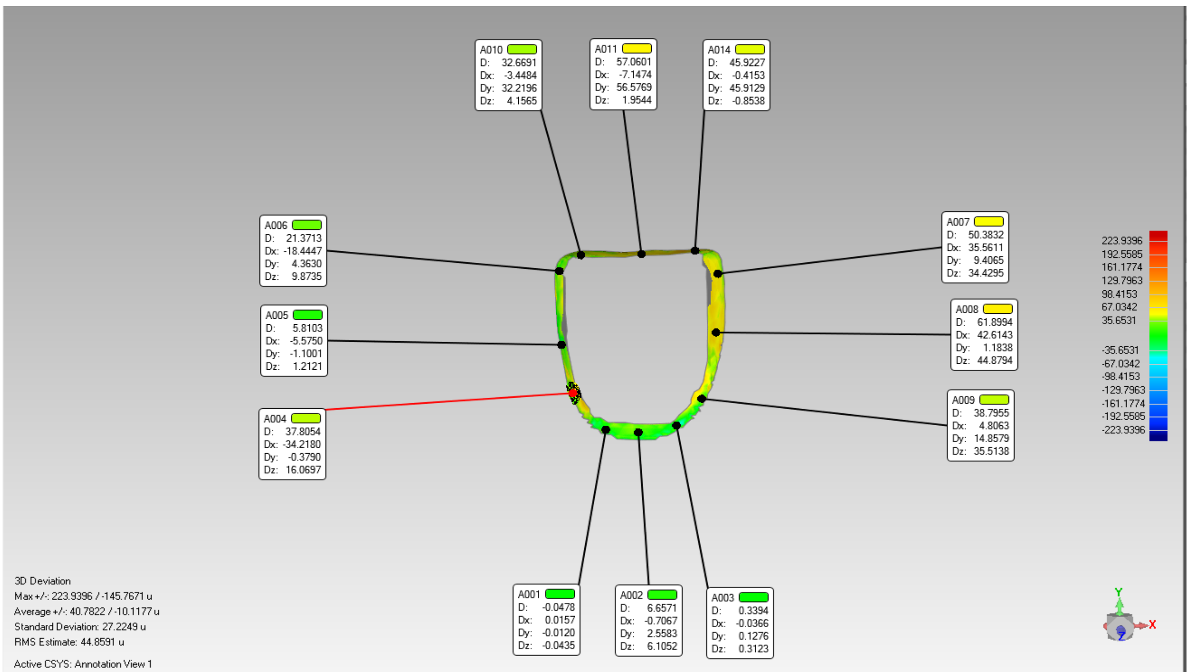

Figure 14: Measurements at various points along with the overall marginal fit.

All values obtained by Geomagic software were the average of 25,000 to 30,000 points. Any negative values were excluded from the calculations, since it is unrealistic the marginal openings to be less than 0. The mean of these three values was calculated producing an overall value for the mesial, distal, cervical and occlusal areas for each specimen. This measuring protocol was conducted before and after the firing of each sample.

2.4 Power Analysis

Prior to initiation of the study, a pilot study was conducted with the same methodology and with three specimens per group. The purpose of the pilot was to test the methodology and determine adequate sample size for 80% power and an alpha level of 0.05. G-power revealed that 9 specimens per group are needed in order to have power of 80% and alpha level of 0.05.

2.5 Statistical Analysis

Data was analyzed using a statistical software (SPSS 19.0, SPSS Inc., Chicago, IL). Normality was evaluated with the Shapiro-Wilk test. Student T-test (α=.05) was used to evaluate differences between and within the groups in the four locations; cervical, mesial, distal and occlusal.

3. RESULTS

The mean marginal opening after firing (standard deviation) for group CB was 67.5 µm (8.4) and for S was 63.4 µm (9.7). The difference was not statistically significant (p= 0.44, t-value=-0.78) (Table 3).

Table 3. Student t-Test for the mean marginal fit after the firings

	S	CB
Mean	63.4	67.5
df	17	
t Stat	0.782	
P(T<=t) two-tail	0.44	

Table 4 summarizes the mean overall marginal gaps after firing for both groups. The mean marginal fit change as a function of firing procedures and measurement locations.

Table 4. Mean marginal fit in microns

	S	**CB**
Mean	63.4	67.5
SD	12.6	9.7

More specifically, for the "staining" technique marginal openings found before and after firing were not statistically significant in all areas of measurement (Table 5).

Table 5. Mean marginal gaps before and after firing in microns for S group

	Cervical	Mesial	Distal	Incisal
Before	39	56.1	58.9	54.2
After	38.1	57.2	58.8	54.1
Significance * ($P \leq 0.05$)	0.35	0.3	0.97	0.9

However, for the "cut-back" group statistically significant differences found in the incisal area ($p=0.04$), showing an increase in marginal openings after the three firings. Table 6 shows the mean marginal gap before and after firing for the "cut-back" group and the significance level after the paired T-test.

Table 6. Mean marginal gaps before and after firing in microns for CB group

	Cervical	Mesial	Distal	Incisal
Before	32.2	57.2	47.8	45.7
After	37.1	56.8	50.0	56.5
Significance * ($P \leq 0.05$)	0.66	0.93	0.6	0.04*

The mean marginal opening (SD) was 43.8 µm (18.6) on the incisal before the firing. After the application of porcelain and the glaze firing, mean marginal opening was increased to 56.5 µm (13). The mean marginal openings found on the cervical and interproximal areas before and after the intervention were not statistically significant.

Table 7, 8 compares the mean marginal gap on the four areas between "cut-back" and "staining" technique before and after firing respectively along with probabilities values. No statistically significant differences were found before and after firing between the two techniques.

Table 7. Mean marginal gaps before firing in microns for CB & S group

Before Firing	Cervical	Mesial	Distal	Incisal
S	39	56.1	58.9	54.2
CB	32.2	56.1	47.8	43.8
Significance * (P≤0.05)	0.17	0.89	0.1	0.17

Table 8. Mean marginal gaps after firing in microns for CB & S group

Before Firing	Cervical	Mesila	Distal	Incisal
S	38.1	57.7	58.8	54.1
CB	37.1	56.8	50	56.6
Significance * (P≤0.05)	0.85	0.87	0.11	0.68

4. DISCUSSION

The purpose of this study was to compare the marginal fit of heat-pressed lithium disilicate veneers fabricated with the “staining”, or the “cut-back” technique. The study failed to reject the null hypothesis because the veneers produced with these two techniques showed no significant differences in all areas of measurement. The mean marginal opening for the “staining” and “cut-back” technique was 63.4 μm and 67.5 μm ($p=0.44$) respectively (See Table 4). These results are not in agreement with the previous studies on marginal fit of heat pressed lithium disilicate veneers. Aboushelib et al.[29] found a horizontal and vertical misfit of the pressable lithium disilicate veneers of 105 μm and 242 μm respectively. Yuse et al.[30] found a marginal gap of 295 μm. These differences can be attributed to the fact that they used a different methodology and different measuring methods compared to the present study. More specifically, Aboushelib used SEM images to evaluate the marginal fit. Yuse used an impression replica technique. Both these methods provide limited information on the marginal fit, as a small number of measurement can be obtained. Moreover, both studies have high values for the standard deviation showing high variability and questionable results. The results of the present study are in agreement with studies for heat-pressed lithium disilicate crowns. In a critical review of e-max margins, the mean marginal fit varies from 31 μm to 138 μm[46]. Anadioti et al. in a study with similar methodology, used the triple scan protocol described by Holst to evaluate the 2D and 3D marginal fit of pressed and CAD/CAM generated lithium disilicate crowns fabricated by conventional and digital impressions[43]. They found that mean marginal fit of heat-pressed lithium disilicate crowns was 48 μm. However, the crowns were not cemented on the die, and this can affect and decrease the marginal discrepancy.

Most of the studies investigating marginal discrepancies in crowns use master dies made either from metal or acrylic resin [47,48,13 49]. However, in studies evaluating the marginal fidelity of feldspathic porcelain veneers the master dies were extracted human teeth[25,27]. In the present study the master die was duplicated with high filled epoxy resin. The advantage of duplicating the die with the acrylic resin is the lack of wear of the die during the measurements, as each die was used on only one specimen and acting as self control, minimizing the effect of variability due to the fact that duplicated dies are not identical. Moreover, a natural tooth could not be used on the present study, as it would be impossible to standardize the tooth preparation and the restorations.

Die spacing can affect the marginal fit of crowns. More specifically, it is clear that there is a positive relationship between cement space and marginal fit[51,52,53]. However, die spacer was applied because the present study was focused on the simulation of practical laboratory procedures.

The marginal fit of each veneer was evaluated at different stages in the manufacturing process. The first set of measurements were obtained after the core fabrication of each group (baseline). The core thickness used met the minimum requirements from the manufacturer. No significant differences were found between the two groups in the four areas of measurements. This results are in agreement with a study by Farid et al. which evaluated the effect of core thickness and fabrication stages on the marginal fit of heat-pressed lithium disilicate crowns[54]. They found no significant differences in the core fit of 0.8mm and 1.5mm before the porcelain application and the “glaze” firing. In the “cut-back” group the porcelain application and the amount of porcelain applied was controlled to manage the potential effects of a non-uniform mass of porcelain application on marginal distortion. No significant differences were found between the two groups in the four areas of measurements. This is in agreement with a study by Cho et al.[13].

The study failed to reject the null hypothesis for the "staining" group. The glaze/stain firing had no significant effect on the marginal fit in all four areas of measurements. Several studies[46, 54, 55] found similar results, that glaze firing does not affect marginal fidelity. However, Cho et al. found a significant effect of glazing on the marginal integrity of heat-pressed lithium disilicate crowns[13]. A possible explanation is that glaze firing for the "staining" group has different parameters than the one that it is used after the porcelain application in the "cut-back" technique.

For the "cut-back" group, the null hypothesis was rejected as a significant difference was found on the incisal areas. No significant difference was noted on the cervical and interproximal areas. It has been shown by several studies that the application of porcelain can increase the marginal gap[54]. Moreover, it is known that porcelain shrinks toward its greatest mass[47]. During fabrication of the "cut-back" group porcelain is applied mainly on the incisal third. This can explain the significant increase on marginal discrepancy of the incisal areas compared to the cervical and interproximal where less porcelain was applied. These results are not in agreement with the findings from studies evaluating the marginal fit of porcelain laminate veneers[25-27]. Sorensen et al. showed that after firing[25], porcelain veneers fabricated either with the refractory die or platinum foil technique had interproximal openings two to four times greater than the cervical and occlusal areas. As a result, better marginal fit was achieved with the heat-pressed lithium disilicate veneers compared to porcelain labial veneers.

In the present study the virtual replica technique along with the Geomagic software was used. A low viscosity poly vinyl siloxane impression material was used to create the replica. It has been shown that the replica material could prevent correct adaptation of the restorations[56] and that a low-viscosity silicone can be used as a replica to reduce this error[57]. The overall margin was calculated by averaging 200,000 data points of measurements. Moreover, the mean marginal discrepancies on the cervical, mesial, distal and incisal areas were calculated, by measuring data points on a radius of 0.5mm. This is a novel method for measuring marginal discrepancies, that has been validated and the main advantages of this technique are that methodological errors can be reduced and a better representation of marginal fit can be achieved[38].

There are several limitations of this study. This is an in vitro study that does not reflect the intra-oral conditions with the presence of soft tissue and saliva. Moreover, with the 3D analysis it is difficult to describe the discrepancies as vertical and horizontal misfit. Finally, the study evaluated the effect of firing only on heat pressed lithium disilicate veneers of specific ingots.

In last few decades CAD/CAM technology started to gain popularity in the dental field. An increasing number of restorations are designed and produced with the aid of the technology. The main advantage of CAD/CAM technology is that it reduces the total production time and claims to have better marginal fit compared to traditional techniques. As a result, it is prudent for future studies to investigate and compare the marginal and internal fit of CAD/CAM to heat-pressed lithium disilicate veneers.

In summary, lithium disilicate veneers fabricated with the two aforementioned techniques have overall marginal fit within the clinical acceptable limits for all ceramic restorations.

Furthermore, the present study showed that the porcelain application increases the marginal discrepancies on the “cut-back” group without affecting the overall marginal fit. The results suggest a better marginal fit of heat-pressed lithium disilicate veneers compared to the feldspathic veneers. Considering the fact that marginal fit is paramount for the long term success of dental restorations, heat-pressed lithium disilicate veneers are preferred whenever a patient is restored with labial porcelain veneers with the strength and the marginal fit being the ultimate objective. However, these restorations lack in esthetics when compared to the feldspathic porcelain laminate veneers. As a result, the appropriate material selection is patient dependent. The clinician should take into consideration the specific treatment objectives for each patient, such as changing the shape or the shade of a tooth, before determine which material should be used. Finally, it may be time to reconsider the clinical acceptable limits, for standard of care, for all ceramic restorations, as many studies have shown that it is feasible to achieve marginal discrepancies of less than 70 μm for all ceramic restorations.

The clinical implications of the present study are that multiple firings do not affect the marginal fit of heat-pressed lithium disilicate veneers and that the marginal fit is within the clinical acceptable limits independent of the fabrication technique.

The clinical implications of the present study are that heat pressed lithium disilicate veneers can be fabricated with the two aforementioned techniques without compromising the marginal fidelity of the final restorations.

5. CONCLUSIONS

Within the limitations of this in vitro study, the following conclusions can be drawn:

1. There is no difference in the marginal fit between the "cut-back" and the "staining" technique
2. Heat-pressed lithium disilicate veneers fabricated either with the "cut-back" or the "staining" technique demonstrate marginal fit within the clinical acceptable limits for ceramic restorations.
3. There is a statistically significant ($p=0.04$) increase in the marginal discrepancies of the incisal areas of the heat-pressed lithium disilicate veneers fabricated with the "cut-back" technique.
4. The glaze cycling does not appear to affect the marginal fit of the heat-pressed lithium disilicate veneers fabricated with the "staining" technique.

REFERENCES

1. Layton, D., Clarke, M. and Walton, T, *A systematic review and meta-analysis of the survival of feldspathic porcelain veneers over 5 and 10 years.* Int J Prosthodont, 2012.**25**(6): p.590-603.

2. Peumans, M., Van Meerbeek, B., Lambrechts, P. and Vanherle, G, *Porcelain veneers: a review of the literature.* J Dent, 2000. **28**: p.163–177.

3. Pincus, C.R., *Building mouth personality*. J South Calif Dent Assoc, 1938. **14**: p.125–9.

4. Anusavice, K., Shen, C. and Rawls, R, Phillips' science of dental materials. Chapter 12. Elsevier 2013;12th edition: 257-74.

5. Buonocore, M.G., *A simple method of increasing the adhesion of acrylic filling materials to enamel surfaces*. J Dent Res, 1955. **34**: p.849-53.

6. Simonsen, R.J. and Calamia, J.R., *Tensile bond strength of etched porcelain*. J Dent Res, 1983. **62**: p.297.

7. Hein, S. and Geller, W., The platinum foil technique: *History, Indication, Fabrication, and Adaptation.* QDT, 2011. **34**: p.1-15.

8. Guazzato, M., Albakry, M., Ringer, S.P. and Swain, M.V, *Strength, fracture toughness and microstructure of a selection of all-ceramic materials. Part I. Pressable and alumina glass-infiltrated ceramics.* Dent Mater, 2004. **20**: p.441–8.

9. Ohyama, T., Yoshinari, M. and Oda, Y., *Effects of cyclic loading on the strength of all-ceramic materials*. Int J Prosthodont. 1999; **12**: p.28–37.

10. Demir, N., Ozturk, A.N. and Malkoc, M.A., *Evaluation of the marginal fit of full ceramic crowns by the microcomputed tomography (micro-CT) technique*. Eur J Dent, 2014. **8**: p.437-444.

11. Fonzar, R.F., Carrabba, M., Sedda, M., Ferrari, M., Goracci, C. and Vichi A., *Flexural resistance of heat-pressed and CAD-CAM lithium disilicate with different translucencies*. Dent Mater, 2017.**33** (1): p.63-70.

12. Mounted., R., Layton, D.M. and Azar, B., *The marginal fit of E.max Press and E.max CAD lithium disilicate restorations: A critical review.* Dent Mater J, 2016. **35**(6): p.835–844.

13. Cho, SH., Nagy, W.W., Goodman, J.T., Solomon, E. and Koike, M., *The effect of multiple firings on the marginal integrity of pressable ceramic single crowns*. J Prosthet Dent ,2012.**117**(1): p.17-22.

14. Holmes, J.R., et al., Considerations in measurement of marginal fit. J Prosthet Dent, 1989.**62** (4): p.405-408.

15. Goodacre, C.J., et al., Clinical complications in fixed prosthodontics. J Prosthet Dent, 2003. **90**(1): p.31-41.

16. Orstavik, D., and Orstavik, J., *In vitro attachment of Streptococcus sanguis to dental crown and bridge cements*. J Oral Rehabil, 1976. **3**(2): p. 139-44.

17. Fradeani., M., *Six-year follow-up with Empress veneers.* Int J Periodontics Restorative Dent, 1998. **18**(3): p.216-25.

18. American Dental Association, ANSI/ADA Specification No. 8 for zinc phosphate cement. In Guide to Dental Materials and Devices (ed 5). Chicago, IL: American Dental Association,

1970-1971: p.87-88.

19. Holden, J.E., Goldstien, G., Hittelman E.L., et al., *Comparison of the marginal fit of pressable ceramic to metal ceramic restorations*. J Prosthodont, 2009.**18**: p.645-648.

20. Christensen, G., *Marginal fit of gold inlays castings*. J Prostate Dent, 1966. **16**(2);297-305.

21. Lin, T.M., Liu, P.R., Ramp, L.C., et al., *Fracture resistance and marginal discrepancy of porcelain laminate veneers influenced by preparation design and restorative material in vitro.* J Dent, 2012.**40**: p.202-209.

22. Schaefer, O., Watts, D.C., Sigusch, B.W., Kuepper, H. and 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): p.320–326.

23. McLean, J.W. and von Fraunhofer, J.A., *The estimation of cement film thickness by an in vivo technique.* Br Dent J, 1971. **131**: p.107-111.

24. Holmes, J.R., et al., *Marginal fit of castable ceramic crowns*. J Prosthet Dent, 1992. **67**(5): p. 594-9.

25. Sorensen, J.A., Strutz, J.M., Avera SP, et al., *Marginal fidelity and microleakage of porcelain veneers made by two techniques.* J Prosthet Dent, 1992. **67**: p.16 – 22.

26. Sim, C., Ibbetson, R.J., *Comparison of fit of porcelain veneers fabricated using different techniques. Int J Prosthodont*, 1993. **6**: p.36 – 42.

27. Harasani, M.H., Isidor, F. and Kaaber, S. *Marginal fit of porcelain and indirect composite laminate veneers under in vitro conditions*. Scand J Dent Res,1991. **99**: p. 262 -8.

28. Jha, R., Jain, V., Das, T.K., Shah, N. and Pruthi, G., *Comparison of Marginal Fidelity and Surface Roughness of Porcelain Veneers Fabricated by Refractory Die and Pressing Techniques*. J Prosthodont, 2013. **22**: p. 439–444.

29. Aboushelib, M.N., Elmahy, W.A. and Ghazy, M.H., *Internal adaptation, marginal accuracy and microleakage of a pressable versus a machinable ceramic laminate veneers*. J Dent, 2012. **40**: p. 670-677.

30. Yuce, M., Ulusoy, M. and Turk, A.G., *Comparison of Marginal and Internal Adaptation of Heat-Pressed and CAD/CAM Porcelain Laminate Veneers and a 2-Year Follow-Up*. J Prosthodont, 2017. **00:** p.1–7.

31. Groten, M., et al., *Determination of the minimum number of marginal gap measurements required for practical in-vitro testing.* J Prosthet Dent, 2000. **83**(1): p. 40-9.

32. Sorensen, J.A., *A standardized method for determination of crown margin fidelity*. J Prosthet Dent, 1990.**64**: p.18-24.

33. Hayashi, M., Watts, D.C., Ebisu, S. and Wilson, N.H., *Influence of vision on the evaluation of marginal discrepancies in restorations*. Oper Dent, 2005. 30(**5**): p.598-601.

34. Nawafleh, N.A., Mack, F., Evans, J., Mackay, J. and Hatamleh, M.M., *Accuracy and reliability of methods to measure marginal adaptation of crowns and FDPs: a literature review.* J Prosthodont, 2013. **22**: p. 419–428.

35. Boening, K.W., Wolf, B.H., Schnmidt, A.E., Kastner, K. and Walter, M.H., *Clinical fit if Procera All Ceram crowns.* J Prosthet Dent, 2000. **84**: p.419–424.

36. Contrepois, M., Soenen, A., Bartala, M. and Laviole, O., *Marginal adaptation of ceramic*

crowns: A systematic review. J Prosthet Dent, 2013. **6**: p.447-454.

37. Att, W., Komine, F., Gerds, T., et al., *Marginal adaptation of three different zirconium dioxide three-unit fixed dental prostheses*. J Prosthet Dent, 2009. **101**: p.239-247.

38. Lee, D.H., Digital approach to assessing the 3-dimensional misfit of fixed dental prostheses. J Prosthet Dent, 2016. **116**(6): p.836-9.

39. Good, M., Mitchell, C., Pintado, M., et al., *Quantification of all-ceramic crown margin surface profile from try-in to 1-week post-cementation*. J Dent, 2009. **37**: p.65-75.

40. Shearer, B., Gough, M.B., Setchell, D.J., *Influence of marginal configuration and porcelain addition on the fit of In-Ceramcrowns.* Biomaterials, 1996. **17**: p.1891-1895.

41. Mitchell, C.A., Pintado, M.R. and Douglas, W.H., *Nondestructive, in vitro quantification of crown margins*. J Prosthet Dent, 2001. **85**: p.575-584.

42. Pelekanos, S., Koumanou, M., Koutayas, S.O., Zinelis, S. and Eliades, G., *Micro-CT evaluation of the marginal fit of different In-Ceram alumina copings*. Eur J Esthet Dent,2009. **4**: p.278–292.

43. Anadioti, E., Aquilino, S.A., Gratton, D.G., Holloway, J.A., Denry, I., Thomas, G.W. and Qian F. *3D and 2D marginal fit of pressed and CAD/CAM lithium disilicate crowns made from digital and conventional impressions*. J Prosthodont, 2014.**23**(8): p.610-7.

44. Luthhard, R.G., Bornemann, G., Lemelsol, S., Walter, M.H. and Huls, A., *An innovative method for evaluation of the 3-D internal fit of CAD/CAM crowns fabricated after direct optical versus indirect laser scan digitizing*. Int J Prosthodont, 2004.**17**(6): p.680-5.

45. Holst, S., Karl, M., Wichmann, M. and Matta, R.E., *A new triple scan protocol for 3D fit*

assessment of dental restorations. Quintessence Int, 2011. **42**(8): p.651-7.

46. Mounajjed, R., Layton, D.M. and Azar, B., *The marginal fit of E.max Press and E.max CAD lithium disilicate restorations: A critical review.* Dent Mater J, 2016. **35**(6): p.835–844.
47. Balkaya, M.C., Cinar, A. and Pamuk, S., *Influence of firing cycles on the margin distortion of 3 all-ceramic crown systems.* J Prosthet Dent, 2005. **93**: p.346-55.
48. Komine, F., Shiratsuchi, H., Kakehashi, Y. and Matsumura, H.*, Influence of porcelain-firing procedures on the marginal distortion of electroformed metal-ceramic restorations*. Quintessence Int, 2007. **38**: p.583-8.
49. Buchanan, W.T, Svare, C.W. and Turner, K.A., *The effect of repeated firings and strength on marginal distortion in two ceramometal systems*. J Prosthet Dent, 1981. **45**: p.502-6.
50. Lui JL. *The effect of firing shrinkage on the marginal fit of porcelain jacket crowns*. Br Dent J, 1980. **149**: p.43-5
51. Eames, W.B., et al., *Techniques to improve the seating of castings*. J Am Dent Assoc, 1978. **96**(3): p.432-7.
52. Wang, C.J., Millstein P.L, and Nathanson, D., *Effects of cement, cement space, marginal design, seating aid materials, and seating force on crown cementation*. J Prosthet Dent, 1992. **67**(6): p.786-90.
53. Weaver, J.D., Johnson, G.H. and Bales, D.J., *Marginal adaptation of castable ceramic crowns*. J Prosthet Dent, 1991.**66**:747-53.
54. Farid, F., Hajimiragha, H., Jelodar, R., Mostafavi, A.S. and Nokhbatolfoghahaie, H., *In vitro evaluation of the effect of core thickness and fabrication stages on the marginal accuracy of an all-ceramic system*. J Dent, 2012. **9**(3): p.188-94.
55. Sulaiman, F., Chai, J., Jameson, L.M. and Wozniak, W.T., *A comparison of the marginal fit*

of In-Ceram, IPS Empress, and Procera crowns. Int J Prosthodont, 1997. **10**: p.478-84.

56. Qualtrough, A.J., Piddock, V. and Kypreou, V., *A comparison of two in vitro methods for assessing the fitting accuracy of composite inlays*. Br Dent J, 1993. **19**: p.450-454.
57. Karakaya, S., Sengun, A. and Ozer, F., *Evaluation of internal adaptation in ceramic and composite resin inlays by silicon replica technique.* J Oral Rehabil, 2005. **32**: p.448-453.

APPENDIX

Staining Group													
Before firing	**sample**	**Cervical**			**Mesial**			**Distal**			**Incisal**		
	Area	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
	1	31.7	42.7	78.1	67.8	44.7	57.1	63	49.1	54.9	34	49	32.4
	2	50	30.8	14.3	73.6	91.1	71.4	38.9	23.8	61.4	37.6	36.1	39.1
	3	23.2	20.9	79.4	107.5	75.3	48.5	48.6	77.7	98.8	33.8	41.4	49.4
	4	17.8	25.9	26.6	33.1	44.9	64.6	72	76.6	47.7	45.9	76.9	65.8
	5	23.2	24.1	25.7	58.9	21.3	32.2	44.7	70.1	52.1	50.3	57.1	38.9
	6	54.7	30.9	10.6	57.2	36.7	28.7	64.5	85.4	63.5	55.4	74.6	44.7
	7	37.7	30.2	48.4	59.9	38.7	34.3	33.4	40.6	63.3	60.5	107.3	68.7
	8	22.4	14.9	44.4	47.5	77.5	56	38	57.7	33.4	51	54.8	91.8
	9	26.1	50.9	89.9	50.7	70.2	80.3	70.1	87.2	34.8	34.4	77.3	73.5
	10	42	62.1	91.3	22.3	69.1	62.1	96.1	72.6	46	52.1	35.4	57.6

Staining Group													
	sample	**Cervical**			**Mesial**			**Distal**			**Incisal**		
	Area	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
After firing	**1**	40.5	37	65.1	42	30.4	75.9	58.6	65.8	50.7	49	39.2	31.1
	2	42	28.8	29.2	76.3	88.6	68.1	34.7	59.6	64.1	49.7	45.3	28.9
	3	35.6	58.1	15	46.3	98	93.4	27.7	61.8	88	39.3	40.3	45.6
	4	14	25.8	29.9	38.3	34.9	77.6	61.7	82.2	57	51.7	67.7	80
	5	24.2	24.6	20.5	56.7	36.1	28	43.4	49	70.6	53.2	32.4	61
	6	52.3	21.6	31.1	62.5	41.2	38.7	39.9	76.5	84.8	40.4	75.2	49
	7	60.2	23.2	39.6	57.5	40.8	28.3	34.8	49	69.6	89.1	91.6	60.2
	8	23.7	16.4	44.8	35.9	81.6	63.6	31.5	66.7	32.7	89.5	49.4	48.9
	9	46.7	30.1	81.9	57.5	68.6	3.5	48.2	91.9	52.7	26.5	72.2	73.3
	10	54.7	41	86.7	57.1	65	57.7	85.7	62	62.7	48.9	58.7	36.1

Cut-back Group													
Before firing	**sample**	**Cervical**			**Mesial**			**Distal**			**Incisal**		
	Area	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
	1	56.8	67.1	35.8	57.8	80.5	37	74	107.3	48.8	31.4	54	36.3
	2	69	25.4	18.8	69.1	54.8	40.5	81.2	25.7	87.1	72.6	48.2	45.7
	3	19	20.6	9.1	81.7	74	42.9	38.5	46.2	48.6	-	34.6	20.3
	4	7.4	28.5	11.7	45.5	48.6	31.6	43.5	78.7	56.5	11.8	66.7	25.3
	5	28.7	36.7	23.4	54.7	17.1	35.9	34.1	61.3	43.2	66.1	-	54.3
	6	17.4	7	1	31.1	62	49.2	25.3	28	21.2	24.4	30.7	15.6
	7	35.9	10.4	16.5	58.5	69.3	46.8	28.1	48.5	60.9	22.4	38.4	55
	8	36.9	9.9	30.4	83.1	86.2	66.2	53.5	43.3	36.9	33.5	50.6	37.5
	9	60.9	50.1	28.9	51.1	34	21	43.4	44.4	46.8	31.2	28.7	33.5
	10	41.5	55	34.7	98	59.9	95.3	31.1	23.3	23.3	96.1	-	74.8

Cut-back Group													
After firing	**sample**	**Cervical**			**Mesial**			**Distal**			**Incisal**		
	Area	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
	1	54	61.6	39.7	81.8	73	32.1	44.1	68.9	23.9	51.2	76.3	41.9
	2	34.2	47.5	24.4	72.1	65.5	30.2	52.4	67.3	79.8	49.8	40.4	96
	3	25.2	60.1	18.3	90.7	71.4	24.8	57.6	61.3	51.3	62.5	56.4	35.1
	4	64.5	24.1	15.6	66.1	84.2	39.4	47.7	83	49.6	52.1	61.3	26.1
	5	21.5	49.3	39.7	90.4	52.8	47.7	63.3	57.9	48.6	79.6	55.6	-
	6	63.5	109.3	14.8	39.4	54.1	25.5	24.2	12.6	24	76	55.4	80.7
	7	41.8	25.5	27.2	71.5	79.4	56.3	26.6	63.1	76.6	49.2	65.6	38.5
	8	22.3	18	23.2	53.7	50.8	17.1	23.2	37.7	79	18.6	43.1	32
	9	30.7	36.2	21.3	83.8	67.6	44.7	56.9	59.4	60.1	38.7	87.5	31.5
	10	42.3	27.9	30.2	50	61.6	25	39.3	25.1	35.2	89.4	101.2	36.3