Tufts UNIVERSITY | School of Dental Medicine

The effect of different marginal configurations and scanning powders on the accuracy of the marginal adaptation of zirconia crowns

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Thesis Defense Date: 07/24/17

ABSTRACT

Introduction:

The quality of a dental restoration is often assessed by its marginal adaptation and coverage. The importance of marginal adaptation lies in the protection of the tooth from such different types of biological failure as periodontal disease, caries, pulpal inflammation and consequent possible tooth loss. When viewing the literature, an opening of 50-120 microns is considered clinically acceptable. CAD/CAM technology has been introduced to the dental world to make dentistry more efficient and pleasant. This technology can reduce clinicians' time spent on lab procedures and in the clinic . There are many variables to consider with this rather new technology, such as marginal design and the type of scanning material used. The purpose of this study was to compare such finish line designs as chamfer and shoulder and such imaging materials as 3M, Vita, and Sinbrio.

Materials and methods:

A pilot study was conducted to determine the sample size for the main study. Two different marginal configurations were tested (1mm chamfer, 1.5 shoulder) and three different types of imaging materials (3M high resolution powder, Vita powder spray, Sinbrio scanning paint) in various permutations. The sample size for the main study was determined to be 18 per group (n=18). Two typodonts were prepared and scanned using the 3M True Definition scanner and milled. A total of 108 zirconia crowns were milled. Finally, the replica technique and a high magnification microscope 92x were used to measure the marginal gap.

Results:

The means (standard deviation) for each group were 13.04 (1.66) μm for the chamfer and 3M powder group; 12.34 (1.77) μm for the chamfer and vita powder spray group; 12.45 (2.01) μm for the chamfer and Sinbrio scanning paint; 11.63 (1.25) μm for the shoulder and 3M powder group; 12.70 (1.43) μm for the shoulder and vita powder spray group; and 12.05 (2.69) μm for the shoulder and Sinbrio scanning paint group. The difference between marginal preparation designs was not statistically significant ($p = 0.180$), nor was the difference among imaging materials ($p = 0.826$).

Conclusion:

There was no significant difference between the finish line designs utilized and the types of imaging materials tested on the marginal adaptation of zirconia crowns.

ACKNOWLEDGMENTS

First, I wish to express my gratitude to Dr. Hiroshi Hirayama for accepting me into the Advanced Graduate Prosthodontics program at Tufts University School of Dental Medicine. Second, I would like to thank my principal advisor, Dr. Ala Ali, for all his help and guidance throughout this process. To my supportive committee members, starting with Dr. Mathew Finkelman: without your constant help and support I would know nothing about statistics. Mr. Yukio Kudara, your technical knowledge, lab supervision and help is what made this research possible. Dr. Khaled Elrafie, thank you for all you've done for me whether it was during my residency in the clinic or for this research. Thank you from the bottom of my heart.

I also would like to extend my gratitude to two amazing friends who helped me beyond words: Mr. Haleem Ragis, an MDT student at Tufts, and Dr. Nesereen Albar, who went through this before me and taught me everything she knows. Not to forget Mr. Jeffrey Daddona, for his assistance and guidance in the research lab.

Last but not least I would like to thank my amazing mother. Without her prayers and constant support, I would not be here today.

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The Effect of Different Marginal Configurations and Scanning powders on the Accuracy of the Marginal Adaptation of Zirconia Crowns

I. INTRODUCTION

CAD/CAM is an abbreviation for computer aided design/computer aided manufacturing. [1] The parallel terminology in other industries is CAD/NC (Numerical Control). [2] CAD/NC provides industrial companies with the ability to manufacture products easily with less rendering time. The machining industry was transformed in the 1960s when CAD/NC was released to the market. [2] Shortly thereafter, CAD/CAM was unraveled and utilized by the aerospace and automotive industries. CAD/CAM is recognized now in many industries as an aid in designing and fabricating merchandise.

CAD/CAM was first introduced to the dental world in the 1970s by Duret et al [3] A digital scanner was created that formed an optical impression of a tooth requiring a crown from which a crown was milled. Soon, a commercially available machine was created called the Sopha system. [3] In the same period, more developments were made to this system. [4] In the decades following, more advancements were made. In the 1980s (Cerec® (Sirona®), Bensheim, Germany) claimed same day deliveries of inlays using CAD/CAM. [5] However, the inlays produced had incorrect occlusal morphologies and more work was needed to improve the technology. [6]

In general, using the technology for intra-oral impressions proved to have many challenges; therefore, a second generation of CAD/CAM was developed that consisted of taking a conventional impression and scanning the stone model produced to create either metal or ceramic restorations. [3] Contact probes and laser beams were

later introduced to the scanning machine. [3] The third generation of CAD/CAM machines teemed with networking possibilities for milling crowns. [3] Now, milling removable partial denture frameworks (Sensible®) and maxillofacial prostheses using CAD/CAM is achievable. [7] Also, the milling of zirconia frameworks has been made possible. Zirconia, which is known for shrinkage, can be milled in two ways: before sintering or post sintering. Elaborate arithmetic has been used to estimate how much shrinkage will occur in order to produce accurate restorations. It was found that milling zirconia post sintering caused wearing of the burs used in drilling. [3] It is now possible to produce complete dentures and templates for implant surgeries that allow immaculate implant placement using CAD/CAM, . [8]

CAD/CAM technology utilizes the conversion of object-into-data with the use of a scanner. The data are deciphered by a special software that induces the milling process. Due to the advancement of the technology by way of adding networking to the devices, milling can be done in the office, in the lab, or in a distant commissioned lab.[3]

The scanner, the design software, and the milling unit are the main constituents of CAD/CAM devices. [3] Types of scanners include optical and mechanical; the difference between the two is that mechanical scanners use ruby balls to scan master casts, which is a is a very accurate technique. A good example of a mechanical scanner is the Procera by Nobel. Optical scanners use either a white light or a laser; the 3M Lava True definition scanner is an example of the latter. Every scanner and milling machine on the market has different software according to manufacturer preferences.

Milling machines vary in complexity according to number of axes used. Three types exist: three-, four- or five-axis systems. The differences among these is in the intricacy of the manufacturing process that created them. Three-axis systems are less expensive and easier to use. [9] Four-axis systems permit tension bridge adjustments. Five-axis milling systems allow for the latter in addition to a rotating milling spindle that permits the creation of FPDs and intricate frameworks.

The quality of a dental restoration is often assessed by its marginal adaptation and coverage. The importance of marginal adaptation lies in the protection of the tooth from such biological failure as periodontal disease, caries, pulpal inflammation and consequent possible tooth loss [10]. According to the literature, an opening of 50-120 microns is considered clinically acceptable [11].

In a study by Zimmer et al [12] on CAD/CAM restoration failure, specifically Cerec 1, the authors found that the survival rate over a five-year period was 94.7%, and the ten-year survival rate was 85.7%. 226 restorations were examined, but there were no crowns in the study. Failure included five factors: recurrent decay, restoration loss, fracture of restoration, tooth fracture, and a marginal gap reaching dentin or base material. Wittneben et al, [13] however, found the five-year success rate for CAD/CAM crowns to be 91.6%. Their findings were a result of conducting a systematic review. The systems used were Cerec 1, Cerec 2 and Celay. More advanced systems are now available; thus, the results may not apply to this date and time.

Lee et al [14] conducted a study that compared two types of ceramics and CAD/CAM systems. The examiners checked the internal gap and the marginal gap using Procera® (Nobel Biocare, Zurich, Switzerland) and Cerec 3D. Procera produced

copings and ultimately had porcelain added to them. The Cerec 3D were final crowns. The authors concluded that there was a difference between the systems in the marginal gap, with an increase in the Procera with the added porcelain. Post placement, the marginal discrepancies found ranged between 123 to 154 microns. The authors explained that the larger numbers were due to a larger bur of the milling machine.

Tan et al. [15] compared CAD/CAM, WAX/CAM, and WAX/CAST techniques. The authors found that the vertical marginal opening discrepancy was statistically significant between the WAX/CAST group and the other two groups, with the conventional WAX/CAST technique having the smallest gap. There was no statistically significant difference between the CAD/CAM and the WAX/CAM groups.

Bindl and Mormann [16] investigated the marginal fit of Cerec 1 and Cerec 2 intra-coronal crowns using Cerec 1 software, Cerec 2 with standard wall software, and Cerec 2 with wall-spacing software. The mean marginal gap for the Cerec 1 crowns was between 63-228 microns. However, the mean marginal gap for the Cerec 2 ranged between 56-121 microns. A total of 818 partial crowns were made, and only 12 of each group were randomly selected and examined.

Types of finish lines and marginal fit

Holmes et al. [17] defined the marginal gap as the angular combination of the vertical and horizontal distance from the internal surface of the crown to the prepared tooth surface close to the preparation finish line. Many authors have investigated the effects of finish line design (shoulder, chamfer, feather edge, and bevel) on marginal

adaptation. It was determined that different marginal configurations affect the marginal gap in various ways. Gavelis et al [18] concluded in their study on the fit of PFM crowns that a 90 degree full shoulder marginal configuration allows for a better seating of crowns. Another study evaluating the effect of different finish line designs (chamfer, 135 degree shoulder, and rounded shoulder) on the cervical adaptation of metal crowns found that the marginal adaptation was best when a chamfer finish line was present [19].

In addition to the studies on the effects of finish line design on metal crowns, there have been studies on the effects of finish line design on all ceramic crowns [20, 21], the results of which are contradictory. For example, Quintas et al [22] found no difference among various marginal designs on the fit of all ceramic crowns, and that finding has been supported by other studies [23-26]. Lin et al [27] compared four different finish lines (feather edge, chamfer, 0.8mm rounded shoulder and 0.5 mm rounded shoulder) using Procera copings. The researchers found no difference between chamfer and shoulder finish lines; however, the feather edge was not readily detected. In addition, Akbar et al [28] in 2006 found no difference between different margin designs (chamfer, shoulder) on the marginal integrity of Cerec 3 CAD/CAM composite crowns. They used scanning electron microscopy (SEM) and modified United States Public Health Service (USPHS) criteria in assessing marginal adaptation. Subasi et al. [23] arrived at the same conclusion in 2012 when they compared the marginal fit of different ceramic copings made on machined stainless steel dies with either chamfer or rounded shoulder finish lines. On the other hand, Pera et al [29] insisted on the importance of heavy chamfer and shoulder finish lines when

manufacturing all ceramic crowns. It should be noted, however, that this study was conducted in 1994, and milling machines have advanced significantly in the interim. Tsitrou et al. [30] found no statistical difference between shoulder, chamfer, and bevel finish lines in terms of the accuracy of marginal fit on CAD/CAM composite crowns. However, they found a tendency for a better fit when shoulder finish line was used. The examiners used the replica technique and a travelling microscope to measure marginal adaptation. The crowns were cemented with resin composite cement and sectioned. All the studies mentioned were conducted in vitro; thus, clinically, they may not apply due to the presence of saliva and other interferences when working with patients.

Methods for measuring marginal gap

The literature presents many ways to measure marginal discrepancy. As determined by a study conducted in 2005, [31] the method used in evaluating the marginal gap can affect the accuracy of the results. The following are examples of presented measuring methods:

1. Visual examination using an explorer. In 1971, Cvar et al [32] discussed the United States Public Health Service (USPHS) criteria method by use of visual and tactile sense in evaluating marginal adaptation.

2. Direct view technique. High power microscopy or SEM can be utilized for this technique. Many authors used digital microscopy in comparing the marginal fit of restorations [33-35]. Albert et al [36] utilized a traveling microscope to measure marginal discrepancies when comparing four types of cement in porcelain crowns.

Groten et al [37] used two types of measuring methods: light microscopy and SEM techniques. They found no significant differences between the two in their results. In contrast, Gonzalo et al [38] found different results in comparing between image analysis and SEM, with SEM having significantly higher readings in marginal gap thus displaying superior accuracy.

3. Cross-sectioning method. This involves destroying the samples post cementation for measurement of the cement width horizontally and vertically. This method does not show the marginal gap in the whole crown [39, 40].

4. Profilometery. This is an accurate method of examining marginal discrepancies. It is not useful, however, in detecting vertical overextension [40, 41].

5. Replica Technique. This technique involves the use of silicone impression material to determine the marginal gap. First, a light body is injected into the internal surface of the crown. The crown is then placed on the die. A heavier body impression material is then injected to give the light body strength and support [40]. Many authors advocated the use of the replica technique, as it is not destructive [40, 42-46], but researchers reported higher measurements when using the technique [45]. According to Shearer et al [47], the cross sectioning method showed superior results to the replica technique in terms of accuracy. Tsitrou et al [30] found different results when they compared between the cross sectioning method and the replica technique. They found no statistical difference between the methods. In agreement, Rahme et al [48, 49] found similar results when comparing the cross-sectioning technique to the replica technique. They found no significant difference between the two and, in addition,

concluded that the replica technique was an accurate and reliable method for measuring the marginal gap.

6. 3-D analysis of marginal fit. This involves digitally scanning the crowns, dies and the replica impression material films [49]. Research has indicated that the technique is reliable for measuring the marginal gap [50].

7. Micro CT (microtomography). This is a technique using a microtomography device to scan the restorations on the dies. Then the marginal gap is measured. This technique allows for accurate 2D and 3D measurements in multiple points and directions [51, 52].

ZIRCONIA

Zirconia is an oxide of zirconium, which is a white crystalline structure. It is identified as a transition metal in the periodic table for chemical elements resembling titanium. However, it belongs in the all-ceramic family.

The indication for using zirconia in dentistry has become very apparent in recent years. With the development of this material in 2004 and its constant advances, it has proven itself as a material that can be used in most cases. Zirconia has a high fracture toughness, high hardness, wear resistance, and chemical resistance. It can also be used in areas with limited interocclusal space. In addition, esthetics is no longer an issue due to the presence of high translucency monolithic zirconia and the ability to cut back and apply a feldspathic veneer to zirconia frameworks [53, 54].

Kelly et al [55, 56] described zirconia's vital property of fracture toughening,

which is the inhibition of fracture propagation by the transformation of tetragonal zirconia particles to the monoclinic phase. An expansion of 3.5% in the area of the crack allows for ceased crack propagation.

Zirconia can be milled either pre sintering or post sintering. It has been reported that zirconia milled post sintering is more accurate because there is no volumetric change due to heating. Conversely, it has also been reported that zirconia milled post sintering suffers from micro cracks, which can cause future failure in the restoration [49].

Digital intra-oral scanners

Traditional impression techniques often present many challenges to the operating dentist, including material dimensional stability and time constraints. Such technically sensitive procedures as the pouring of the cast, possible tearing of the material, difference in expansion between materials and the many steps leading to the final restoration, can lead to many errors. Last but certainly not least, patient comfort and time spent in the clinic has a major effect on both the patient and the clinician. Now, with CAD/CAM intraoral scanners, these processes can be eliminated [57].

Cardelli et al [58]summarized intra-oral scanners in terms of components and technology in 2011. Since then, author Anadioti [20] adjusted and added two new systems: the 3M True Definition scanner and Sirona Omnicam.

Lava True Definition scanner

The intra-oral scanner utilizes different technologies: an active triangulation

method, a structured light 3D technology, and Conofocal microscope 3D technology. Also, 3D-in-motion stereo imaging technology is used employing sophisticated aspheric optics. In addition, including the newest accelerometers and gyroscopes to simplify starting and ending the scan without using switches has added to the advantages of using this system. Lastly, computer vision technologies were utilized to create the 3D point cloud [59].

In a study by Shembesh et al [60] in 2015, four different impression systems were examined: PVS impression scan, cast impression scan, Cadent iTero, and Lava True Definition. Three unit zirconia FPDs were milled, and marginal accuracy was then compared between the groups. The authors found that the Lava True Definition scanner group had significantly lower marginal gap measurements compared to the other three groups.

Imaging materials

With the evolving CAD/CAM technology, many variables come to mind, such as different preparation designs and finish line configurations. Akbar [28] concluded in his study that the preparation design had no effect on the accuracy of the restoration. Another variable is the imaging material used. The producers of traditional dental scanners advocate the employment of scanning powders to amplify the reflectivity of conventional stones. The most common chemical structure in imaging powders is titanium oxide (TiO2), which is an opaque powder that catches light and reduces the light disseminated from the substrate. There is a lack of evidence on the effect of powder composition and particle shape on the marginal gap; therefore, the effects of

different imaging powders with different scanning systems and restorations should be examined, and many imaging materials are available on the market.

Vita powder scan spray has the largest particle size and has a concentrated powder amount. The manufacturer claims that the high concentration of powder increases the efficiency of scanning. In addition, it has a blue pigment that reportedly adjusts the optical reflective surface of the objects being scanned. Lastly, it can be used either intra-orally or extra-orally as it is mint flavored [61]. 3M came out with 3M high resolution scanning spray, which is made of titanium oxide [62] and has a very small particle size. The company claims that it enhances the speed of capture. Sinbrio scanning paint, according to its manufacturer, is designed to provide an ultra-thin, matte flat finish to promote precise scanning, but it has not yet been studied. While Luthardt et al. [63] found that imaging powders could affect the accuracy of internal adaptation and another study found a dissemblance in the marginal gap when Vita powder was used, [64] there is a dearth of research on how these different materials affect the marginal gap.

II. RESEARCH AIMS

The **objective** of this study was to compare marginal preparation designs and imaging materials in zirconia crowns. Two marginal preparation designs (1mm chamfer, 1.5mm shoulder) and three imaging materials (Vita, 3M, Sinbrio), were examined and marginal adaptation was evaluated.

HYPOTHESIS

The **hypothesis** was that the Sinbrio scanning paint would provide the lowest marginal gap, followed by 3M and then Vita powder spray. It was further hypothesized that the shoulder finish line design would produce a lower marginal gap than the chamfer. Sinbrio scanning paint is in liquid form; thus, it was assumed that it would provide a thinner layer and produce less marginal gap. In addition 3M scanning powder is claimed to have very small particle size [62].

SIGNIFICANCE

The incorporation of the latest technology into everyday dental practice is necessary and in most cases provides the best practice. CAD/CAM technology saves both time and money, both of which are essential for the success of any dental practice. This study was dedicated to finding a successful formula in creating well-fitting digitally formed crowns.

III. MATERIALS AND METHODS

Pilot Study

Due to a lack of studies on Sinbrio liquid, a pilot study was necessary to estimate a sufficient sample size. Accordingly, a pilot study was designed and conducted. Six groups were identified. Each of the marginal preparation designs (1mm chamfer, 1.5mm shoulder) was combined with one of three imaging materials (Vita, 3M, Sinbrio). Figure 9 displays group combinations.

For the purpose of the pilot study, three teeth were examined per group for a total of 18 teeth. Two lower right molar typodonts were used for the preparation.

The typodont teeth were prepared using a standardized preparation design: employing a Ney surveyor to stabilize the angle of the hand piece. The teeth were prepared using a high-speed hand piece and round tip parallel diamond bur. The amounts of preparation were 1.5mm occlusal reduction, 1mm and 1.5mm axial reduction and 4mm occlusogingival height preparation.

The typodonts were scanned three times per group using the 3M True Definition scanner, and an STL file was obtained. Each time, the dies were sprayed for 10 seconds and cleaned between each scan using alcohol wipes. When the Sinbrio scanning paint was used, a thin layer was painted each time on the die and excess paint was brushed off. A total of 18 STL files were obtained. STL files were delivered to Exocad dental software, and the crowns were designed. Also the cement space was standardized to 80 μm. The margins were designed to have an excess thickness of 0.2 mm to prevent chipping. Designs were sent to a five- axis milling machine Tizian Cut 5 (Schutz Dental Group,. Germany). Presintered Monolithic High Translucency Zirconia Blanks Copran Zr-I (WHITEPEAKS Dental Solutions, Germany) were used. The crowns were then sintered according to manufacturer instructions.

Measuring the marginal gap

Holmes et al [17] defined the marginal gap as the vertical distance from the internal surface of crown to the prepared tooth surface close to the preparation finish line. The replica technique was used. Light body silicone impression material (Reprosil, Dentsply Sirona) was injected into the crown and placed it on the typodont using a constant defined load 20Ncm to replicate finger pressure. After setting, a heavy body silicone impression material was injected into the crown to support the

thin light body layer. The silicone was removed after setting and segmented into four pieces (buccolingually, mesiodistally) using a sharp blade (Bard-parker). A high magnification traveling microscope (OLYMPUS, Japan) was used to measure the gap and Buehler Omnimet 9.0 software was used to image the sectioned impression materials and measure the gap. Four points were measured and averaged. Means and standard deviations were computed.

The software package nQuery Advisor (Version 7.0) was used to perform a power calculation to determine the sample size of the main study. The calculation assumed a variance of means of 0.18* for the different marginal preparation designs, a variance of means of 3.31* for the different materials, and a within-group standard deviation of 1.51*. Based on these assumptions, a sample size of n = 18 per subgroup was adequate to obtain a power of at least 80% for both the comparison of marginal preparation designs and the comparison of materials, using a significance level of α = 5%.

* Values obtained from pilot study (n = 3 per subgroup)

Main study

Following the pilot study, the sample size was determined to be 18 per group, leading to a total of 108 crowns. The steps conducted in the pilot group were repeated for the main study. The same dies were used and were scanned 18 times per group. Each time, the dies were sprayed for 10 seconds and cleaned between each scan using alcohol wipes. When Sinbrio scanning paint was used, a thin layer was painted each

time on the die and excess paint was brushed off. After the STL files were obtained for all the groups, a total 108 STL files were delivered to Exocad dental software and designed the crowns. Also, the cement space was standardized to 80 μm. Designs were sent to a five- axis milling machine Tizian Cut 5 (Schutz Dental Group, Germany). Presintered Monolithic High Translucency Zirconia Blanks Copran Zr-I (WHITEPEAKS Dental Solutions, Germany) were used. The crowns were then sintered according to manufacturer instructions.

The replica technique was then performed exactly as described in the pilot study section for all 108 zirconia crowns obtained. A high magnification traveling microscope (OLYMPUS, Japan) was used to measure the gap and Buehler Omnimet 9.0 software was used to image the sectioned impression materials and measure the gap. Four points were measured and averaged. One operator performed all steps.

A descriptive analysis was conducted: means and standard deviations were obtained. Two-way ANOVA was used to determine significance. The assumption of normality was assessed via the Shapiro-Wilk test, and the assumption of homogeneity of variances was assessed via Levene's test. The significance level was set at $P<0.05$. The statistical analyses were carried out using SPSS version 22 (IBM, USA).

IV. RESULTS

Assumptions of the two-way ANOVA were checked. The Shapiro-Wilk test indicated no significant evidence of non-normality, and Levene's test indicated no significant evidence of heterogeneity of variances ($p > 0.05$).

The marginal gap was measured on four points and averaged using a traveling microscope under 92x magnification. The means (standard deviations) for the different groups are shown in Table 1 and are as follows: 13.04 (1.66) μm for the chamfer and 3M powder group; 12.34 (1.77) μm for the chamfer and vita powder spray group; 12.45 (2.01) μm for the chamfer and Sinbrio scanning paint; 11.63 (1.25) μm for the shoulder and 3M powder group; 12.70 (1.43) μm for the shoulder and vita powder spray group; and 12.05 (2.69) μm for the shoulder and Sinbrio scanning paint group.

In comparing means (standard deviations) of the different finish lines, the mean marginal gap (standard deviation) of the 54 samples in the chamfer group was 12.61 (1.81) μm, while the mean and standard deviation of the 54 samples in the shoulder group was 12.12 (1.92) μm. The difference was not statistically significant ($p = 0.180$).

In addition, when the means (standard deviations) for the different powders (regardless of the margins) were calculated, the results were as follows: 12.52 (1.59) μm for the vita powder spray; 12.33 (1.62) μm for the 3M powder; and 12.25 (2.35) μm for the Sinbrio scanning paint. The differences were not statistically significant ($p = 0.826$).

V. DISCUSSION

The purpose of this study was to evaluate the effects of different marginal preparation designs (chamfer, shoulder) and different imaging materials (Vita scanning powder spray, 3M Imaging powder, and Sinbrio scanning paint) on the marginal gap. It was hypothesized that the Sinbrio scanning paint would provide the lowest marginal gap, followed by 3M and then Vita powder spray, and that the

shoulder finish line design would produce a lower marginal gap than the chamfer. Sinbrio scanning paint is in liquid form thus it is assumed that it would provide a thinner layer and produce less marginal gap. In addition 3M scanning powder is claimed to have very small particle size [62]. Pera et al [29] recommended heavier finish lines in all ceramic restorations. This study is designed to see if a heavier finish line and a scanning material in the liquid form had any effect on the accuracy of the margins.

3M True Definition optical scanner was used and a five-axis milling machine (Tizian Cut 5, Schutz Germany) was utilized. The replica technique and a high magnification-imaging microscope (OLYMPUS, Japan) were employed. The imaging materials examined in this study have varying particle sizes; thus, this study was designed to compare the effects of these different formulations on the marginal gap. In addition, it examined whether a more conservative finish line configuration had a worse marginal gap.

Not many studies have examined the effects of imaging materials on the marginal gap. In this study, there was no statistically significant difference between the materials used. Alghazzawi et al [65] concluded in his study that there was no difference between imaging powders and recommended using the least expensive one.

There are many digital scanners available on the market. Some require the use of imaging powders, such as the 3M True Definition scanner and the Cerec blue cam scanner, while some do not, such as Cerec Omnicam and Trios. However, Costa et al [64] found a dissimilarity in the marginal gap when Vita powder was used. In addition, Neves et al [66] found that using no imaging powders created the worst marginal gap

in all the groups. Luthardt et al. [63] had similar results; they found that it is possible for imaging materials to affect the internal adaptation of crowns.

Many authors have examined the effects of finish line design. In this study, the finish line design had no significant bearing on the accuracy of the margins. However, Pera et al [29] advocated the use of heavy chamfer and shoulder finish lines when manufacturing all ceramic crowns. In agreement with the results of this study, multiple studies found no statistically significant difference between different finish lines examined [22, 23, 25, 28].

A five axis-milling machine was used in this study. It is an advanced machine utilizing small-sized burs, which leads to higher accuracy in crowns [14]. In addition, the type of intra-oral scanner used could affect results; the more advanced the scanner, the better the results, as claimed by Patzelt et al [67]. The cement space the current study was programmed to be 80 microns. Nakamura et al [68] examined the effect of cement space and concluded that the lesser cement space of 10 microns provided less marginal accuracy than that of 30-50 microns. The marginal gap in this study ranged between 7.31-24.45 microns, which is substantially below the acceptable range of 120 microns as recorded by McLean and Fraunhofer [11].

While conducting the study, the examiner observed a difference in scanning time between the materials. It was noticed that the 3M powder had the shortest scanning time and the vita scanning spray had the longest scanning time. Unfortunately those numbers were not recorded but these finding could have a major effect on the clinic time. A follow up study is necessary to look into scanning time.

Limitations of the study

- The study was done in vitro; the specimens were not put through thermal cycling (fatigue testing), and there was no saliva. Thus, it did not resemble oral conditions, which could affect the accuracy of results and comparability to clinical conditions.
- The marginal gap for each group was not examined after cementation of the crowns.
- Examination was done once by one examiner, i.e, there was no reliability testing.

Suggestions for future studies

- Assess time spent scanning for each group and conduct a comparison. Time spent can affect the experience of the patient and the practitioner.
- Examine different cement spaces.
- Have a (no powder) group with a different scanner that does not require the use of scanning materials.
- Investigate different finish line designs preferably narrower.

VI. CONCLUSION

Within the limitations of this in-vitro study, the finish line designs and the different imaging materials used provided clinically acceptable crowns. In comparing the different marginal preparation designs and imaging materials, there was no statistically significant difference in marginal gaps.

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VIII. APPENDIX

List of tables

Table 1. Means and standard deviations of groups (μm)

Margin design	Scanning material	Mean marginal gap	Std. deviation	N
Chamfer	3M	13.04	1.66	18
	Vita	12.34	1.77	18
	Sinbrio	12.45	2.01	18
	Total	12.61	1.81	54
Shoulder	3M	11.63	1.25	18
	Vita	12.70	1.43	18
	Sinbrio	12.05	2.69	18
	Total	12.12	1.92	54
Total	3M	12.33	1.62	36
	Vita	12.52	1.59	36
	Sinbrio	12.25	2.35	36
	Total	12.37	1.87	108

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Figure 1. Example of a three-axis milling machine Cerec® In Lab (Sirona®)

(Bensheim, Germany)□

Figure 2. Example of four-axis milling machine from Creative Dental Laboratory

(Scottsdale, Arizona, United States)

Figure 3. Example of the TiZian™ Cut 5 Smart five-axis milling machine

(Schutz Dental Group, Germany)

Figure 4. Example of Presintered Monolithic Zirconia Blanks

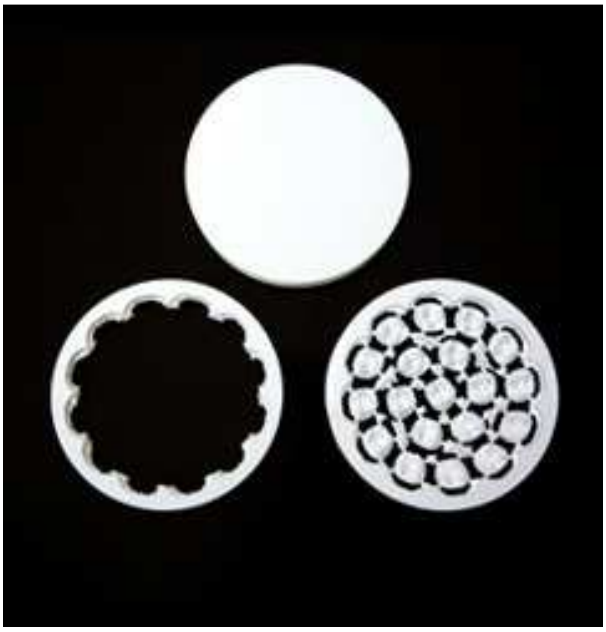

Figure 5. 3M Lava True Definition Intra-oral Scanner

Figure 6. Vita scanning powder spray

Figure 7. 3M high-resolution powder

Figure 8. Sinbrio scanning paint

Figure 9. Flow chart displaying research groups

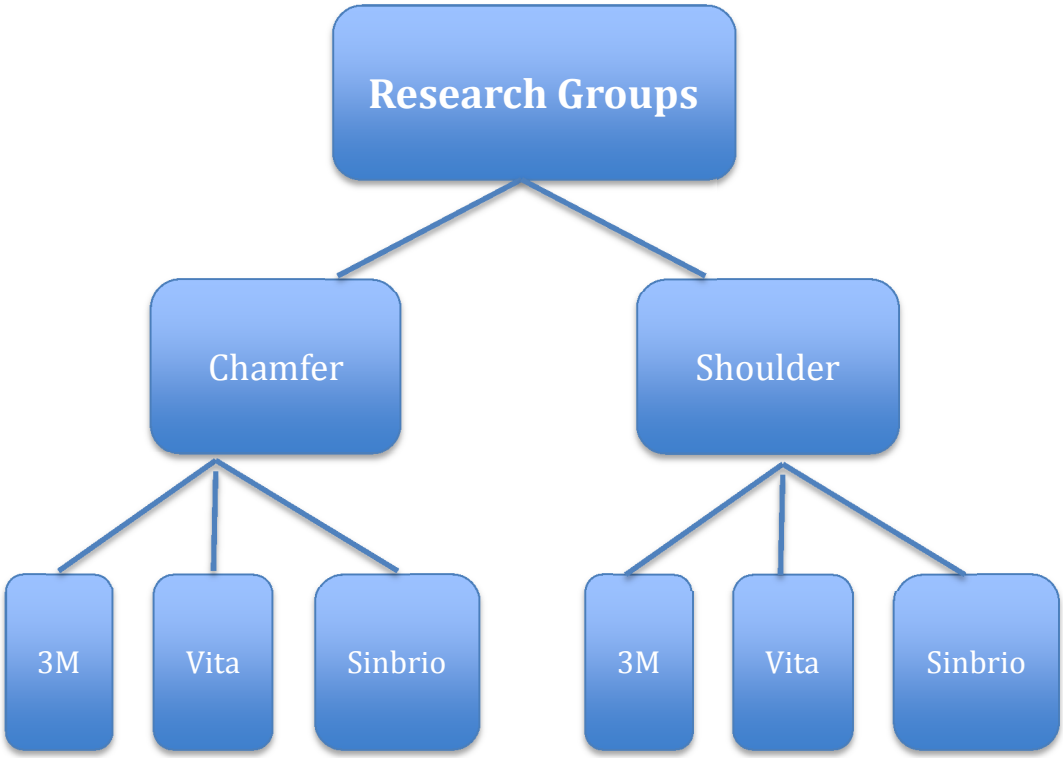

Figure 10. Image of hand piece mounted in Ney surveyor for standardization

Figure 11. Prepared typodonts

Figure 12. Image of scanned die using 3M True Definition scanner

Figures 13,14,15. Images of designed crowns using Exocad software

Figure 13.

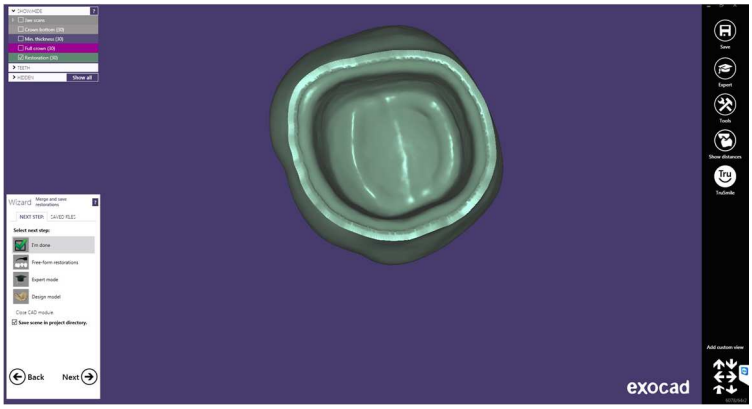

Figure 14.

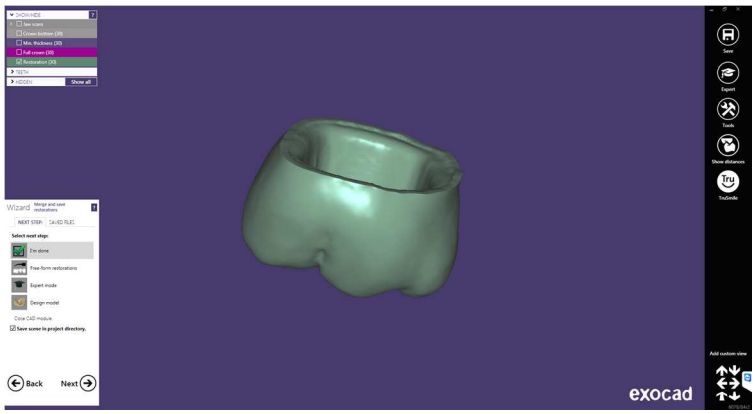

Figure 15.

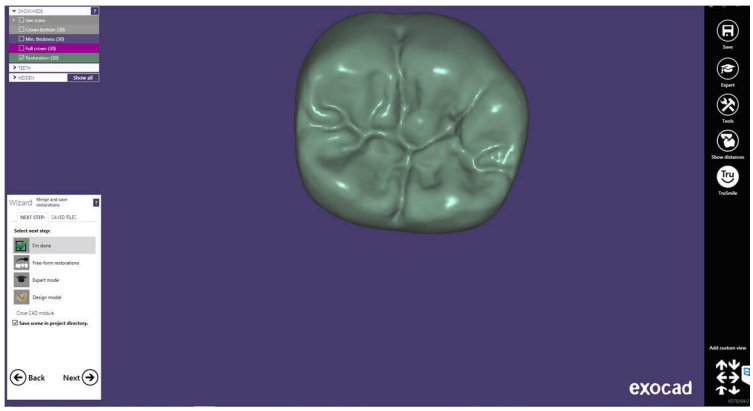

Figure 16. Image of a fraction of the zirconia crowns milled

Figure 17. Image of stainless steel 5lb-weight calibration applied on crowns to mimic 20N finger pressure

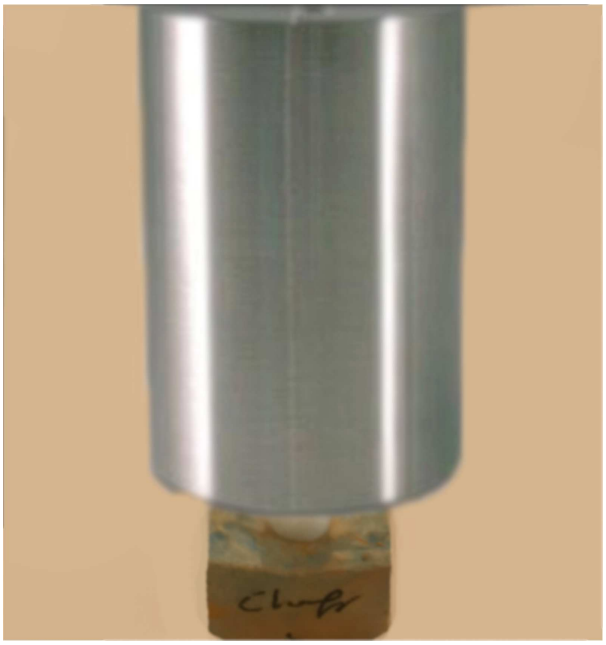

Figure 18. Image of heavy body impression material injected to support light body impression material

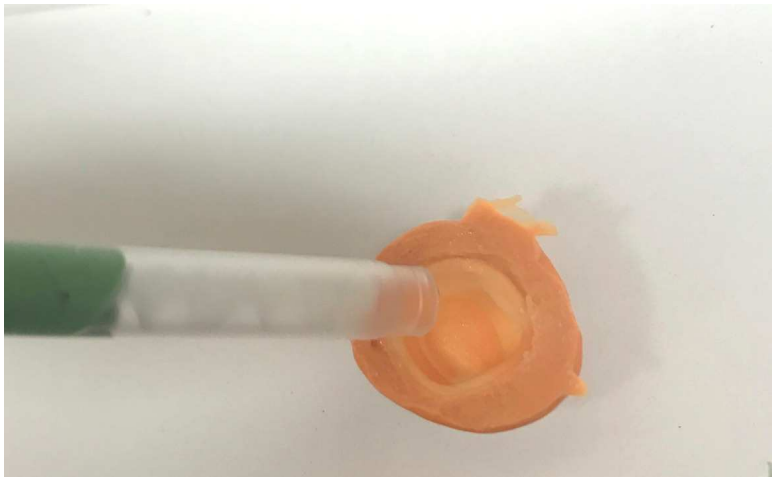

Figure 19. Pre sectioning (Replica Technique)

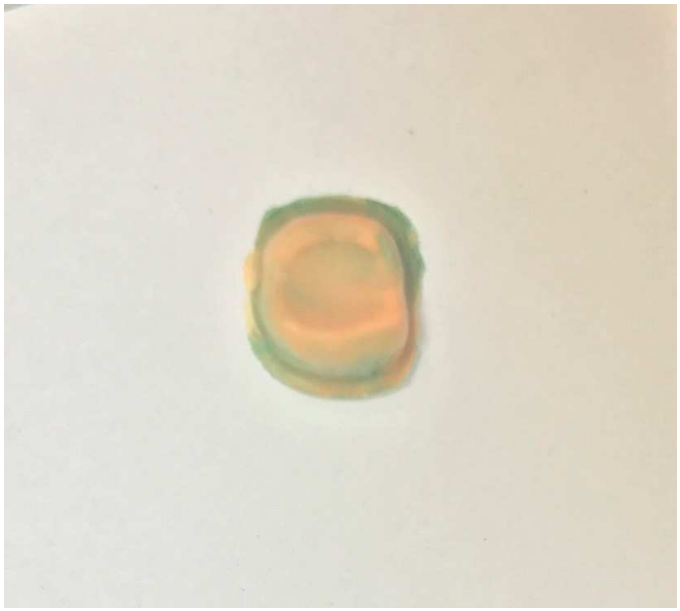

Figure 20. High magnification traveling microscope (OLYMPUS, Japan)

Figures 21, 22. Post sectioning sagittal image under high magnification 92x

(Replica Technique)

Figure 21.

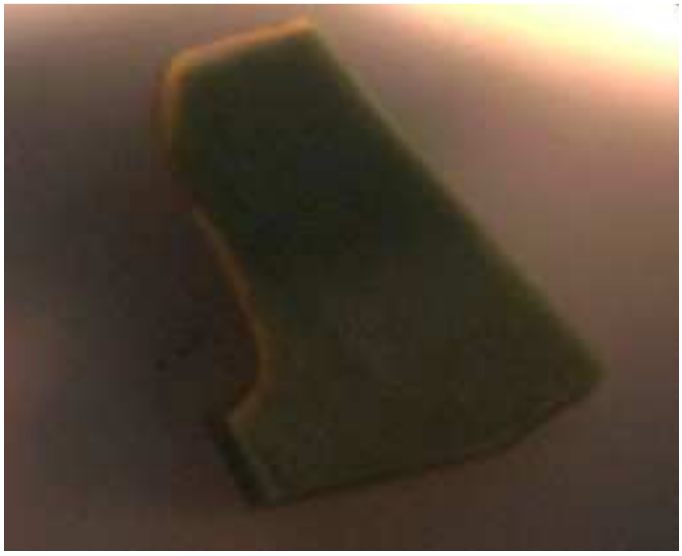

Figure 22.

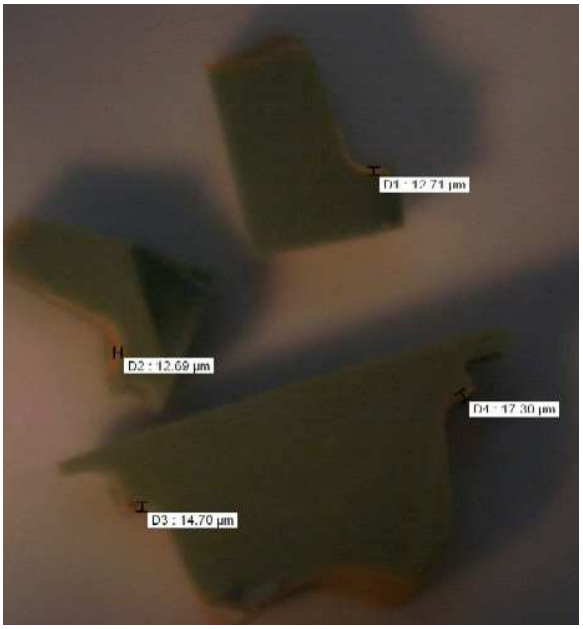
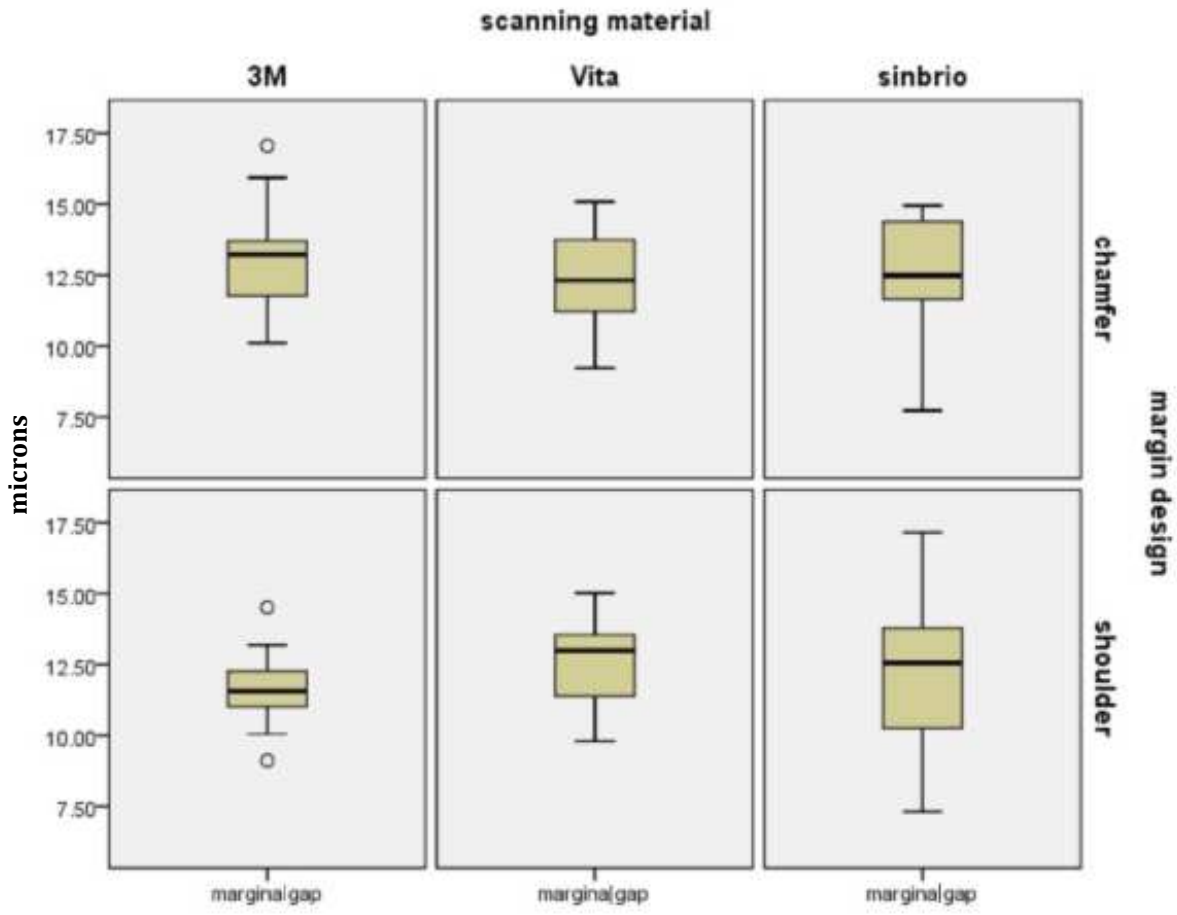
Figure 23. Side-by-side boxplots showing the distribution of the marginal gaps of the six groups