MARGINAL FIT OF LITHIUM DISILICATE CROWNS USING THREE DIFFERENT FABRICATION TECHNIQUES

A Thesis

by

STEVEN ANDREW WILLIAMS

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 Nagy
Committee Members,	John Goodman
	Elias Kontogiorgos
	David Murchison
Head of Department,	Larry Bellinger

May 2017

Major Subject: Oral Biology

ABSTRACT

The purpose of this *in vitro* study was to evaluate the three-dimensional marginal fit of lithium disilicate crowns fabricated by pressed or CAD/CAM milled four- or five-axis machines. The three groups were Pressed, McX and McX5, and differed in their fabrication technique. The Pressed group was fabricated with IPS e.max Press and was heat pressed with the lost wax technique. Both of the CAD/CAM milled restorations McX and McX5 were scanned and designed using the same process and differed only in the milling machine used to fabricate them, four-axis chairside mill and five-axis laboratory mill respectively.

All specimens were evaluated using the 3D replica technique, digitized and examined with a digital analysis software (Geomagic Control, 3D Systems, Rock Hill, S.C.). A mean marginal fit was acquired by the software and loaded into a statistical analysis software.

The data was analyzed using a one-way ANOVA. Normality was checked using the Shapiro Wilk test for normality, and Levine's Test was used to insure that there was homogeneity of variance. A p-value of less than 0.05 was used to determine if the difference was statistically significant.

The Pressed group's mean marginal fit was 49.37 µm. The average fit for the CAD/CAM milled restorations was 54.53 µm for McX and 50.74 µm for McX5. The results obtained indicated clinically acceptable marginal fit for all groups with no significant difference between the three fabrication methods.

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Nagy, for his countless hours of reading, editing, and encouraging. His patience, motivation, and immense knowledge made this project possible.

The members of my committee, Dr. Goodman, Dr. Kontogiorgos, and Dr. Murchison, have graciously given their time and expertise to better my work. I want to thank them for their contributions and support. My time in this program would not have been the same without them.

Thanks to Tra Chambers who helped with the laboratory 5-axis milling portion of this study. He donated both his time and equipment to help complete this project.

Thanks also go to my co-residents, who have made my time in the Prosthodontics program an unforgettable experience. It has been great sharing a laboratory with all of you the past three years.

Thank you to my parents for their encouragement and support. I would not be here without the two of you.

Thank you to my sister, Shanna, for her countless hours of proofreading and editing not only for this project but for all the projects along the way. Thank you for always being there.

And finally, thank you to my wife, Kelsey, for her patience throughout this process and for being my biggest cheerleader. I could not have gotten through this without you by my side.

CONTRIBUTORS AND FUNDING SOURCES

Contributors

This study was supported by a thesis committee consisting of Dr. William W. Nagy, Dr. John T. Goodman, Dr. Elias Kontogiorgos from the Department of Restorative Sciences and Dr. David Murchison from the Department of Diagnostic Sciences of Texas A&M University College of Dentistry.

Statistical analysis of the research data was performed by Dr. Elias Kontogiorgos.

All other work for this dissertation was completed independently by the resident.

Funding Sources

Funding for this study was provided by the Office of Research and Graduate Studies of Texas A&M University College of Dentistry.

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

Page

1. INTRODUCTION AND LITERATURE REVIEW

As dentistry and technology progresses, techniques and materials for fabrication of indirect fixed restorations have continuously evolved. Historically, restorations were cast from gold alloy, but as the public became more esthetically aware ceramics were proposed and metal ceramic bonding was introduced in the late 1950’s.[1] With the introduction of CAD/CAM technology, high strength ceramic appears to be the next generation of restorative dental materials.[2] The purpose of this study was to evaluate an all-digital workflow to an analog workflow for the fabrication of a full coverage all-ceramic restoration.

There are many ways to evaluate full coverage all ceramic restorations. Previous studies have evaluated fabrication time, esthetics, occlusion, internal fit, etc. This study examined marginal fit of an indirect dental restoration due to its correlation with success and longevity of the restoration. [3] Failure to obtain a clinically acceptable margin causes many problems such as plaque accumulation, recurrent caries, sensitivity, and ultimately failure of the restoration.[4, 5] In 2003, Goodacre published a systematic review that examined fixed dental prosthesis and found that caries was the most common complication. [6] Schwartz et al determined that 11.3% of restorations fail due to defective marginal fit, correlating marginal fit to success of the restoration.[3] Unfortunately, there is no consensus on what is clinically acceptable when evaluating marginal fit. Christenson et al evaluated marginal fit on cast gold restorations. He found that marginal fit ranged from 2 μm to 51 μm for clinically visible margins, and 119 μm was clinically acceptable for inaccessible margins.[7] Holmes et al looked at all ceramic restorations and found that it had better misfit as compared to gold restorations, 48 µm and 57 µm respectively.[8] Most of the current literature indicates that clinically acceptable marginal fit is between 75-120 µm.[9, 10] Mclean and von Fraunhofer determined that if the marginal fit was less than 120 µm, it was a clinically acceptable restoration. [10]

There are many techniques that have been employed to evaluate the marginal fit of a restoration. Direct visualization with a light microscope is one of the most common ways of evaluating marginal fit. This technique has two disadvantages: it is difficult to identify a reference point to measure, and the light microscope may lead to projection errors. A second method for measuring marginal fit is to cement and section specimen. The problem with this technique is only a limited number of sections can be cut, and in doing so it destroys the specimen. A third way of measuring marginal fit is to create a light-bodied silicone replica of the gap between the crown and the tooth, section the specimen, and measure the thickness of the silicone replica. [11, 12]

The third way of measuring marginal fit, the original replica technique, was developed in 1993 and is one of the most commonly used marginal fit evaluation procedures. Inlay crowns were seated on their corresponding stone die with a light bodied silicone impression material. The silicone was intended to fill the intermediary space between the restoration and preparation. After the light bodied material had achieved a final set, the restoration was removed and the light body was reinforced with heavy bodied silicone. The reinforcement allowed the silicone to be sectioned and evaluated. The intermediary space that this technique sought to evaluate was the misfit between the restoration and the prepared specimen.[12] This technique has grown in popularity due to its simplicity and ability to be used with *in-vitro* and *in-vivo* studies. The replica technique has been used for years to evaluate fit of restorations.[11]

In 2008, Rahme et al published a study evaluating the replica techniques' accuracy. It was found that the replica technique was reliable for evaluating marginal and internal gaps.[13] The main disadvantage is the silicone replica must be sectioned in order to evaluate thickness. When sectioning silicone, only a limited number of sections can be created without distorting or destroying the replica.[14] Groten et al determined that 50 marginal fit measurements were required to provide clinically relevant results irrespective of whether the measurements were recorded in a random or systematic manner.[15]

With the introduction of accurate laboratory scanners, limitations present in the original replica technique were eliminated. A recent study by Kim used the *3D replica technique* to evaluate the misfit of full coverage crowns by digitizing the silicone replica. This digitization allowed thousands of data points to be generated and compared to a reference model. From these generated points a mean marginal fit was calculated for the entire margin.[16] This provides a much more accurate and useful tool when evaluating marginal fit. This technique allows for a 3D analysis of the misfit between the crown and the master preparation. The advantages of this technique are that it is non-destructive to the master model and it allows a 360-degree evaluation of the margin.[16, 17]

The present study evaluates the marginal fit of lithium disilicate restorations, specifically IPS e.max Press and CAD (Ivoclar, Vivadent), because this particular restorative material can be completely fabricated using CAD/CAM as well as using the lost wax technique. In 2005 Ivoclar introduced IPS e.max, a lithium disilicate glass ceramic. Since its introduction, IPS e.max and other lithium disilicate restorations have grown in popularity due to its versatility and highly esthetic appearance.[18] Ivoclar's recommendations for IPS e.max CAD indicate that the material can be used for anything from thin veneers to multiple unit posterior restorations. A systematic review over a five-year period found that lithium disilicate had a high survival rate. This review found lithium disilicate and leucite reinforced single unit crowns had a 96.6% estimated survival rate at five years when compared to metal ceramics 94.7%.[19] By designing and milling a full contour monolithic restoration, a dental technician can eliminate time consuming steps and fabricate restorations with greater efficiency.[20]

Current CAD/CAM systems consist of three parts: scanning, designing and milling.[21] The scanning procedure has been shown in numerous studies to be an accurate way of making an impression by using light to record overlapping images and compile them into triangular meshes or point clouds.[22, 23] These point clouds are then assembled by computer algorithms and merged with standard tessellation language (STL) to create a digital impression.[24] This model can be manipulated so accurate articulation can occur via the use of a bite scan. After identifying a restorative margin and specifying an insertion direction the software generates a restoration proposal. This proposal can be modified and adjusted until it meets the desired form. The last step in the CAD process is to position the proposed restoration inside a virtual CAD/CAM block. The information and location of the desired restoration is sent to the milling unit for manufacturing. The most common machining strategy employed by the CAM unit is Z-level strategy, where the CAM software divides the CAD model in parallel planes perpendicular to the machining direction. The restoration is milled based on the two dimensional curves corresponding to the contour lines.[24]

Although IPS e.max CAD and IPS e.max Press are structurally very similar, they are fabricated by very different procedures. IPS e.max CAD originates from the manufacturer as a millable block that is lavender in color and in the form of a cube with a metal adaptor for fixation in a milling unit. [18] These prefabricated blocks are specifically formulated for the CAD/CAM technique. The manufacturer casts the blocks in one piece using a continuous process that prevents the formation of defects.[25] The blocks are only partially crystallized which ensures they can be easily milled using CAD/CAM systems. This “blue state” or partial crystallization procedure develops lithium metasilicate crystals, Li2SiO3, which are responsible for the favorable processing properties of IPS e.max CAD. The partial crystallized blocks are then loaded into milling units, which use computer aided manufacturing (CAM) to mill the restoration. IPS e.max CAD blocks are softer than their final “sintered” state. After milling the restoration, it is placed in a furnace that heats the restoration to 850°C converting the lithium metasilicate crystals to lithium disilicate crystals Li2Si2O5 imparting the ceramic with its final shade and desired strength.[25]

IPS e.max Press originates as a pressable ingot in the shape of small cylinders colored according to their corresponding tooth shade and are fabricated using the lost wax technique. These pressable ingots consist of lithium disilicate glass-ceramic in various levels of opacity. The structure of IPS e.max Press consists of lithium disilicate crystals (70% by volume), surrounded by a glassy matrix.[26] Lithium disilicate is the main crystalline phase which consist of crystals, in a needle-like form, measuring 3 to 6 μm in length.[26] This differs from the IPS e.max CAD crystalline structure which consists of finer platelet shaped crystals ranging from 0.2 to 1.0 μm in length.[25] The lost wax technique begins with the fabrication of a wax pattern, which is made off a stone die fabricated from an impression. This pattern is invested in a refractory mold, the wax eliminated, and the lithium disilicate ingot is loaded and heat pressed in a special furnace.[25]

A main question that this study intends to answer is can in-office chair-side milling units fabricate a restoration with the same accuracy as a five-axis mill, as seen in a dental laboratory. Two of the chairside milling units on the market are CEREC (Sirona Dental Systems, Bensheim, Germany) and E4D (Planmeca-E4D). With the CEREC system you have the option of designing and milling a restoration using an in-office mill or sending the digital impression to a laboratory to fabricate the restoration.[27, 28] Typically, dental offices use three and four axis milling units, whereas in milling centers, five axis units are more frequently used.[29] These four axis machines are relatively small and are capable of milling a single unit restoration in less than twenty minutes. In comparison, five axis mills are traditionally much larger and require increased processing time (over thirty minutes) to fabricate the same restoration.[29] Currently, there is very little research on the difference in quality between four and five axis mills.

The purpose of this *in-vitro* study was to assess the marginal fit of crowns fabricated using a four-axis or five-axis mill compared to crowns that are heat pressed using the lost wax technique. The null hypothesis was that there would be no difference in marginal fit between milling with a four or five axis mill or heat pressing using the lost wax technique.

2. MATERIALS AND METHODS

Three groups of ten lithium disilicate (IPS e.max) crown restorations were fabricated using three different techniques for a sample size totaling thirty restorations. All crowns were fabricated from a single master die. Group 1, Pressed, was fabricated utilizing the lost wax technique to heat press crowns in lithium disilicate. Group 2, McX and Group 3, McX5 were fabricated using CAD/CAM and differed in the type of mill in which they were fabricated (four or five axis mill respectively). VPS was applied to the master die as well as the intaglio surface of the restoration and with standardized pressure seated on the master die. Utilizing the 3D replica technique, the crown and light bodied replica were digitized and compared. A mean marginal fit was determined for each specimen and analyzed using SPSS.

Group 1. **Pressed**

- 10 crowns impressed with VPS and fabricated with IPS e.max Press (Ivoclar Vivadent) using the lost wax technique.

Group 2**. McX**

- 10 Crowns scanned with Cerec Bluecam, designed with Cerec SW 4.4 and fabricated with a Mc X in-office 4-axis milling machine (Sirona Dental Systems).

Group 3. **McX5**

- 10 Crowns scanned with Cerec Bluecam, designed with Cerec SW 4.4 and fabricated with a Mc X5 laboratory 5-axis milling machine (Sirona Dental Systems).

2.1 Master die fabrication

A master die (Figure 1 and 2) was fabricated from a #30 typodont tooth preparation (LR61B-Kilgore International) and was modified to simulate a lower first molar all-ceramic crown preparation that conforms to Ivoclar’s preparation recommendations. A uniform reduction of 1.5 mm was achieved on all axial and occlusal surfaces. A smooth 1 mm shoulder was prepared using a red stripe finishing diamond (8856DF.31.016 Brasseler, Savannah, GA, USA). The occlusal convergence was kept between five and ten degrees and all internal angles were rounded. This was placed in a typodont (D85SDP-200 Kilgore International) and was used as a master die for all fabrication methods.

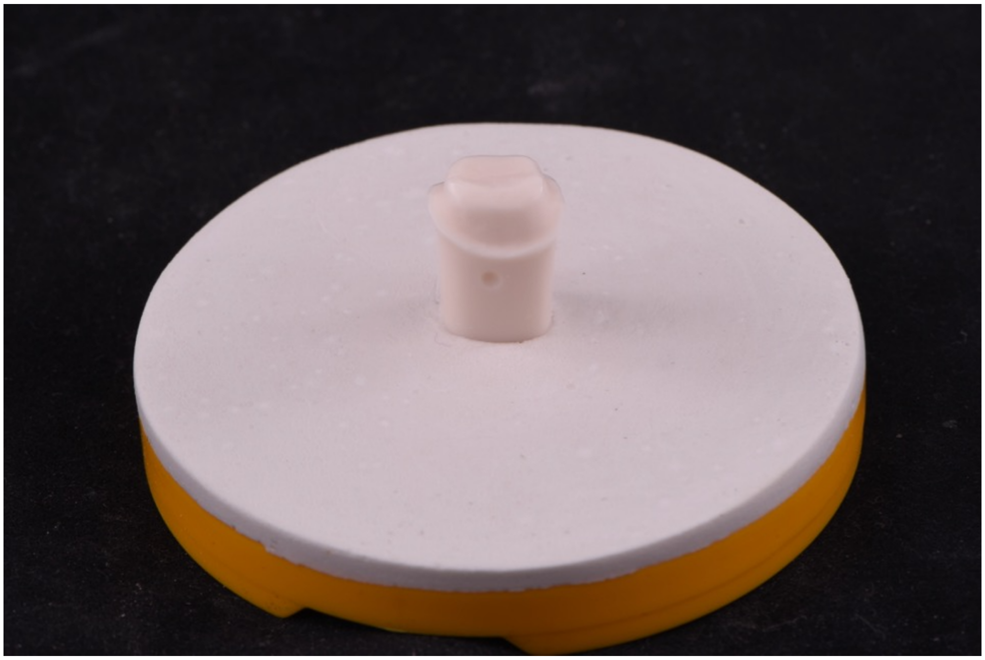


Figure 1. Master die frontal view

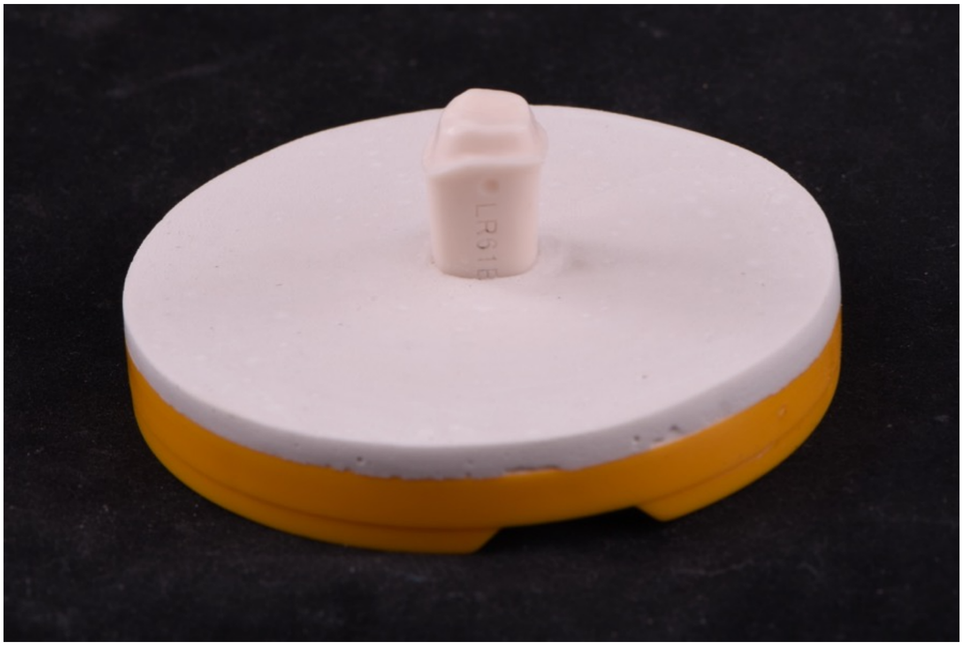


Figure 2. Master die side view

2.2 IPS e.max press crown fabrication

2.2.1 Conventional impressions

Ten full arch master impressions of the tooth preparation were created with heavy and light body VPS (AquasilUltra XLV VPS Type 3: Light-bodied consistency and Type 1: Heavy-bodied consistency Dentsply Milford, DE) in a light cured custom tray (Triad® TruTray™ VLC) that provided a uniform thickness of 2mm for impression material. Each impression was allowed ten minutes of setting time prior to removal. After removal, the impressions were examined under a microscope (10X light, EMT-L, Harris, Lake Zurich, IL) to make sure that the preparation and margins were free of voids or defects. After 24 hours the impressions were poured with ResinRock die stone (WhipMix ISO type 4) for complete setting, in accordance with manufacture's recommendations.

2.2.2 Fabrication of wax pattern

After complete setting of the die stone, the models were removed from the impression and trimmed under a light microscope (10X Magnification, EMT-L, Harris, Lake Zurich, IL) with a carbide bur (H71.11.050 Brasseler USA, Savannah, GA) and discoid-cleoid carving instrument (Carver 2MM, Thompson, Integra, Plainsboro, New Jersey). Each die received uniform layers of die spacer (25 μm total: Tru-Fit, Geo Taub, Jersey City N.J.) in accordance with the manufactures recommendations that extended to within 1 mm of the margin and covered all axial walls and occlusal surfaces. Each die received a light coat of lubrication (Gator Die Lube, Whip Mix, Louisville, KY) prior to receiving a layer of coping wax (Geo-Dip, Renfert Dental Corp.). Each coping was waxed (Geo-Classic, Renfert Dental Corp.) to full contour and the margins were finished under a microscope (10X Magnification, EMT-L, Harris, Lake Zurich, IL).

2.2.3 Fabrication of heat pressed restoration

The wax patterns received a 4mm long 10 gauge wax sprue (#2801007, Lincoln Dental Supply) placed within a 100 g IPS Investment Ring (Ivoclar Vivadent). The pattern was invested (PressVEST Speed, Ivoclar Vivadent) using 16 mL speed investment liquid (Ivoclar Vivadent) and 11 mL deionized water in accordance with the manufacturer's recommendations. The investments were allowed to set for forty minutes and then placed in a preheated 850 °C oven (Jelrus Infinity L30, WhipMix, Louisville, KY) towards the rear wall, tipped with the opening facing downward. The investment remained in the oven for 45 minutes. Following this, an A2 HT IPS e.max Press ingot (Ivoclar Vivadent) was loaded into the investment, followed by a disposable plunger (Zubler USA Inc., Irving, TX). The investment was loaded into the center of a hot press furnace (Vario Press 300 Zubler USA Inc., Irving, TX) and the press program was initiated as recommended by the manufacturer. After cooling to room temperature (60 minutes), the crowns were divested using glass-polishing beads (58 psi rough divestment, 29 psi fine divestment, Pearson Dental, Sylmar, CA). The crowns were immersed for 20 minutes in Invex Liquid (IPS e.max Press Invex Liquid, Ivoclar Vivadent) and air abraded with aluminum oxide (20 psi, 50 Micron, Comco inc., Burbank, CA) to remove the reaction layer. The sprues were removed with a separating disk (#942, Brasseler USA, Savannah, GA) at low speed with irrigation. The internal aspect of the crowns was examined under a microscope (10X Magnification, EMT-L, Harris, Lake Zurich, IL) and any positives associated with the investment process were carefully removed with a diamond bur (801.11009 Brasseler USA, Savannah, GA). Complete seating was confirmed using a microscope (10X Magnification, EMT-L, Harris, Lake Zurich, IL) and an explorer tip (EXPL-5/6, Brasseler USA, Savannah, GA).

2.3 CAD/CAM milled technique

2.3.1 Digital impression

Prior to making a digital impression with the CEREC AC Bluecam (Sirona USA, Charlotte, NC) the camera was calibrated in accordance with the manufacturer's specifications. The surface of the typodont and master die was cleaned with 2X2 gauze and air-dried prior to each optical impression. A light coat of powder (Cerec Optispray, Sirona USA, Charlotte, NC) was applied at a distance of 10mm to all surfaces that were to be scanned. An optical impression was taken (Cerec AC Bluecam, Sirona USA, Charlotte, NC) using the automatic acquisition mode, approximately 9 mm from the preparation surface. The optical impression was carefully reviewed to confirm images were sufficiently bright, sharp and free of motion blurring.

2.3.2 Design of milled restoration

Once images were approved, the margins were virtually marked (Figure 3), and the software (Cerec SW 4.4, Sirona USA, Charlotte, NC) generated a restoration. The milling parameters were adjusted (60 µm spacer) and the crowns were sent to the mill via a Wi-Fi connection. After each crown was digitally fabricated, a .rst file was exported to a flash drive.

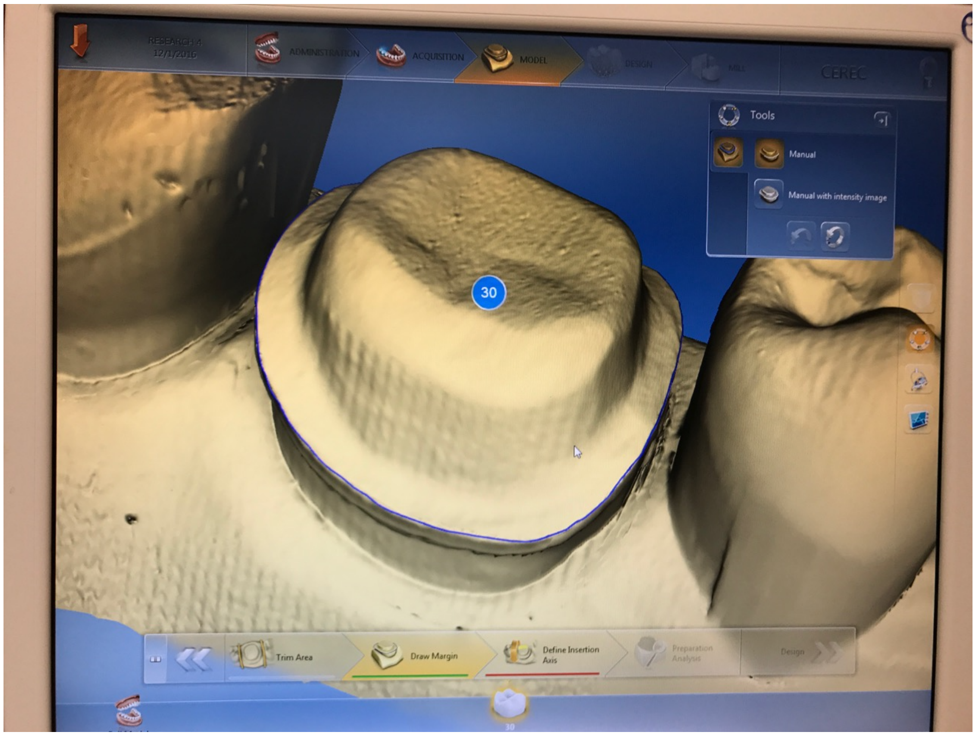


Figure 3. Identification of margins (Cerec SW 4.4, Sirona USA, Charlotte, NC)

2.3.3 Cerec MC X (4-axis mill)

Group McX, consisting of ten crowns, was fabricated using the in-office Cerec Mc X (Sirona USA, Charlotte, NC) milling machine. Prior to milling, the MC X (Figure 4.) was calibrated according to the manufacturer's specifications. New burs (Step Bur 12 S and Cyl. Pointed Bur 12 S, Sirona USA, Charlotte, NC) were installed prior to milling the first crown and used for all crowns in this sample. A new water filter was placed, the reservoir was filled with clean distilled water, and 75 mL of DENTATEC (Sirona USA, Charlotte, NC) was added to the tank. Prior to each mill, an IPS e.max CAD block (Size C14, A2 HT, Ivoclar Vivadent) was installed and tightened into the Mc X. After milling was completed, the crown was removed and the sprue was gently removed with an abrasive rubber wheel (R17DCHP Blue #1, Dialite, Brasseler USA, Savannah, GA). The crown was affixed to a firing peg (Figure 5.) with firing paste (IPS e.max CAD Crystallization Pins, IPS Object Fix Putty), carefully ensuring the margins were completely covered. The firing peg was secured onto a firing tray (IPS e.max CAD Crystallization Tray) and placed in a ceramic furnace (Programat® CS, Ivoclar Vivadent) in accordance with the manufacturer's directions. After the firing cycle, each crown was steam cleaned and complete seating was verified on the master die using a microscope (10X Magnification, EMT-L, Harris, Lake Zurich, IL) and explorer tip (EXPL-5/6, Brasseler USA, Savannah, GA).

Figure 4. Cerec McX 4-axis chairside milling unit

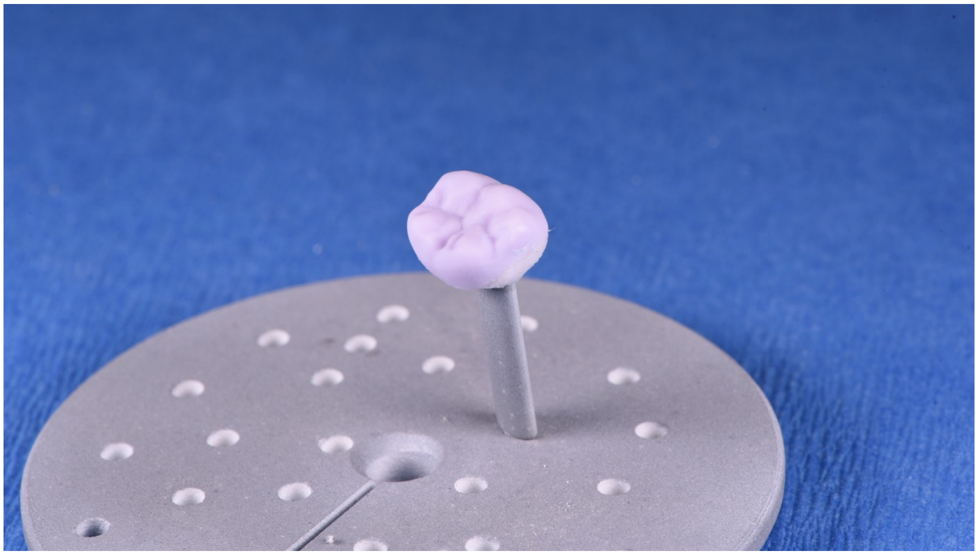


Figure 5. IPS e.max CAD (Ivoclar, Vivadent) crown in “blue state”

2.3.4 Cerec MC X5 (5-axis mill)

The Cerec Mc X5 (5-axis, Sirona USA, Charlotte, NC) was used to mill the third group of crowns (Group McX5). Prior to milling, the machine was calibrated and new burs were installed. The .rst files acquired from the chairside scans were converted to .stl and loaded into Cerec inLab SW 15.0 (Sirona USA, Charlotte, NC) software (Figure 6.) and prepared for milling. The blocks (Size C14, A2 HT, Ivoclar Vivadent) were secured inside the fabrication ring and the crowns were milled (Figure 7.). After the process was complete, the crowns were removed from the machine. Next, the crown was separated from the milling adaptor with a diamond separating disk (#942, Brasseler USA, Savannah, GA) and the sprue was gently removed with an abrasive rubber wheel (R17DCHP Blue #1, Dialite, Brasseler USA, Savannah, GA). The crown was affixed to a firing peg (Figure 5.) with firing paste (IPS e.max CAD Crystallization Pins, IPS Object Fix Putty), carefully ensuring the margins were completely covered. The firing peg was secured onto a firing tray (IPS e.max CAD Crystallization Tray) and placed in a ceramic furnace (Programat® CS, Ivoclar Vivadent) in accordance with the manufacturer's directions. After the firing cycle, each crown was steam cleaned and complete seating was verified on the master die using a microscope (10X Magnification, EMT-L, Harris, Lake Zurich, IL) and explorer tip (EXPL-5/6, Brasseler USA, Savannah, GA).

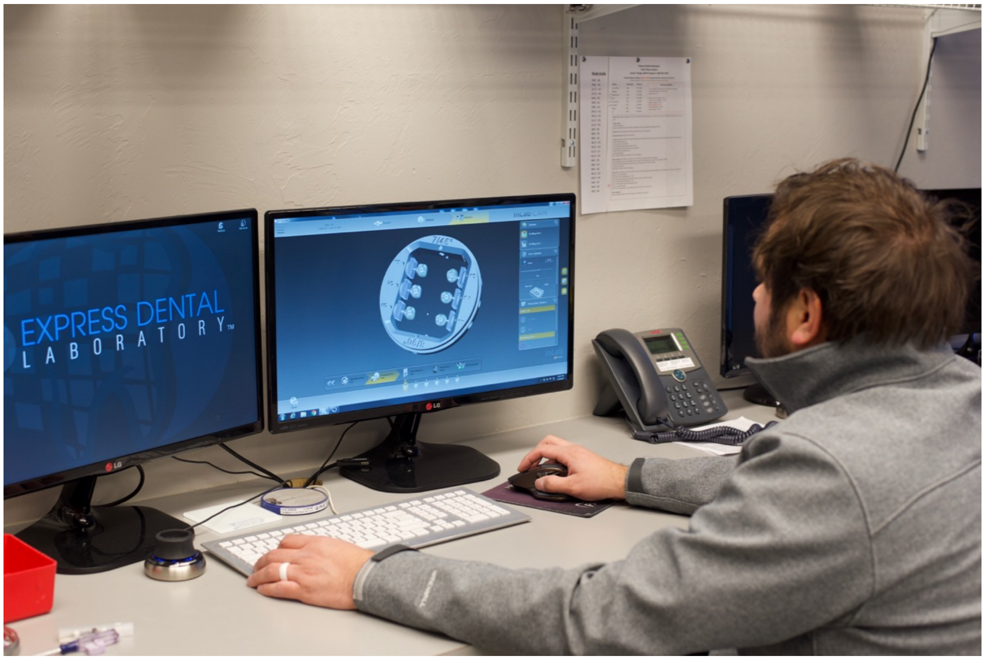


Figure 6. Cerec inLab SW 15.0

Figure 7. Mc X5 fabrication ring after milling

2.4 Measuring marginal fit

The current study utilized the 3D replica technique to evaluate marginal fit. First, light body silicone was added to the intaglio of the crowns and each one was cemented on the master die. Next, each crown was removed leaving the silicone replica on the master die. The silicone replica, representing the marginal misfit between the crown and tooth preparations, was scanned using a laboratory scanner and then merged with the master model file. From there, margins were selected and the mean marginal fit was calculated. The term ‘mean marginal fit’ was used to describe the average marginal gap between the tooth prep and crown calculated by analysis software (Geomagic Control). This 3D version of the replica technique is based off the original replica technique.[12]

2.4.1 Master die holder fabrication

Each crown was steam cleaned prior to data collection. A master die holder (Figure 8.) was fabricated using a mounting plate (SAM Präzisionstechnik GmbH, München, Germany) and mounting stone (WhipMix, ISO type 3, Louisville, KY). Before scanning, four indentations were made in the master die with a 6 round bur (Brasseler USA, Savannah, GA) located 4 mm below the margin that could be used by the analysis software (Geomagic Control, 3D Systems, Rock Hill, S.C.) as a best-fit alignment aid. The master die and holder were digitized using a 3D laboratory scanner (8 μm ISO, D900 3 Shape, Copenhagen, Denmark) to create a master .stl file.

2.4.2 Crown seating

A very thin layer of adhesive (V.P.S. Tray Adhesive, Kerr) was applied to the master die (Figure 8.) with a microbrush (Microbrush Int., Grafton, WI). A layer of light body VPS (AquasilUltra XLV VPS Type 3: Light-bodied consistency, Dentsply Milford, DE) was applied to the intaglio of the crown and was seated on the master die with firm finger pressure (Figure 9.). The excess VPS was quickly cleaned with 2X2 gauze and the crown remained under a standardized force of 20N for ten minutes (Figure 10 and 11). The crown was then carefully removed from the master die (Figure 12).

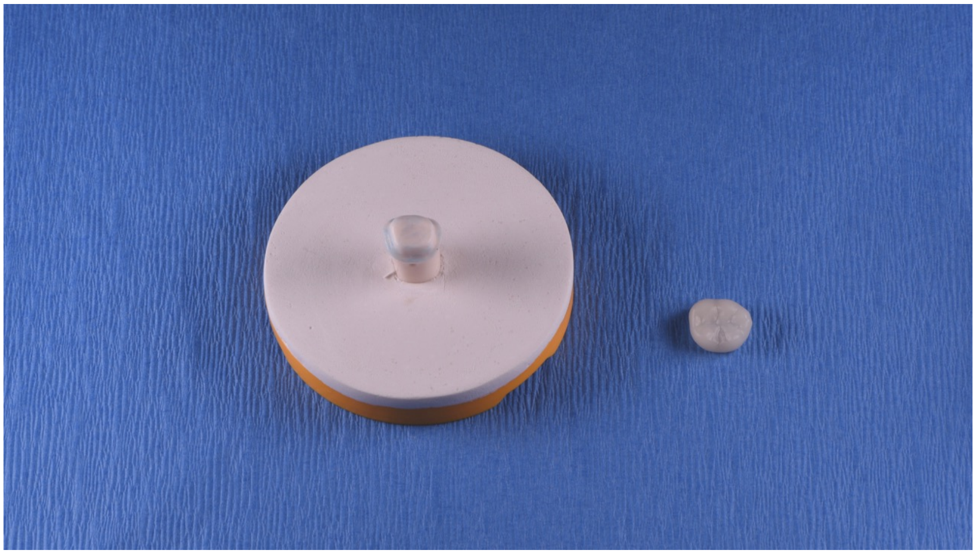


Figure 8. VPS tray adhesive coat

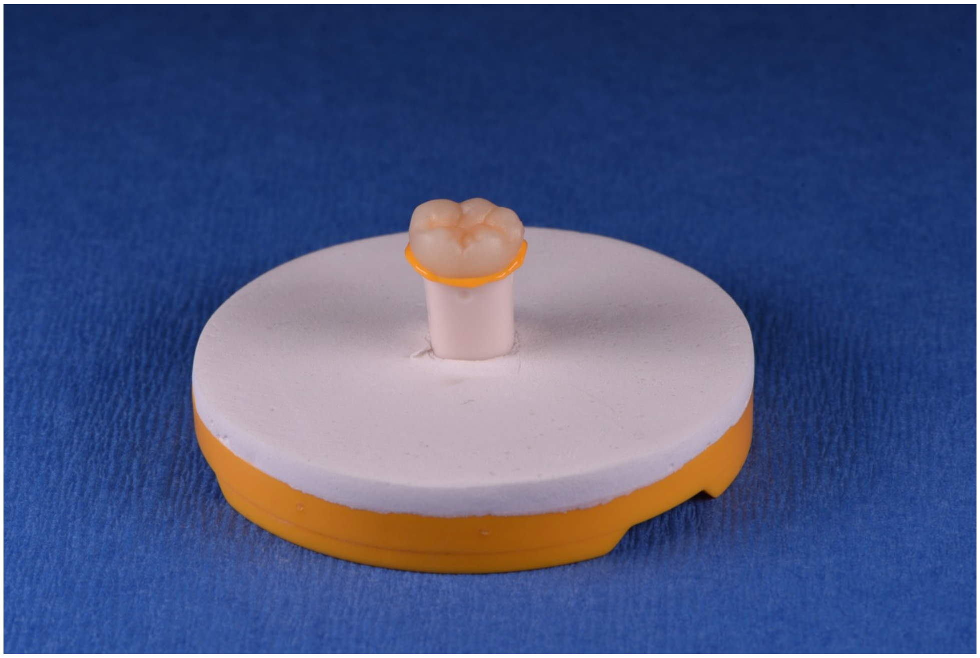


Figure 9. Crown immediately after cementation

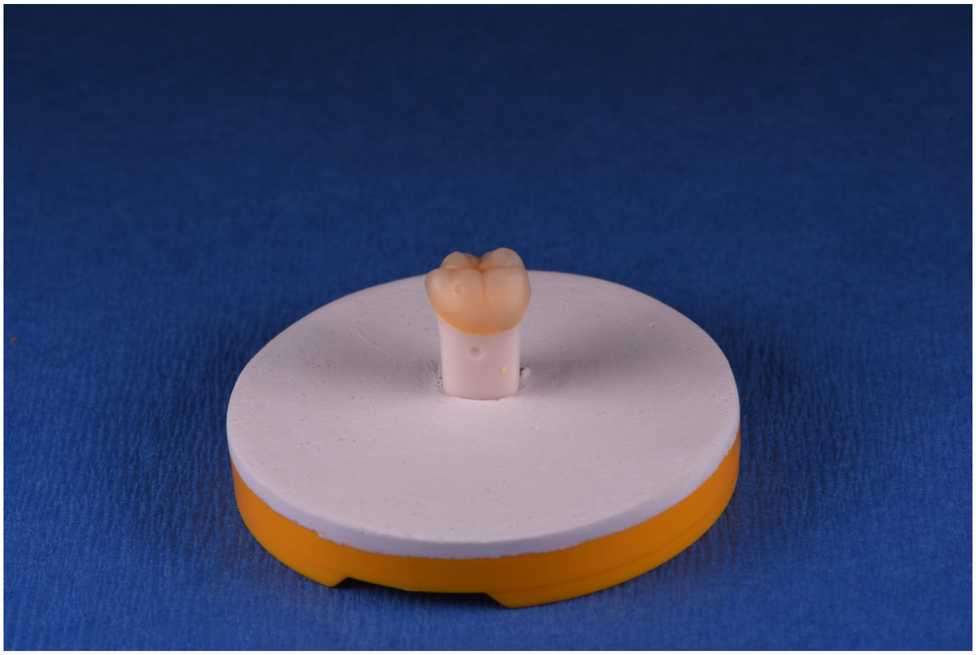


Figure 10. Cementation of replica after removal of residual VPS

Figure 11. Standardized seating force (20N)

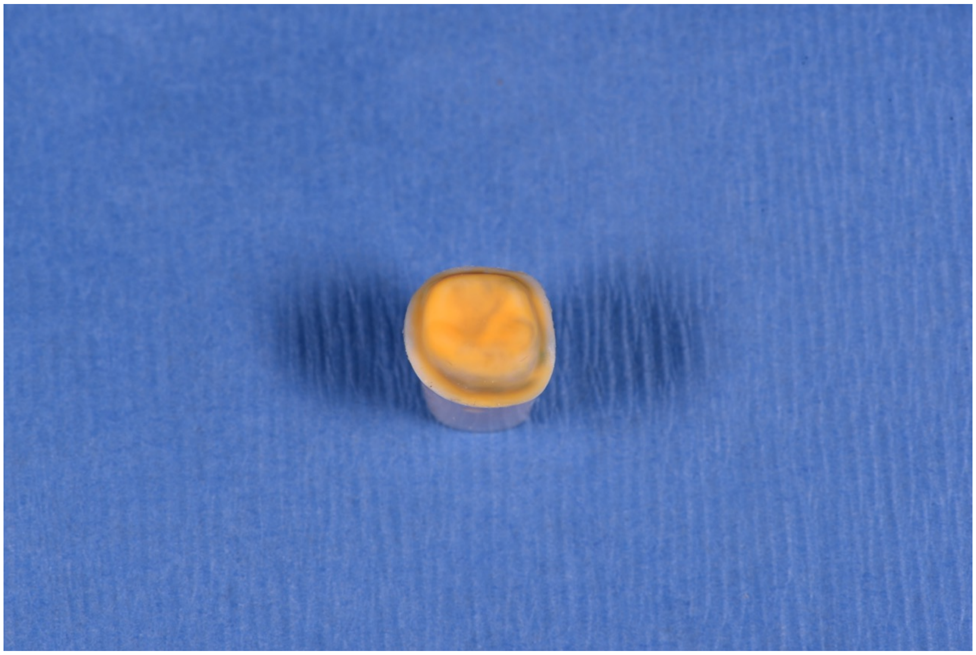
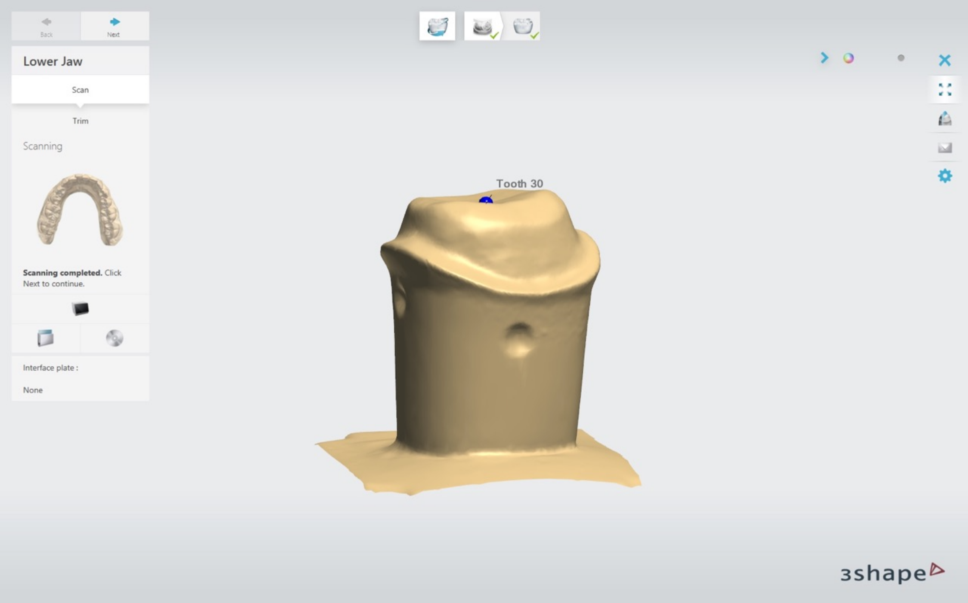


Figure 12. Master die and VPS replica

2.4.3 Digitization and comparison with master model

Once each crown was removed, the resulting VPS and die combination was scanned using the laboratory scanner (8 µm ISO, D900 3 Shape, Copenhagen, Denmark) and a .stl was generated and labeled (Figure 13 and 14). This procedure was repeated for each of the 30 crowns. The resulting test .stl and master .stl were opened in a three-dimensional analysis software, (Geomagic Control 3D Systems, Rock Hill, S.C.).

Figure 13. 3Shape D900 scanner and computer terminal



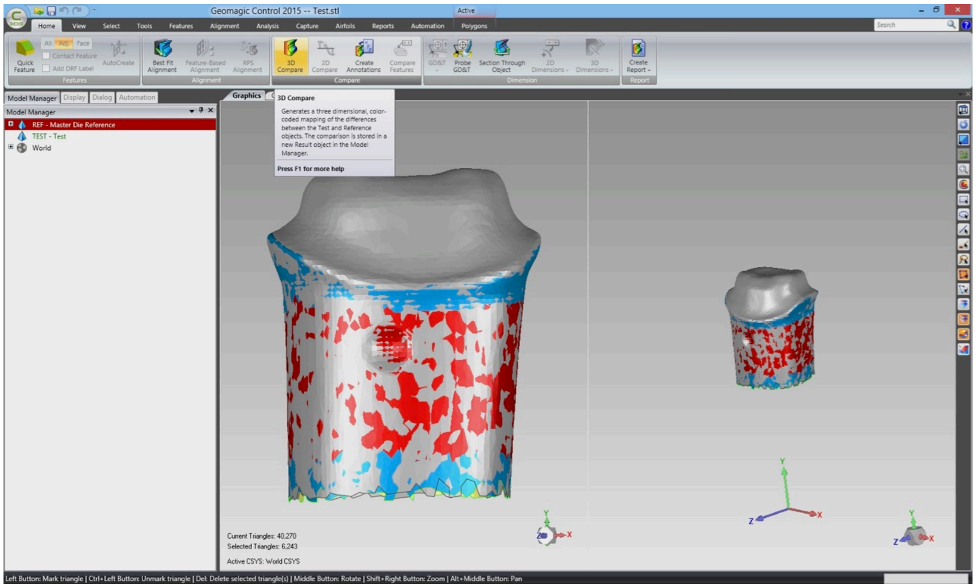
Scanning completed. Click Next to continue.

Interface plate :

None

Figure 14. Scan of master die using 3Shape scanner and software

Using the software's selection tool, the 3D files were trimmed so only relevant information remained. The master die STL was assigned as the REFERENCE object and the experimental STL was assigned as the TEST object. A best-fit alignment was run in the software by selecting the information below the margin and utilizing the four index points (Figure 15). To verify the accuracy of the alignment, a 3D analysis was run to confirm that proper alignment had occurred (Figure 16).



3D Compare

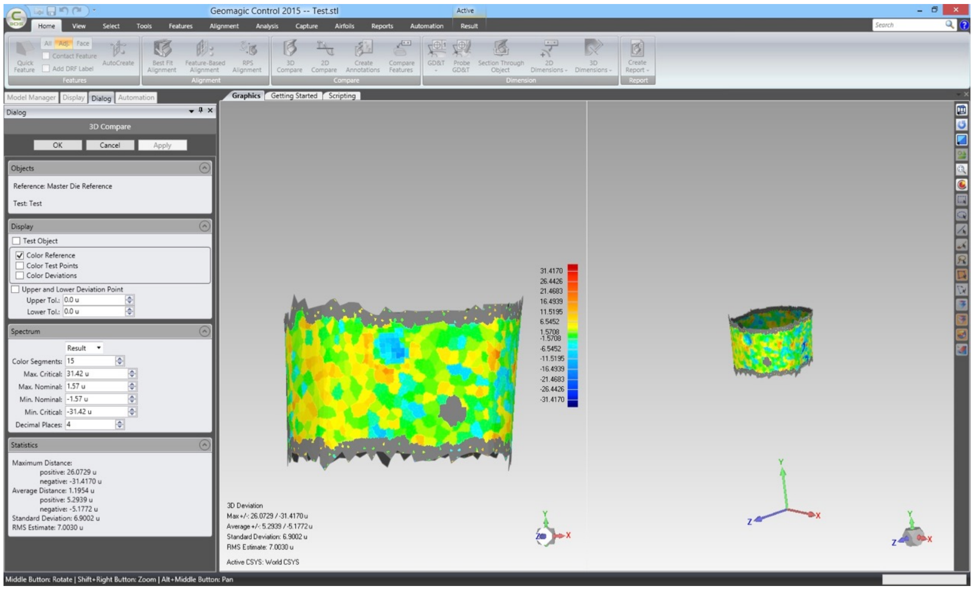
Generates a three dimensional, color-coded mapping of the differences between the Test and Reference objects. The comparison is stored in a new Result object in the Model Manager.

Press F1 for more help

Current Triangles: 40,270
Selected Triangles: 6,243
Active CSYS: World CSYS

Left Button: Mark triangle | Ctrl+Left Button: Unmark triangle | Del: Delete selected triangle(s) | Middle Button: Rotate | Shift+Right Button: Zoom | Alt+Middle Button: Pan

Figure 15. Best-Fit alignment



Dialog

3D Compare

Objects

Reference: Master Die Reference

Test: Test

Display

☐ Test Object

☑ Color Reference
☐ Color Test Points
☐ Color Deviations

☐ Upper and Lower Deviation Point
Upper Tol.: 0.0 u
Lower Tol.: 0.0 u

Spectrum

Result
Color Segments: 15
Max. Critical: 31.42 u
Max. Nominal: 1.57 u
Min. Nominal: -1.57 u
Min. Critical: -31.42 u
Decimal Places: 4

Statistics

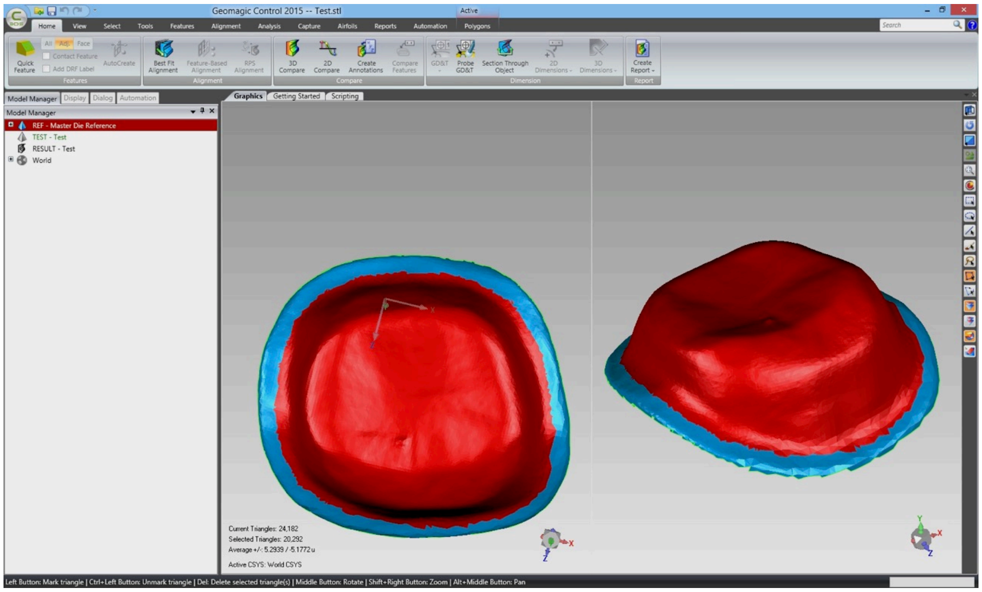
Maximum Distance:
positive: 26.0729 u
negative: -31.4170 u
Average Distance: 1.1954 u
positive: 5.2939 u
negative: -5.1772 u
Standard Deviation: 6.9002 u
RMS Estimate: 7.0030 u

3D Deviation
Max +/-: 26.0729 / -31.4170 u
Average +/-: 5.2939 / -5.1772 u
Standard Deviation: 6.9002 u
RMS Estimate: 7.0030 u

Active CSYS: World CSYS

Middle Button: Rotate | Shift+Right Button: Zoom | Alt+Middle Button: Pan

Figure 16. Result of Best-Fit analysis and RMS values in bottom left



Model Manager
REF - Master Die Reference
TEST - Test
RESULT - Test
World

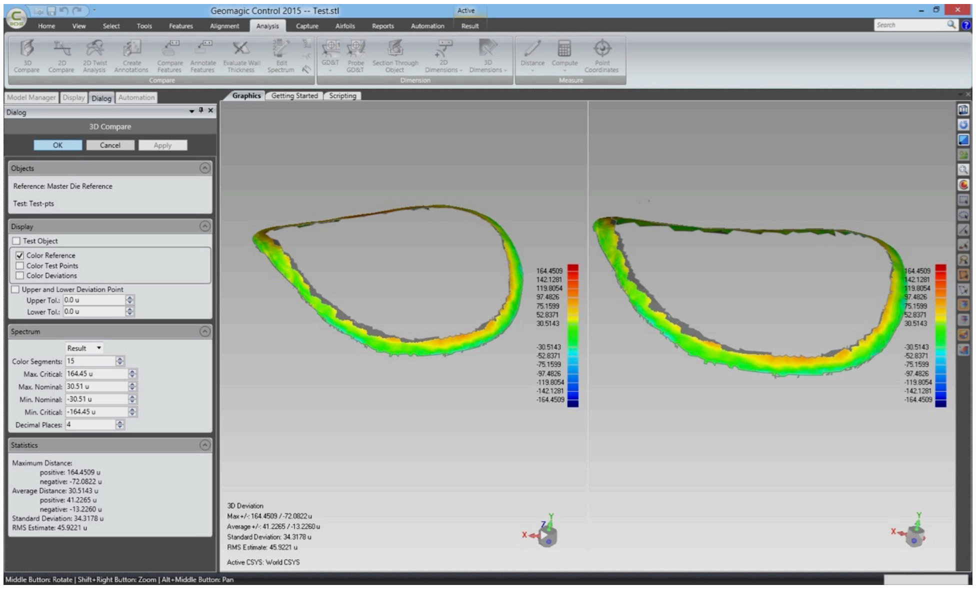
Current Triangles: 24,182
Selected Triangles: 20,292
Average +/-: 5.2939 / -5.1772 u

Active CSYS: World CSYS

Left Button: Mark triangle | Ctrl+Left Button: Unmark triangle | Del: Delete selected triangle(s) | Middle Button: Rotate | Shift+Right Button: Zoom | Alt+Middle Button: Pan

Figure 17. Selection of margin to evaluate fit

Once the alignment was verified, the margin was selected on both specimen and all other data was removed (Figure 17.). The TEST object was converted in a point cloud with 20,000 data points. A 3-D analysis was run between the TEST point cloud and the REFERENCE, and the average deviation was used for comparison (Figure 18.). A report was run for each specimen and all data was loaded into an excel work document.



Objects

Reference: Master Die Reference

Test: Test-pts

Display

☐ Test Object

☑ Color Reference

☐ Color Test Points

☐ Color Deviations

☐ Upper and Lower Deviation Point

Upper Tol.: 0.0 u

Lower Tol.: 0.0 u

Spectrum

Result

Color Segments: 15

Max. Critical: 164.45 u

Max. Nominal: 30.51 u

Min. Nominal: -30.51 u

Min. Critical: -164.45 u

Decimal Places: 4

Statistics

Maximum Distance:
positive: 164.4509 u
negative: -72.0822 u
Average Distance: 30.5143 u
positive: 41.2265 u
negative: -13.2260 u
Standard Deviation: 34.3178 u
RMS Estimate: 45.9221 u

3D Deviation
Max +/-: 164.4509 / -72.0822 u
Average +/-: 41.2265 / -13.2260 u
Standard Deviation: 34.3178 u
RMS Estimate: 45.9221 u

Active CSYS: World CSYS

Figure 18. Sample output file shows 3-dimensional mean marginal fit evaluation

2.5 Statistical analysis

The data was analyzed using a one-way ANOVA. Normality was checked using the Shapiro Wilk test for normality, and Levine’s Test was used to insure that there was homogeneity of variance. A p-value of less than 0.05 was used to determine if the difference was statistically significant. All statistical data was analyzed using SPSS (SPSS 19.0, SPSS Inc., Chicago, IL)

3. RESULTS

The results of the one-way ANOVA found that there was no significant difference between the three groups. The Pressed group's average marginal fit was 49.37 µm. The average fit for the CAD/CAM milled restorations were 54.53 µm for McX (4-axis) and 50.74 µm for the McX5 (five-axis). Table 1 and 2 shows the mean marginal fit, standard deviation and the minimum and maximum values found for each group.

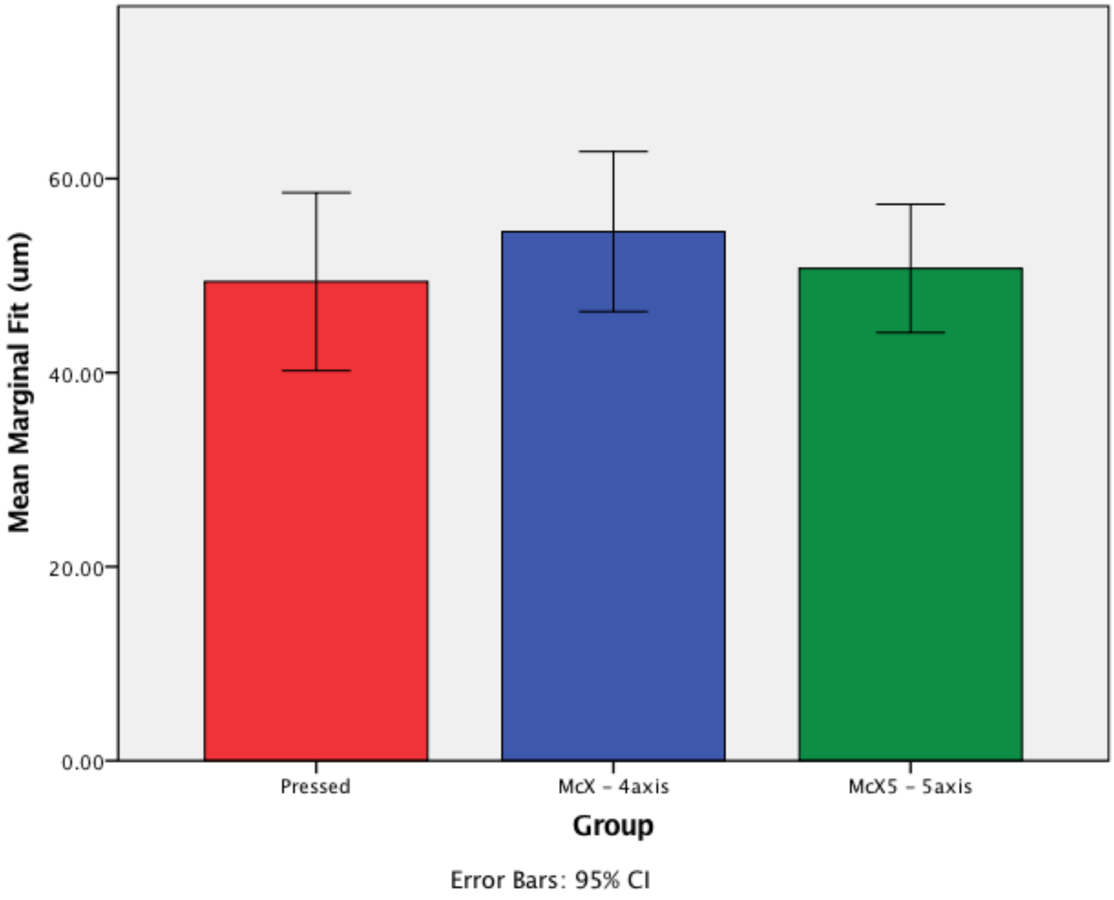
Table 1. Mean marginal fit for each group and statistics

	Pressed	**McX-4 axis**	**McX5-5 axis**
Sample Size	10	10	10
Mean Marginal Fit	**49.4 µm**	**54.5 µm**	**50.7 µm**
SD[a]	12.8 µm	11.5 µm	9.2 µm
Minimum	26.1 µm	41.7 µm	40.5 µm
Maximum	70.3 µm	72.9 µm	65.1 µm

---

[a] Standard Deviation

Table 2. Bar graph of mean marginal fit and confidence intervals



4. DISCUSSION

The purpose of this in vitro study was to measure the marginal fit of IPS e.max restorations using three different fabrication techniques: heat pressing using the lost wax technique, chairside 4-axis milling, and milling with a laboratory five-axis mill. The least closely adapted margin was seen in the McX chairside milling group followed by the laboratory five-axis McX5 group and the best fit in the lost wax technique, or Pressed group. The deviation between groups was minor with no significant differences between the data sets. Therefore, the data failed to reject the null hypothesis that there would be no significant difference in marginal fit between the three groups. All margins were well below the 120-µm maximum set for clinical acceptability.[10]

When evaluating marginal fit of an indirect restoration it is important to have the appropriate number of samples to get a clinically significant result. Groten et al determined that a minimum of 50 measurement points taken circumferentially around the margin was required to obtain clinically significant results.[15] With the 2D replica technique it would be difficult if not impossible to achieve this number of measurements. By utilizing the 3D replica technique, we converted our 3D replica to a “Point Cloud” with 200,000 data points which is much larger than the 50 data points required for a clinically acceptable result. This large sample size allowed us to determine a mean marginal discrepancy, which is the absolute marginal discrepancy, not just a few points averaged together seen in other studies.

Few studies have used the 3D replica technique to evaluate marginal fit of lithium disilicate restorations. A study by Neves et al evaluated lithium disilicate restorations fabricated using heat pressing or CAD/CAM chairside systems. This study compared pressed crowns to CEREC chairside mill and the E4D chairside milling systems.[21] Their study differed from the current study by evaluating marginal fit using micro CT. The advantage of micro CT is it is nondestructive and can achieve a sufficient number of measurements needed to achieve a clinically significant result. However, critics of this technique say that it is expensive and is prone to radiological scatter.[11] Neves et al determined no significant difference between crowns fabricated with either Pressed or CEREC chairside mill. However, it was found that crowns fabricated with the E4D chairside 4-axis mill had significantly larger marginal fit than the other two groups.[21] This is in agreement with our current study, that no significant difference exists between the pressed or CEREC milled restorations.

A study by Ng et al examined differences in marginal fit of lithium disilicate using an all-digital workflow (five-axis laboratory mill) as compared to the lost wax technique (PVS impression, wax up, and heat pressing). Marginal fit was evaluated using a light microscope, which identified 8 sites per crown. The results indicated that the all-digital workflow with five-axis mill had lower marginal fit as compared to the lost wax technique. The results for the all-digital restorations compared to the heat-pressed restorations were 48 μm and 74 μm respectively. Both groups in this study were within clinically acceptable limits but with a statistically significant difference. The results of our study are similar to the marginal fit found with the all-digital workflow, but the heat pressed group had a marginal fit of 74 μm compared to 49.4 μm found in the current study.[30] Fabricating lithium disilicate crowns using the lost wax technique is technique sensitive with many variables, which could account for the differences between the studies.

One limitation of the current study was using the same digital file to mill both groups of crowns in McX and McX5. A 5-axis milling machine has the ability to operate on an additional axis that is unavailable to a four-axis machine.[29] This additional axis allows the 5-axis to mill undercuts and other nuances in the intaglio of the crown that are unavailable to 4-axis machines. To minimize variability, the same digital files were used for both 4- and 5-axis groups in our study. This allowed the comparison in the milling precision, but could have prevented a finding of statistical significance between the 4- and 5-axis machines.

Kirsch et al looked at three different milling machines, The MC X5 (Sirona Dental Systems), the MCXL (Sirona Dental Systems) and the CORiTEC 450i (5-axis mill, imes-icore, Eiterfeld, Germany). To evaluate the trueness of the milled restorations they digitized their specimen and compared them to the master file. Their study found that there was no significant difference between the four-axis mill compared to the five-axis mill when precision milling settings were used on the four-axis device. However, they found that the four-axis milling unit performed significantly worse when precision milling settings were not used.[29] In our study we did not use precision milling settings on the four-axis device and still found no significant difference between groups.

One interesting finding from this study was the mean marginal fit of the three groups as compared to the 120 μm standard that has been reported in the literature. All specimens in the present study had mean marginal fit of less than 75 μm and the average for the three groups was below 55 μm, which is much lower than the 120 μm standard seen in literature.[7, 10] With such low values seen in this study and other recent publications there is a need for a new standard for marginal fit lower than the dated value of 120 μm.

Another limitation to our study has been reported in the literature with other replica studies. Although great care is taken when removing the crown from the master die, some replicas did tear or lift away upon removal of the restoration. This resulted in having to repeat the replica cementation procedure. When a replica did adhere to the surface of the master preparation it still had the potential of lifting away or distorting that may have been imperceptible to the eye but could have influenced measurement.

A dentist has the ability to fabricate lithium disilicate crowns in a variety of ways. This study attempted to evaluate whether newer fabrication techniques were better or worse than more traditional techniques. The time-tested method of making an impression and fabricating a stone model which can then be used to fabricate a restoration was represented in our study by the Pressed group. Recently, there has been a large influx of intraoral scanners used to take optical impressions, which are then sent to a dental laboratory for fabrication of a restoration. The workflow utilizing a laboratory 5-axis mill was represented by the group McX5. The last group, McX, utilizes a chairside mill to fabricate a restoration in-office. With multiple fabrication techniques available, it is extremely important to determine which fabrication technique will provide a patient with the highest quality restoration. Based on the results of this *in-vitro* study it was found that there was no significant difference in marginal fit between these three fabrication methods. All fabrication methods appear to be clinically acceptable; therefore, clinicians must base their decisions on factors other than marginal fit.

Future research is needed to examine the different fabrication techniques of lithium disilicate crowns. As digital technology becomes more prevalent in dentistry, materials and techniques will evolve. With each evolution, evaluation of marginal fit will necessary. With newer non-destructive evaluation techniques, marginal adaptation studies will continue to improve and advance.

5. CONCLUSIONS

This study examined the three-dimensional marginal fit of pressed and crowns fabricated using four or five axis mills. Within the limitations of this *in vitro* study we failed to reject the null hypothesis and found no significant difference between the three techniques. All fabrication methods provided clinically acceptable marginal fit below the 120-µm threshold stated in the literature.

REFERENCES

[1] Bertolotti RL. Alternative casting alloys for today's crown and bridge restorations. Part II: metal-ceramic restorations. *CDA Journal California Dental Association* 1983; **11**: 63-69.

[2] Gehrt M, Wolfart S, Rafai N, Reich S, Edelhoff D. Clinical results of lithium-disilicate crowns after up to 9 years of service. *Clinical oral investigations* 2013; **17**: 275-284.

[3] Schwartz NL, Whitsett LD, Berry TG, Stewart JL. Unserviceable crowns and fixed partial dentures: life-span and causes for loss of serviceability. *The Journal of the American Dental Association* 1970; **81**: 1395-1401.

[4] Bader JD, Rozier RG, McFall Jr WT, Ramsey DL. Effect of crown margins on periodontal conditions in regularly attending patients. *The Journal of Prosthetic Dentistry* 1991; **65**: 75-79.

[5] Jahn KR, Baum W, Zuhrt R. Secondary caries frequency under complete crowns in relation to the material and design of the crown as well as the crown margin finish. *Stomatologie der DDR* 1985; **35**: 665-670.

[6] Goodacre CJ, Bernal G, Rungcharassaeng K, Kan JYK. Clinical complications in fixed prosthodontics. *Journal of Prosthetic Dentistry* 2003; **90**: 31-41.

[7] Christensen GJ. Marginal fit of gold inlay castings. *The Journal of Prosthetic Dentistry* 1966; **16**: 297-305.

[8] Holmes JR, Sulik WD, Holland GA, Bayne SC. Marginal fit of castable ceramic crowns. *J Prosthet Dent* 1992; **67**: 594-599.

[9] Hung SH, Hung K-S, Eick JD, Chappell RP. Marginal fit of porcelain-fused-to-metal and two types of ceramic crown. *The Journal of Prosthetic Dentistry* 1990; **63**: 26-31.

[10] McLean JW, Von F. The estimation of cement film thickness by an in vivo technique. *British Dental Journal* 1971; **131**: 107-111.

[11] Contrepois M, Soenen A, Bartala M, Laviole O. Marginal adaptation of ceramic crowns: a systematic review. *The Journal Of Prosthetic Dentistry* 2013; **110**: 447-454.e410.

[12] Molin M, Karlsson S. The fit of gold inlays and three ceramic inlay systems: A clinical and in vitro study. *Acta Odontologica Scandinavica* 1993; **51**: 201-206.

[13] Rahmé HV, Tehini GE, Adib SM, Ardo AS, Rifai KT. In vitro evaluation of the "replica technique" in the measurement of the fit of Procera® crowns. *Journal of Contemporary Dental Practice* 2008; **9**: 025-032.

[14] Laurent M, Scheer P, Dejou J, Laborde G. Clinical evaluation of the marginal fit of cast crowns - Validation of the silicone replica method. *Journal of Oral Rehabilitation* 2008; **35**: 116-122.

[15] Groten M, Axmann D, Pröbster L, Weber H. Determination of the minimum number of marginal gap measurements required for practical in vitro testing. *Journal of Prosthetic Dentistry* 2000; **83**: 40-49.

[16] Kim KB, Kim JH, Kim WC, Kim JH. Three-dimensional evaluation of gaps associated with fixed dental prostheses fabricated with new technologies. *Journal of Prosthetic Dentistry* 2014; **112**: 1432-1436.

[17] Luthardt RG, Walter MH, Bornemann G, Lemelson S, Hüls 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. *International Journal of Prosthodontics* 2004; **17**: 680-685.

[18] GW T. The science behind lithium disilicate: a metal-free alternative. Dentistry Today, March 2009. *Dental Abstracts* 2009; **54**: 318-319.

[19] Sailer I, Makarov NA, Thoma DS, Zwahlen M, Pjetursson BE. All-ceramic or metal-ceramic tooth-supported fixed dental prostheses (FDPs)? A systematic review of the survival and complication rates. Part I: Single crowns (SCs). *Dental Materials* 2015; **31**: 603-623.

[20] Beuer F, Schweiger J, Edelhoff D. Digital dentistry: An overview of recent developments for CAD/CAM generated restorations. *British Dental Journal* 2008; **204**: 505-511.

[21] Neves FD, Prado CJ, Prudente MS, et al. Micro-computed tomography evaluation of marginal fit of lithium disilicate crowns fabricated by using chairside CAD/CAM systems or the heat-pressing technique. *The Journal of Prosthetic Dentistry* 2014; **112**: 1134-1140.

[22] Ender A, Mehl A. Full arch scans: Conventional versus digital impressions - An in-vitro study. *International Journal of Computerized Dentistry* 2011; **14**: 11-21.

[23] Luthardt R, Loos R, Quaas S. Accuracy of intraoral data acquisition in comparison to the conventional impression. *International Journal of Computerized Dentistry* 2005; **8**: 283-294.

[24] Tapie L, Lebon N, Mawussi B, Fron-Chabouis H, Duret F, Attal JP. Understanding dental CAD/CAM for restorations--accuracy from a mechanical engineering viewpoint. *International Journal of Computerized Dentistry* 2015; **18**: 343-367.

[25] Denry I, Holloway JA. Ceramics for Dental Applications: A Review. *Materials (1996-1944)* 2010; **3**: 351-368.

[26] Ritzberger C, Schweiger M, Höland W. Principles of crystal phase formation in Ivoclar Vivadent glass-ceramics for dental restorations. *Journal of Non-Crystalline Solids* 2016; **432**: 137-142.

[27] Reiss B. Clinical results of cerec inlays in a dental practice over a period of 18 years. *International Journal of Computerized Dentistry* 2006; **9**: 11-22.

[28] Reiss B, Walther W. Clinical long-term results and 10-year Kaplan-Meier analysis of Cerec restorations. *International Journal of Computerized Dentistry* 2000; **3**: 9-23.

[29] Kirsch C, Ender A, Mehl A, Attin T. Trueness of four different milling procedures used in dental CAD/CAM systems. *Clinical oral investigations* 2016: 1-8.

[30] Ng J, Ruse D, Wyatt C. A comparison of the marginal fit of crowns fabricated with digital and conventional methods. *Journal of Prosthetic Dentistry*; **112**: 555-560.

APPENDIX

RAW DATA

Table 3. Marginal fit for each specimen

	Pressed (µm)	**McX (µm)**	**MCX5 (µm)**
Specimen 1	70.29	68.98	65.13
Specimen 2	47.17	48.28	49.61
Specimen 3	42.72	41.69	40.54
Specimen 4	41.27	72.95	62.76
Specimen 5	56.62	44.37	43.13
Specimen 6	43.68	42.12	40.92
Specimen 7	26.09	66.72	61.25
Specimen 8	51.94	58.03	44.11
Specimen 9	66.47	51.9	49.22
Specimen 10	47.49	50.32	50.76
Mean marginal fit	**49.37**	**54.54**	**50.74**