Fracture resistance of anterior primary CADCAM ceremic restorations

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ABSTRACT

Background:

Computer Aided Design (CAD) and Computer Aided Milling (CAM) have been used to fabricate effective restorations for the past thirty years. Using CAD/CAM, dental providers can accurately capture a digital impression of a tooth preparation and fabricate a restoration without the need for impression material or stone models. The restorations can be delivered on the same day the teeth are prepared and, in most instances, this eliminates the need for a temporary restoration or a second visit for cementation. CAD/CAM restorations are durable and esthetic, yet there is limited research on the use of CAD/CAM restorations on primary teeth.

Purpose:

The purpose of this study is to compare fracture resistance of CAD/CAM restorations on anterior primary teeth with two different thickness and two preparation designs. The results are compared to a control group of non-restored primary teeth.

Methods:

Carious and non-carious extracted primary anterior teeth were collected from the UCSF Pediatric Dentistry clinics from 2013 through 2015. Based on extent and location of caries, the teeth were assigned to four groups with different depths of tooth preparation and restoration designs and one group of non-restored control teeth. Each group had ten (n=10) teeth for a total of fifty (50) teeth in the study. The five groups are: 1) 0.5mm traditional veneer, 2) 0.5mm three-quarter veneer, 3) 0.7mm traditional veneer, 4) 0.7mm three-quarter veneer, and 5) control teeth without restorations.

The teeth were prepped, restorations milled and bonded, and then mounted for the fracture force testing. The universal testing machine applied compressive force along the incisal edge at increments of 1mm/min. The force at fracture was recorded in pounds. Data was collected and entered into an excel spread sheet.

Results:

There was a significant overall difference between the fracture resistances of the five groups (Kruskal-wallis test p=0.0007). Specifically, the 0.7mm three-quarter prep group had significantly lower fracture resistance than the control group (Wilcoxon rank sum test p=0.0443), and 0.7mm traditional veneer prep group had marginally significantly lower fracture resistance than the control group (Wilcoxon rank sum test p=0.0596) while the fracture resistances of 0.5mm three-quarter prep group and the 0.5mm tradition veneer prep group did not differ significantly compared to the control group (p>0.05).

Conclusion:

There was a significant overall difference between all five groups, yet a two-group comparison only found a significant difference between the 0.7mm three-quarter preparation group and control group. The trend was that 0.7mm traditional preparation group showed marginally significant difference from the control group, while both the 0.5mm traditional and 0.5mm three-quarter preparation groups showed no significant difference. Nearly all the teeth in the study groups failed with the fractured occurring within the restorations during load testing; only one sample in the study groups had damage to the underlying tooth structure.

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INTRODUCTION

Dental caries is a common chronic disease in children that may lead to serious complications, including severe pain, dento-alveolar infections, systemic involvement[1] and even death. Quality of life can be compromised by dental infection, such as issues with mastication, missed school, poor school performance and behavior issues. [1] Prevention and treatment of early childhood caries in a timely manner can improve the quality of life and education of a child.[1]

Changes in social and parental perceptions have drawn a new focus to every child deserving a beautiful smile. With the recent development of various esthetic and adhesive materials, clinicians can now make it a reality and have options for providing esthetically pleasing restorations on carious anterior primary teeth. The five most commonly placed esthetic restorations for primary teeth are 1) pre-veneered stainless steel, 2) open window stainless steel with composite, 3) celluloid forms (strip crown), 4) polycarbonate, and most recently 5) zirconia. However, these restorations utilize a pre-fabricated crown or celluloid form and required extensive tooth preparation to provide space for the esthetic layer of restoration.

The major advantage of esthetic crowns with metal base is moisture tolerance because they are cemented with glass ionomer. However, the pre-veneered stainless steel crowns can be bulky if facial reduction is not adequate and have limited retention since the clinician can only cramp on the lingual metal side. Preveneered crowns placed in an ideal environmental setting under general anesthesia showed a high retention rate, but extensive failure of the veneer facing occurred in about one-third of cases after an average of 20 months.[2] Parental concern with preveneered crowns was mainly esthetic, as they complained of the "large size, color and visualization of some metal."[2]

Open-window crowns are created by cutting a window on the facial surface of a pre-fitted and pre-cemented stainless steel crown and filling it with composite. [24] For the best esthetic result, the thickness of the composite must adequately mask the metal window border. The composite is bonded to the tooth and held by mechanical retention with the undercuts. There is no bond between the metal and composite, so the composite that masks the metal can fracture off and dislodge.

Celluloid crowns (resin strip crowns) can be very esthetic, cost effective, and are the most popular treatment option for restoring carious anterior primary teeth by pediatric dentists throughout the world for almost thirty years.[3] However, these restorations are moisture intolerant and designed to be placed 1mm subgingival,[4] making it the most technique sensitive restoration.[3] Celluloid crown forms can be difficult to place in uncooperative patients and are also not recommended for bruxers or those with malocclusion. Even when placed in ideal circumstances with absolute moisture control under general anesthesia, failure rates of the resin strip crowns have found to be as high as fifty-one percent.[5] Polycarbonate crowns are similar to celluloid crowns. Polycarbonate crowns have poor wear resistance, require cementation, and polishing the margins is not recommended as it will ruin the polycarbonate shell.

Zirconia has become popular in the last decade because it is very esthetic and durable. However, more tooth reduction is required compared to other crown preparations and their retention is primarily based on bonding as it is a pre-fabricated crown. Also, they require a pink try in crown to prevent contamination of the final crown. Adjusting the crown is not recommended because it can create a weak point in the ceramic.[4]

All of these restorations are prefabricated and the tooth is prepared to fit the restoration, with the exception of resin strip crowns. Restorations can be more conservative when they are prepared based on the needs of the tooth. The use of Computer Aided Design and Computer Aided Milling (CAD/CAM) can provide more conservative and more precise custom fitting restorations and should be considered when restoring the primary dentition.

Computer Aided Design (CAD) is used to design may things such as: airplanes, buildings, containers, dental crowns, sleep-apnea devices and orthodontic appliances.[6] Extremely precise design and milling is achieved by combining Computer Aided Design with Computer Aided Milling (CAM). CAD/CAM technology has been utilized in dentistry for about 30 years in the permanent dentition; some dental offices exclusively use CAD/CAM for crown and bridge work. It is estimated that 6.9 million CAD/CAM restorations are made each year by 38,000 dentists worldwide.[7]

CAD/CAM has gained the interest of minimally invasive dentistry groups because of “maximum preservation of sound tooth structure and maintenance of vitality.”[8] There is no standard protocol or use of CAD/CAM in the primary dentition. Hence, we have created our own restoration designs in this study to attempt to determine: the feasibility of this conservative restoration, depths of tooth preparation, and thickness of final restoration on primary anterior teeth. The custom designed three-quarter veneer CAD/CAM restorations of our study were used in clinical situations that would have otherwise been restored with prefabricated full coverage crowns. This difference in coronal coverage preserves existing tooth structure. Three-quarter crowns, similar to the three-quarter veneers in our study, are reported to remove half the amount of tooth structure compared to a complete ceramic crown.[9]

With early CAD/CAM technology, the marginal gap was a concern, but Zimmer's study found CAD/CAM margins to be similar to lab fabricated crowns.[10] With the use of composite luting agent for cementation, the margin has not shown increased discoloration, secondary caries, or increased restoration failure.[11] In our study, the CAD/CAM restorations are mechanochemically bonded. The mechanical bond is formed with the resin between the dentin tubules and the roughened intaglio surface; and the chemical bond is created by silane between the organic resin and the non-organic porcelain.[12,36] The strength of the restoration is based on ceramic thickness and the bond to the underlying tooth structure[13], with the bonding layer acting like the dentinoenamel junction.[8, 14]

CAD/CAM restorations are milled out of a "block" which is a rectangular slab of material attached to a pedestal. The block used for our study is 80% ceramic and 20% cross-linked nano-particles in a polymer matrix, and has modulus of elasticity similar to dentin.[15] It has strength from the ceramic and flexibility from the resin. The benefit of resin-based materials is increased plastic deformation, which can reduce spontaneous fractures and provide a wear rate more similar to enamel.[16] The blocks have better mechanical properties than manually cured composite restorations because they are polymerized under controlled conditions to decrease voids.[17]

In our study, teeth were selected for a CAD/CAM traditional veneer or three-quarter veneer based on the presence of interproximal caries; the thickness of the restorations were randomized. None of the teeth selected for traditional veneer had interproximal caries, this allowed for all restoration margins to be caries-free. The teeth restored with three-quarter veneer may have had interproximal caries. All of the veneer preparations had 1mm incisal reduction and a deep chamfer, as recommended by the manufactures.[18] The facial reduction was either 0.7mm as described by Aboushelib et al.[13] or 0.5mm as suggested by Alghazzawi et al..[19] This depth of facial reduction is equally or more conservative than the recommended facial reduction for other esthetic anterior crowns for the primary dentition: 1) pre-veneered stainless steel: 1mm[20], 2) (open window) stainless steel: 1mm[4], 3) celluloid forms (strip crown): 0.5-1mm,[4] 4) polycarbonate: 1mm[4], and 5) zirconia: 0.5mm-1.0mm.[4]

This study utilized CAD/CAM technology on extracted primary anterior teeth. The purpose of the study was to compare fracture resistances among study groups with different restoration designs and thickness of restorations and compared to a control group.

METHODS

Study Design

Quantitative and qualitative analyses of CAD/CAM restorations on extracted anterior primary teeth were conducted in this in-vitro study. Primary incisor teeth in the study groups and control group were collected at the University of California at San Francisco Pediatric Dental Clinic and Operation Room from 2013 through 2015. Teeth were extracted due to infection or near exfoliation with potential aspiration risk. Teeth without interproximal caries were placed in the traditional veneer design, and the teeth in the three-quarter veneer design may have had interproximal caries. The teeth were randomized for depth of tooth preparation and thickness of restoration. The four study groups and one control group are 1) 0.5mm traditional veneer, 2) 0.5mm three-quarter veneer, 3) 0.7mm traditional veneer, 4) 0.7mm three-quarter veneer, and 5) control teeth. When not in use, the teeth were stored in saline solution.

Scanning Teeth Prior to Preparation

The teeth were placed in a typodont, sprayed with the CEREC Optispray (Sirona Dental Systems, New York), and scanned with the CEREC machine. Using the Sirona CEREC 4.2 system this scan was used for a pre-op digital model before the preparatory phase. This model can be used to make a restoration that is almost an identical copy. The pre-op digital model is a new optional feature of the 4.2 software.

Preparing Teeth for Restorations

Half of the teeth in study groups were prepped for traditional veneer restorations, and the other half were prepped for three quarter veneer restorations. Two depths of facial surface reduction were performed for each restorations design (traditional veneer and three quarter veneer) in this study. The 0.7mm facial surface reduction was based off Aboushelib at al.[13] and the 0.5mm reduction was chosen based on Alghazzawi at al.[19] Since there are no CAD/CAM blocks tested or used for primary teeth, the block used in this study was designed for the use on adult teeth with the minimum restoration thickness of 1mm. We designed the tooth preparations for primary teeth by preforming pilot testing on Ivorine teeth in a typodont. We evaluated several possible preparation designs and assessed several depths of facial reduction. Due to the relatively thinner tooth structure of primary incisors compared to the permanent incisors, the investigators speculated that 1mm of tooth structure reduction would be too aggressive for primary incisors, resulting in or near pulpal exposure. The investigators agreed that the reduction of 0.7mm would not frequently cause pulpal exposure, while a 0.5mm reduction approached the limitations of the milling machine.

All teeth were placed and mounted in a Frasaco pediatric dental typodont (Franz Sachs & Co, Tettnang, Germany) to simulate the clinic setting. The teeth had varying amount of root structure remaining. To minimize movement during preparation, an acrylic "root" was made for each tooth to fit into the typodont "tooth socket". Four diamond burs were used for the veneer preparations in the study groups: 1) size 4 round diamond, 2) 0.5mm veneer depth guide, 3) 0.7mm depth guide, and 4) chamfer (801-023) (Brasseler USA, Savannah, Ga).

The first step was to prepare the margin by cutting with a round diamond along the axial surface. Using the round bur along the long axis of the tooth minimizes the possibility of “J” margins. In the second step, the veneer depth guide burs were used to cut a horizontal line from mesial to distal along the facial surface. In the third step, the chamfer bur was used for the 1mm incisal reduction and to blend the facial preparation to the margin. The last step was to smooth roughness at the margin with the round diamond. (Illustrations 1-7)

Imaging and Designing Restorations with Serona CEREC

After the preparation was completed, the teeth were scanned with the CEREC to make digital “impressions’ or “models” of the preparations, the opposing arch, and bite registration. The images for the bite registration were captured from the buccal aspect with the teeth in occlusion. The bite registration allows the software to relate the maxillary and mandibular arches and simulate the occlusal relationship. This is used to prevent occlusal interferences and establish appropriate level of occlusion for the restoration.

Designing the restorations can be done in three different ways with the Sirona CEREC software: 1) Biogeneric copy generates a preliminary design that mimics the pre-op digital model of the tooth, 2) Contralateral copy generates a preliminary design based on a mirror image of the contralateral tooth and creates symmetry, and 3) The standard mode designs the restoration based on the Sirona “library” of teeth. (Illustrations 8)

Restoration designing starts with defining the margins of the preparation. The software displays the preliminary restoration design, made by one of the three techniques above. Then, utilizing the 4.2 software, the investigators manually set parameters to create the 0.5mm and 0.7mm minimal thickness of our restorations. The ruler software application was used to maintain a 1mm incisal thickness. Lastly, the digital restoration was smoothed and checked for errors at the intaglio surface and margins. The investigators inspected the design and entered the type of block that would be used for milling. In this study, the Ultimate Lava block was used.

Milling Process

The Sirona software on the CEREC 3 machine communicates via Bluetooth to the milling machine. The milling machine runs an automated calibration prior to milling. The milling took an average of 15 minutes, with 8 minutes being the fastest and 20 the longest. After milling was complete, the restoration was removed and tried on the tooth to confirm a precision fit and easy replication of placement for bonding. (Illustrations 9)

Bonding Restorations to Teeth

The restoration and the tooth were prepared for bonding. The intaglio surface of the Ultimate Lava (3M ESPE, Seefeld, Germany) restoration was sand blasted with <50um alumina silicate (Dentsply GAC, NY, USA). The teeth were etched with 37% phosphoric acid (Dentsply GAC, NY, USA) for 20 seconds, rinsed with water for 5 seconds, and then lightly air dried. The teeth were still slightly wet by visual examination. Scotchbond Universal Primer (3M St. Paul, MN) was added to the tooth and intaglio surface of the restoration, scrubbed for 10 seconds, lightly air dried for 5 seconds, then allow to cure for 20 seconds. Then, the RelyX (3M St. Paul, MN) cement tube was bled, the mixing tip was added and the cement was extruded onto the restoration. Excess cement was removed with a microbrush and the restoration was cured on the tooth for 40 seconds. The Scotchbond Universal Primer has a silane coupler that "serves as the chemical surface preparation for bonding porcelain."[12] The combined sand blasting and silane application increase the micromechanical interlocking and chemical bonding, respectively, thus, increasing bond strength of porcelain.[12]

Universal Testing Machine

The Ultratester universal testing machine (Ultradent, South Jordan, UT, USA) with the Sentran sensor was used for the load testing. It has an output of 1000lbs of force either pressure or tension. The machine was zeroed with each sample mounted in place prior to pressure testing and was used at a sixty second run time at 1mm/min. (Illustrations 10)

Universal Testing Mount

A custom mount was fabricated to hold the samples on the Ultratester. The mount consisted of a metal platform with a square metal frame to hold the tooth. The frame was 4.5mm x 4.5mm x 5mm and was reinforced with a metal nut around it. The nut provided substantial support and protection to the square frame. All voids between the frame and nut were filled in with liquid epoxy. The testing mount was secured to the universal testing machine with a screw. (Illustrations 11-13)

Fabrication of Acrylic Base

The teeth were mounted into an acrylic base to fit the square frame of our testing mount. When fabricating the acrylic base, a stone model of the square frame was made because the acrylic stuck to the metal. All sample teeth, including control teeth, were sectioned 4 mm from the CEJ. The stone model mount was filled with acrylic and the sample teeth were placed in the acrylic 0.5mm below CEJ. The samples were oriented vertically with the incisal edge parallel to the Ultratester machine base. After the acrylic cured, excess was trimmed and they were tried into the metal testing mount to verify minimal movement

Data Collection

The Ultratester was used to find force required to fracture the restoration or control tooth. Fracture was defined by a noticeable crack in the restoration or, in the case of the control teeth, in the enamel. Usually the crack was accompanied by an audible sound. The Ultratester applied compressive force along the incisal edge at increments of 1mm/min and the force at fracture for each sample was recorded. Prior to the to each sample test, the Ultratester was zeroed. (Illustrations 14) Data was entered into the Excel spreadsheet.

Scanning Electron Microscope

After load testing of the samples was complete, a NeoScope JCM-5000 scanning electron microscope (SEM) (Portsmouth, NH, USA) was used to assess the nature of failure. First the samples were mounted with carbon tape, sputter-coated with a gold and palladium alloy, and scanned with the SEM. Then the investigators assessed the SEM images. (Illustrations 15-20)

Data Analysis

The mean and standard deviation of fracture resistance were computed for each of the five groups. A Kruskal-Wallis test was used to examine the overall difference in fracture resistance among the five groups (Figure 2). As a significant difference was noted, Wilcoxon rank sum test was used for two-group comparisons (Figure 1) between each study group and the control group. All the analyses were conducted in SAS 9.4 (SAS Institute Inc. Cary, NC, USA) and a result was considered as statistically significant if the p-value <0.05.

RESULTS

The force of fracture of four test groups with CAD/CAM restorations bonded to primary teeth and a control group of non-restored primary teeth was measured by the Ultratester universal testing machine, and the mean fracture force of each group was compared. Each group had ten sample teeth (n=10). Figure 1 shows the distribution of the fracture resistance (lbs) in the five groups. The mean fracture force for these five groups are 1) 162.76lbs $\pm$ 24.71 for 0.5 mm tradition veneer, 2) 103.26lbs $\pm$ 42.09 for 0.5 mm three-quarter veneer, 3) 86.00lbs $\pm$ 40.53 for

0.7 mm traditional veneer, 4) 86.24lbs ± 30.64 for 0.7 mm three-quarter veneer, and 5) 141.21lbs ± 54.70 for the control group. (Table 1)

A Kruskal-Wallis test was performed and indicated a significant overall difference between fracture forces among the five groups (p=0.0007) (Table 1). The Wilcoxon test was used for two-group comparisons of each restoration versus control. The force required to cause fracture and failure in the 0.7 mm three-quarter veneer group was significantly lower than the fracture force of the control group (p=0.044). A similar trend was also observed between the 0.7 mm traditional veneer and the control group, although the difference was borderline significant (p=0.0596). There was not a significant difference when comparing 0.5mm traditional and 0.5mm three-quarter with the control group (p=0.3955 and 0.1206, respectively), although 0.5 mm traditional veneer group is the only test group to have higher mean fracture strength than the control group.

DISCUSSION

There has been little change in the practice of esthetic dentistry in the primary dentition for decades besides the development of zirconia, which came into the dental field in the late 1990's.[21] Resin strip crowns using celluloid forms remained the most popular esthetic restoration of choice for primary anterior teeth by pediatric dentists through the world; resin strip crowns have been utilized for three decades in restoring carious primary teeth.[22] However, inherent weakness and difficulty in placement have led to high failure and replacement rate of the resin strip crowns.[4] The experience of going through multiple attempts of restoring anterior teeth at such a young age may shape the child's perception of the dental profession and lead to fear and apprehension in future dental visits.

Patient's behavior and the cost of laboratory-fabricated crowns may have limited other restorative options from being implemented in pediatric dentistry. The primary pediatric restorative armamentarium includes many prefabricated materials, such as: stainless steel crowns, pre-veneered stainless steel crowns, celluloid crowns, polycarbonate crowns, and zirconia crowns. There has been less focus at improving margin adaption with the prefabricated pediatric restorations.

Stainless steel crowns or any crown with metal backing are less esthetic and the pre-veneered esthetic facing material can easily chip.[23] Celluloid and polycarbonate crowns are both esthetic, but they have a tendency to dislodge, break, and wear.[24] Although zirconia crowns are esthetic and strong, they require extensive tooth reduction and removal of sound tooth structure to allow a passive fit. They rely on the luting cement for retention.

Our study appears to be the first on the CAD/CAM restorations of anterior primary teeth. We utilized CAD/CAM technology with blocks that are a combination of ceramic and resin. The restorations are custom designed and milled to fit each individual tooth and are very esthetic. Like ceramic and zirconia, the resin CAD/CAM blocks remain color stable for long time and are durable.[25] Another advantage of the CAD/CAM restorations is the conservation of tooth structure and a better fit at the margin than other pediatric restorations. Also, metal-free restorations have an added benefit as “9 percent of female and 6 percent of male children demonstrated nickel allergy"[26], and the associated inflammatory response would have been misinterpreted as poor hygiene or a poor margin.[15]

Inadequate margins are defined as open margins, overhangs or excess cement. Poor margin adaptation can lead to increased plaque retention, change the composition of the oral flora, and subsequently cause inflammatory response of a vital pulp. [27] The margins of currently available pediatric crowns are intended to be subgingival to minimize leakage and plaque retention, and to enhance esthetics. However, the metal-free crowns rely on a moisture free environment for bonding and this is difficult to obtain subgingivally. For stainless steel crowns, clinical skill is important in minimizing marginal defects and failure; the variance in skill level has been attributed to 42% of defects or open margins. [28] Even with the expert oversight of faculty in a dental school setting, only 10% of defective margins were noted and detected radiographically.[28]

Multiple studies have proven that CAD/CAM restorations have a precise marginal fit comparable to laboratory made restorations, with a marginal gap that is fewer than 100 microns and is usually between 40-80 microns. [29] This precise fit allows for margins to be placed supra-gingivally and lowers the chance of fluid contamination during bonding. Supra-gingival margins may also allow for better removal of excess cement, detection of marginal integrity, and home hygiene care.

With increasing parental demand and vanity awareness, there is increased use of non-metallic esthetic restorations particularly on anterior teeth; however, these restorations require greater reduction of tooth structure compared to the commonly placed stainless steel crowns. The amount of reduction needed for these esthetic restorations may necessitate prophylactic pulpotomy/pulpectomy due to risk of pulpal irritation. [30] In addition, these metal-free esthetic crowns are prefabricated and come in stock, so tooth structure is removed to prepare the tooth to fit the restoration. The CAD/CAM restorations are fabricated based on the needs of the tooth and this is a relatively more conservative approach.

This study found that the custom-made CAD/CAM restorations withstood force less than or comparable to that of the non-restored, control primary anterior teeth. Further research is required to determine the clinical effectiveness and significance of these restorations in-vivo. Similar to the study by Alghazzawi, et. al, lingual reduction was not performed when using CAD/CAM in our study design.[30] Interestingly, our study found no significant difference when comparing the fracture force of the non-restored control tooth group and the more conservative restoration group with tooth reduction of only 0.5 mm, instead of 0.7 mm.

With the recent improvement of CAD/CAM blocks that have resin incorporated into the ceramic, a more conservative and stronger restoration can be made and bonded to the tooth. The introduction of resin into the block allows for increase flexure strength with similar compression strength to ceramic, even if the resin restoration is thinner.[14,31] The resin luting cement has its own intrinsic ability to absorb shear-forces caused by elastic deformation of the tooth.[32] The use of resin luting cement to bond the ceramic/resin restoration to the tooth increases flexural strength, closer to natural tooth then ceramic restorations and thus chipping and fracturing less likely.[25] The incorporation of resin into the ceramic restoration also reduces wear to the opposing teeth. In fact, the resin CAD/CAM blocks demonstrated the least amount of antagonist wear and least antagonist roughness when compared to ceramic and zirconia.[33, 31, 25]

Appropriate steps are critical in designing and fabricating a CAD/CAM restoration, and clinical skill and mastery of the software are main factors in clinical performance of the restoration.[12] The CEREC machine in our study used the blue camera and required a thin coating of powder on the teeth for scanning. The powder was the SIRONA Optispray (Sirona Dental Systems GmbH, Bensheim, Germany), which is mainly composed of titanium dioxide. Newer cameras, like Omnicam (Sirona Dental Systems GmbH, Bensheim, Germany), do not require powder coating of the teeth. A cooperative child would likely be accepting of the powder spray, but the newer powder-free technology would make cooperation less of an issue.

However, the CEREC imaging software is currently designed for use on permanent dentition only, and hence the investigators needed to develop the protocol, design, and manipulate the software for the primary dentition in this study. The current software is programmed to create interproximal contacts and make an adult size restoration even when small primary dentition and tooth preparations are scanned. Each restoration design had to be manually adjusted to create the correct proportions. Altering and establishing a software program to identify primary teeth would greatly reduce working time.

The CEREC machine used for scanning and preparation design connects wirelessly to the milling machine, making it convenient to use. The three-axes milling machine used in the study took an average of 12 minutes to mill the traditional veneer and 16 minutes for the three-quarter veneer. The fastest mill time was 8 minutes and the slowest was 20 minutes. Our machine is different from that used by Kawai et al. in their 1995 study which reported milling time for an adult onlay restoration of 3-13 minutes.[29] Newer milling machines can mill faster with more axis. A countdown timer is also available in the Serona software.

The size of the milling burs limits precision of milling, especially in the fine details of the intaglio surface.[19] This limitation of milling can be beneficial when preparation errors are too small for the machine to mill, providing forgiveness of the restoration. Poor fitting restorations are usually due to "lipped margins, sharp cervicoaxial line angels, beveled and/or spiked and undulating finish lines".[34] The newer milling systems use five-axes, allowing better precision than the three-axes machine used in this study.[35]

Bonding the ceramic/resin composite CAD/CAM restorations with resin luting cement requires several steps. The dental tubules are opened for micromechanical retention using phosphoric acid. The restoration is prepared for micromechanical interlocking by sandblasting the intaglio surface[12] and an application of silane allows the ceramic to chemically bond to the resin luting cement.[36] Research indicates that when ceramic restorations are bonded to the tooth structure, they have increased strength because they respond similarly to the enamel-dentin complex.[8, 14]

Restorations on primary dentition are intended to last for approximately a decade until physiological exfoliation. Primary tooth restorations may not need to withstand the same forces of permanent tooth restorations, because biting force increases as children mature. The biting force of the primary dentition is approximately 53.95lbs (240N), [8, 37] this force was recorded with posterior teeth biting on a tube to determine the greatest strength. As the child develops through early mixed, late mixed and permanent dentition the biting force increases: 64.97lbs (289N), 99.59lbs (443N), and 118.47lbs (527N) respectively.[19] Bakke et al also have evidence that the biting force of 5-10 year olds is 80.25±14.39lbs (357±64N).[38] The range of forces considered relevant to anterior pediatric restorations, excluding canines, should be the force generated from primary dentition to early mixed dentition (64.97-99.59lbs).

The control teeth and restorations in our study fractured within this range or at a greater force. The mean forces of groups with 0.5mm thick restorations were the strongest, with average fracture force of 162.76lbs ± 24.71 for the 0.5 mm traditional veneer and 103.26lbs ± 42.09 for the 0.5mm three-quarter veneer. The mean fracture force for 0.7mm traditional veneer was 86.00lbs ± 40.53 and that of 0.7mm three-quarter veneer was 86.24lbs ± 30.64. These forces at fracture were statistically significantly less than that of the control group, which fractured at 141.21lbs ± 54.70; however, the differences may not be clinically significant. In a study comparing the fracture forces between three-quarters veneers and traditional veneers on permanent dentition, no significant difference was found between these restoration designs.[30]

An interesting observation in this study is that the restorations with a thickness of 0.7 mm fractured at forces less than that of the thinner restorations (thickness of 0.5 mm) and less than that of the non-restored control teeth. This may be due to less tooth structure remaining after preparation for the 0.7 mm restorations. The enamel-dentin complex has been shown to absorb stress placed on the external surface and distribute the force.[8, 14] When more tooth structure is removed, the tooth has less ability to distribute force and deforms more rapidly. The deformation, tension and shear forces ultimately lead to failure of the restoration. Other studies have drawn similar conclusions and note that the fracture is initiated at the point with greatest tension, usually the cervical margins for vertical forces due to the expanding tooth structure. [39]

The compression test is relatively easy to preform, but the causes of fracture are difficult to determine due to all the variables involved such as capacity of composite restoration, cement/bonding layer, angulation of force (shear forces), contact area and plastic deformation.[40] When SEM was used to view the fractured samples after load testing, the surface of the dentin was not exposed on the fracture surfaces, indicating that specimens did not fracture through dentin. We did not detect a failure between the tooth surface and bonding agent. Instead several images showed fracture along the interface between the bonding agent and the luting cement. Others showed a cohesive fracture within the layer of the luting cement. Large portions of the fractured restorations were often still in place as only small areas of the crowns chipped off.

The restorations placed in this study were in direct contact with the metal Ultratester, which led to intense point loads.[41] The intense points from the steel arm cause uneven stress loads and debris. Premature failures may occur due to these intense points because there is no absorptive structure, like the periodontal ligament, to act as a cushion. To reduce the bias associated with the premature failures, all the samples in this study, including control, were subjected to the same metal arm of the universal testing machine and fractured in the range of pediatric biting force or greater.

Another limitation in the study is the variability of amount of healthy tooth structure remaining in the extracted teeth. Standardization is difficult due to variations in extent of caries and size of teeth, but natural teeth are more accurate than using resin abutment teeth.[30] With the restorations being customized based on caries presentation, the randomization of restoration design is less than ideal; teeth with facial caries were selected for traditional veneer restorations and teeth with a combination of facial and interproximal caries were selected for three-quarter veneers restorations. Restoration thickness was randomized among the study groups. The limitations of using natural teeth can also be viewed as a strength, because the results could easily be transferred to the clinical setting. Lastly, this study focused on thickness and design relative to fracture resistance, and therefore, it does not take into account the shear bond strength when the primary teeth have an occlusal force applied at 148 degrees to simulate the primary dentition interincisal angle.[23, 42]

Further investigations on the application and effectiveness of using CAD/CAM restorations as a treatment option for primary anterior teeth in clinical setting are required. Potential areas of study are 1) the shear strength of bonding tested at a simulated interincisal angle, 2) thinner anterior veneers materials can be examined such as the 0.2mm and 0.3mm zirconia veneers that have already been tested for adults[30], and 3) potential application of onlays/crowns on primary posterior teeth. A study by Magne et al. showed a significant higher fatigue resistance of resin occlusal veneers compared to ceramic occlusal veneers on permanent teeth.[41] CAD/CAM restorations have also been shown to be clinically effective and superior compared to cast gold restorations[10] and porcelain restorations.[16] In a study examining CAD/CAM and cast gold restorations on partially erupted molars, both had excellent margins and cleansability at 2-5 year follow up.[26] There is no standard method for measuring marginal fit with multiple methods introduced,[43] but the fit of the margin is critical to maintain oral health and longevity of the restoration.

Due to the small sample size in this study, the differences observed between some study groups and control group may not be significant. Future studies with larger sample sizes are necessary to validate the study findings. Despite the limitations, this study provides a positive outlook for using CAD/CAM technology in restoring primary anterior teeth. Compared to existing practice and treatment options of anterior esthetic restoration on the primary dentition, the CAD/CAM restoration may be more precise with individualized fit, better marginal integrity, excellent esthetics, and more be a conservative treatment option with less tooth reduction.

CONCLUSION

This study compared the fracture resistance of four different types of CAD/CAM restorations and a group of control teeth on extracted anterior primary teeth: 1) 0.5mm traditional veneer, 2) 0.5mm three-quarter veneer, 3) 0.7mm traditional veneer, 4) 0.7mm three-quarter veneer, and 5) non-restored control teeth. There was a significant overall difference observed among all five groups. Two-group comparison showed a significant difference only between the 0.7mm three-quarter preparation group and control group, with the force required to cause fracture on the restored teeth significantly lower than the non-restored control teeth. A marginally significant difference in fracture force was observed between the 0.7mm traditional preparation group and the control group, while both the 0.5mm traditional veneer and 0.5mm three-quarter veneer groups showed no significant difference compared to the control group. The failure of nearly all the teeth in the study groups during the testing was due to fracture of the restorations and bonding, with only one sample in the study groups having the underlying tooth structure damaged.

TABLES

Table 1: Fracture resistance in the five groups

Group	N	Fracture resistance (mean±SD)	Kruskal-Wallis test	Wilcoxon rank sum test*
0.5mm three-quarter prep	10	103.26±42.09	P=0.0007	P=0.1206
0.5mm tradition veneer prep	10	162.76±24.71		P=0.3955
0.7mm three-quarter prep	10	86.24±30.64		P=0.0443
0.7mm tradition veneer prep	10	86.00±40.53		P=0.0596
Control	10	141.21±54.70		

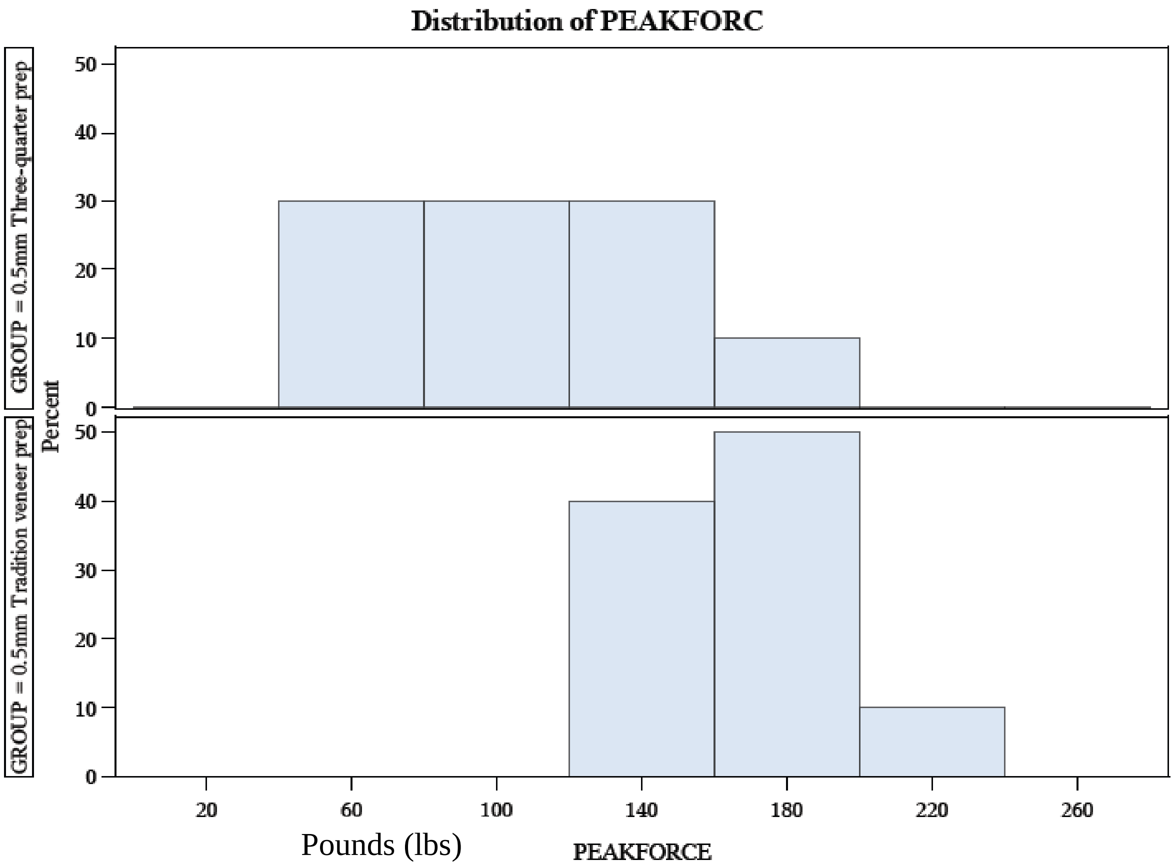
*compared to the control group

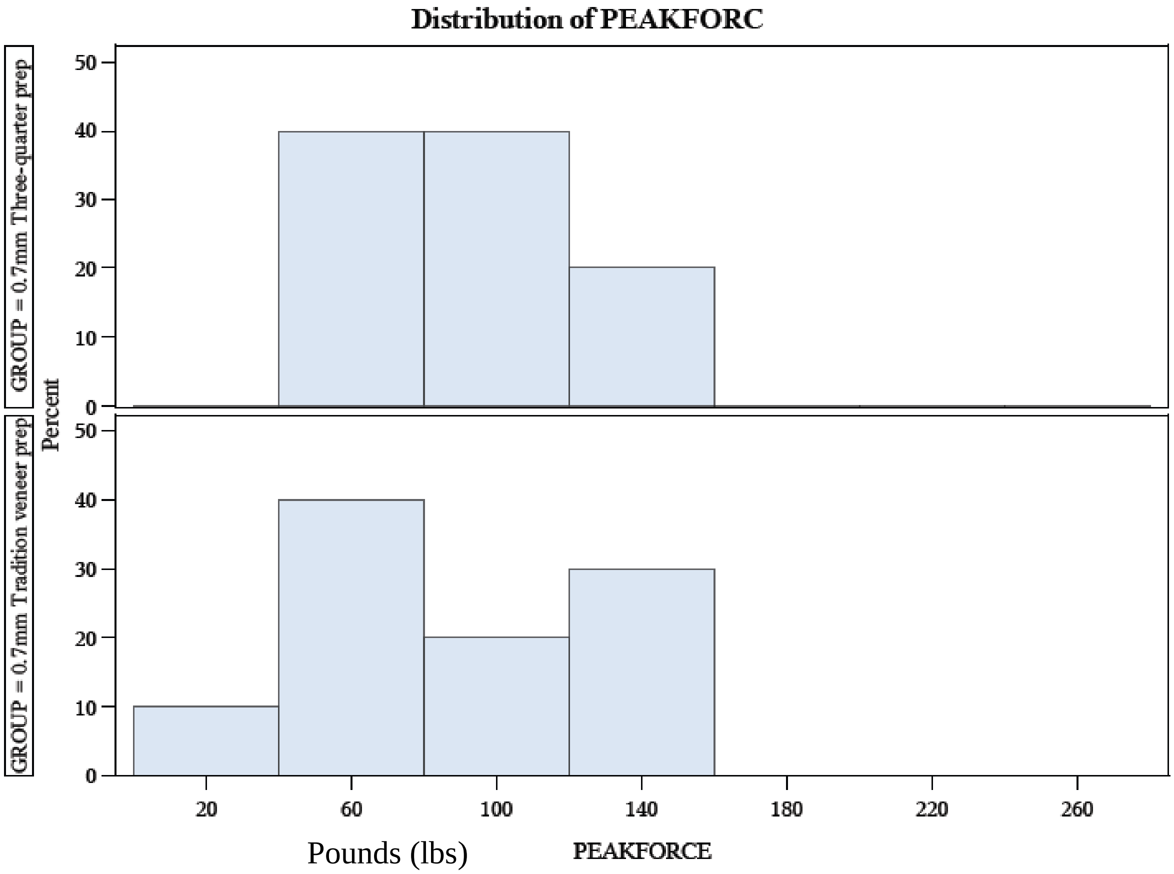
Table 2: Analysis of Samples

Analysis Variable : PEAKFORC PEAKFORCE									
GROUP	N Obs	N	Mean	Std Dev	Minimum	Lower Quartile	Median	Upper Quartile	Maximum
0.5mm Three-quarter prep	10	10	103.2600000	42.0889323	60.7000000	69.8000000	89.2500000	121.8000000	190.1000000
0.5mm Tradition veneer prep	10	10	162.7600000	24.7098811	126.8000000	142.7000000	168.5500000	171.5000000	214.3000000
0.7mm Three-quarter prep	10	10	86.2400000	30.6384725	48.1000000	63.3000000	81.0000000	105.4000000	143.6000000
0.7mm Tradition veneer prep	10	10	86.0000000	40.5254927	30.1000000	49.2000000	80.0500000	130.0000000	140.5000000
Control	10	10	141.2100000	54.6958956	72.6000000	100.9000000	124.4000000	179.8000000	244.1000000

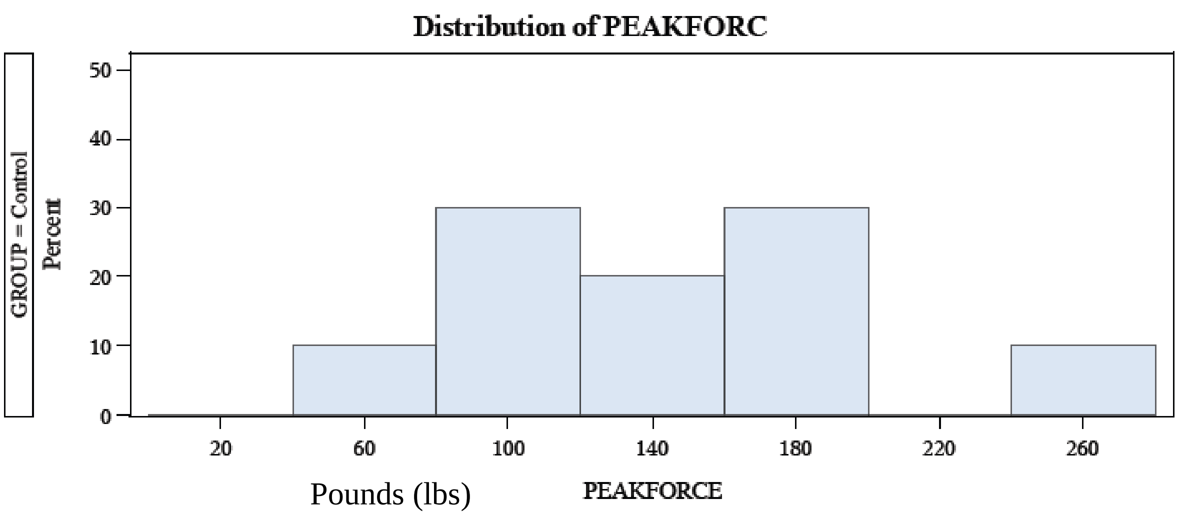
FIGURES

Figure 1: Distribution of fracture resistance (lbs) in the five groups





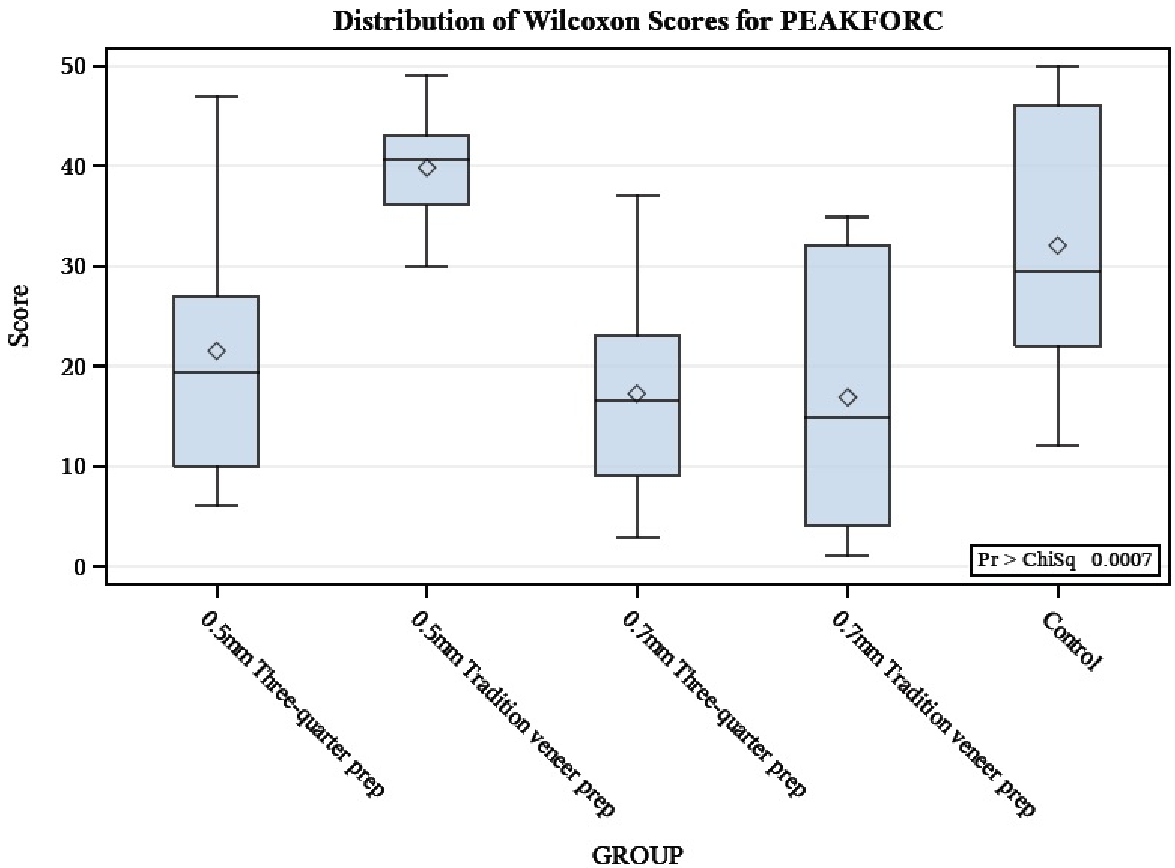
Pounds (lbs)



Pounds (lbs)

Figure 2: Kruskal-Wallis Test

Kruskal-Wallis Test	
Chi-Square	19.1482
DF	4
Pr > Chi-Square	0.0007



ILLUSTRATIONS

Illustration 1 – Margin preparation with round bur

Illustration 2 – Margins preparation

Illustration 3 – Depth guide bur preparation

Illustration 4- Alternative view of margin and depth guide preparation

Illustration 5 – Incisal reducation and blending

Illustration 6 – Three-quarter Preparation

Illustration 7 – Alternative Three-quarter preparation

Illustration 8 – CAD machine

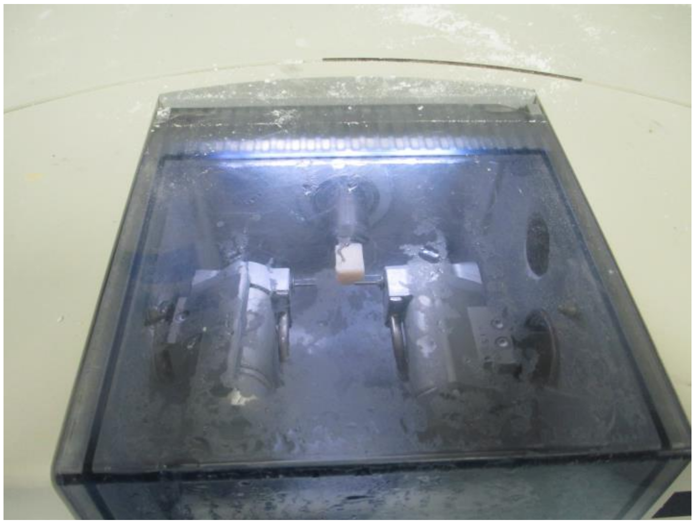


Illustration 9 – CAM machine with block in place

Illustration 10 – Ultratester, Universal Testing Machine

Illustration 11 – Front and lateral view of restoration prior to fracture test

Illustration 12 – Restoration in testing mount prior to fracture test

Illustration 13 – Underside of testing mount, note the screw on the side right side marked with red arrow.

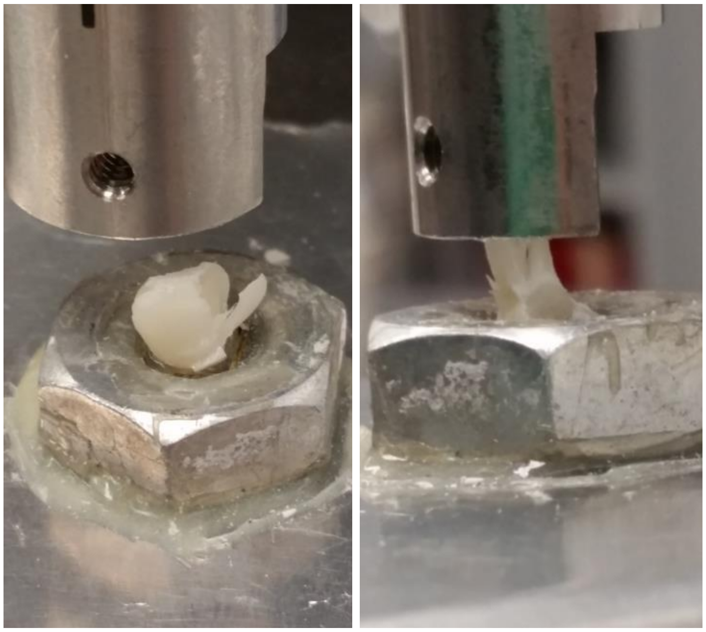


Illustration 14 – Examples of fractures. (left – CAD/CAM, right – real tooth)

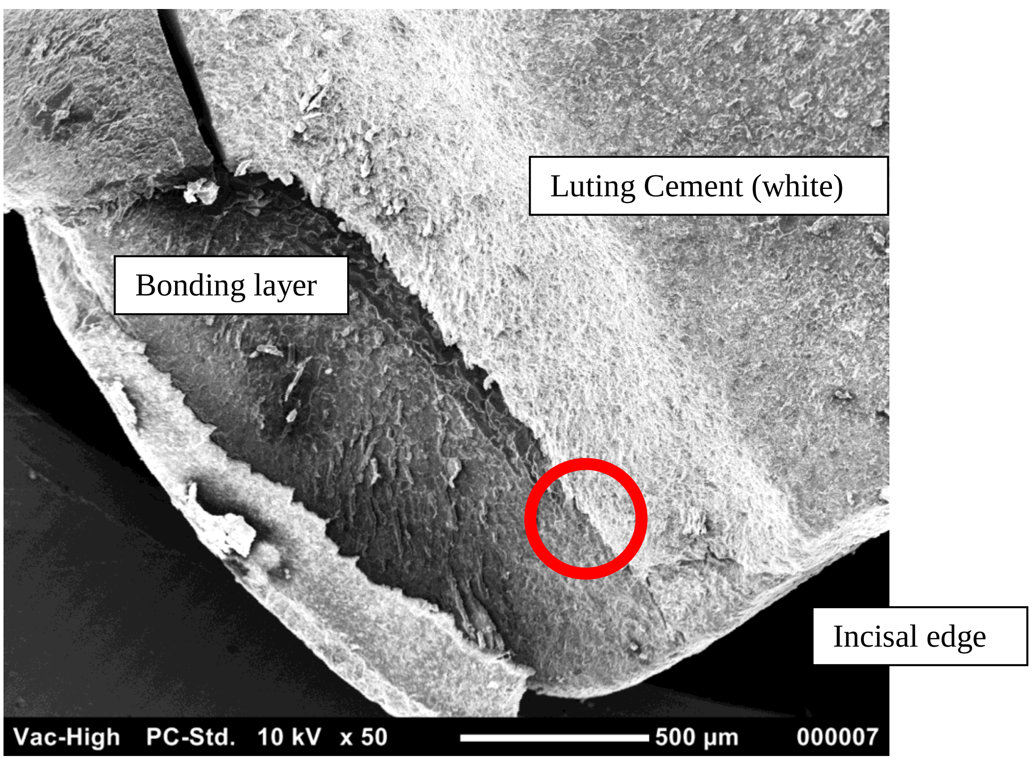


Illustration 15 – Wide angle photo of tooth. Red circle will be magnified for illustration 16

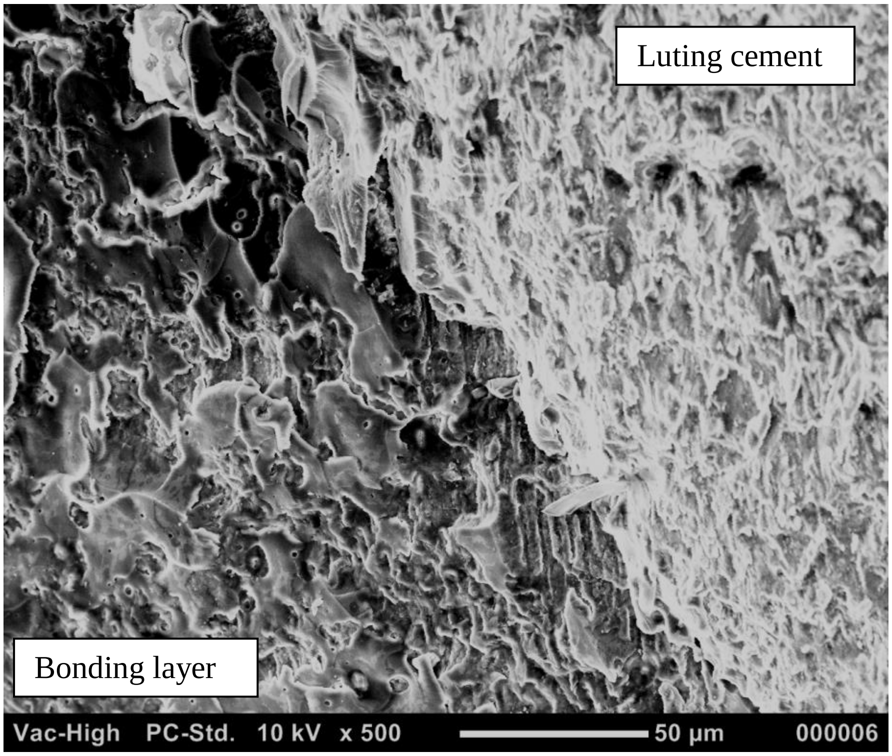


Illustration 16 - Magnification of Tooth, illustration of 15 inside the red circle.

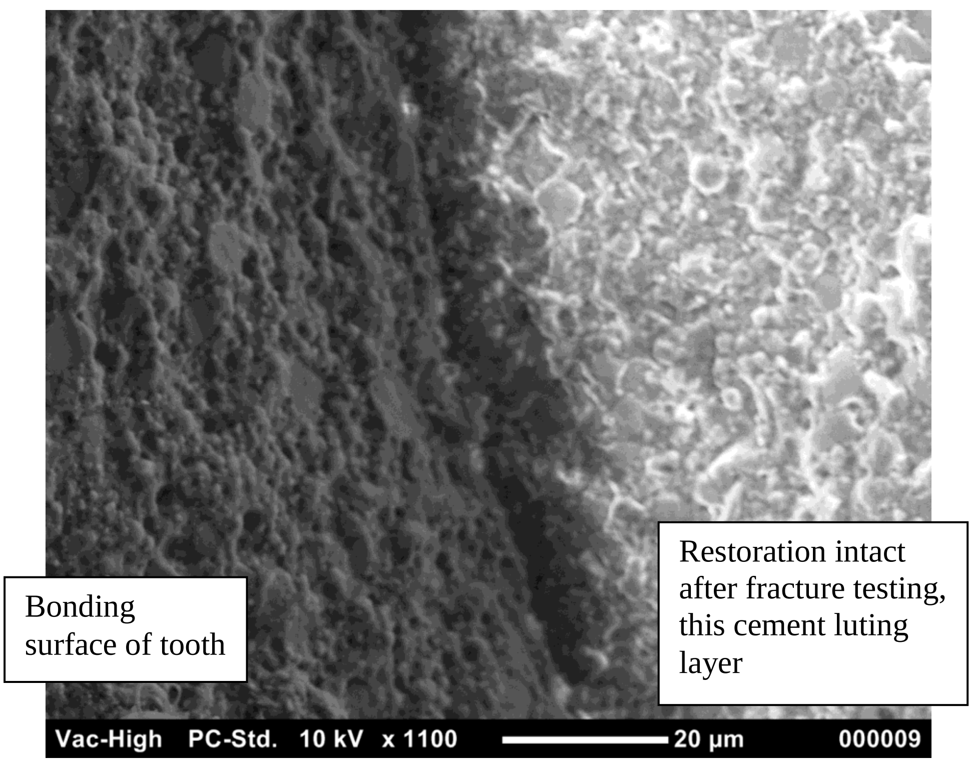


Illustration 17 - Magnification of intact restoration at the bonding/luting cement layer

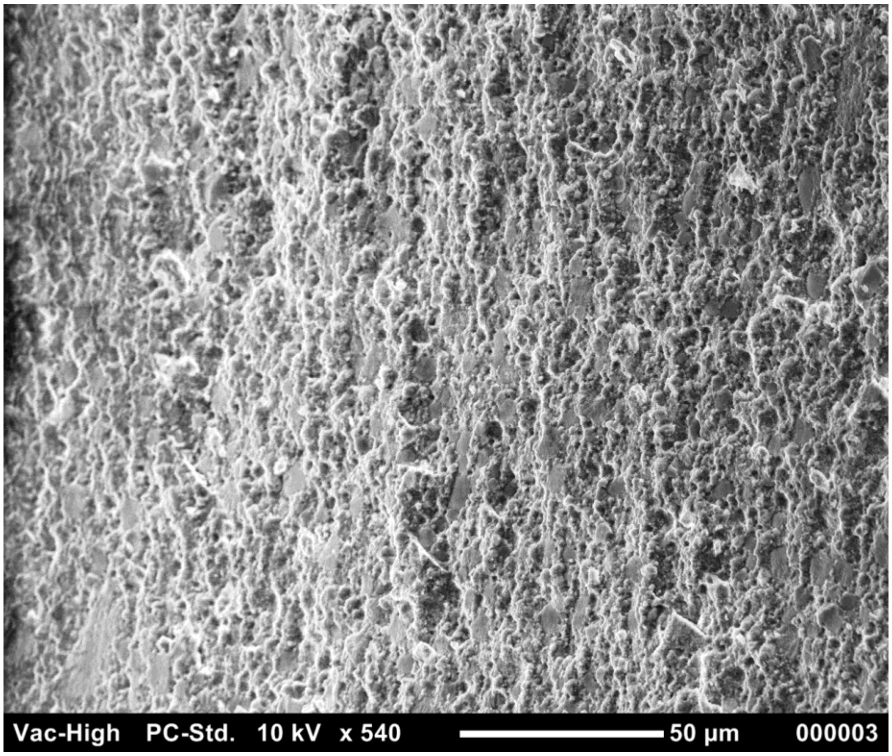


Illustration 18 – Cross section of Lava Ultimate restoration after fracture.

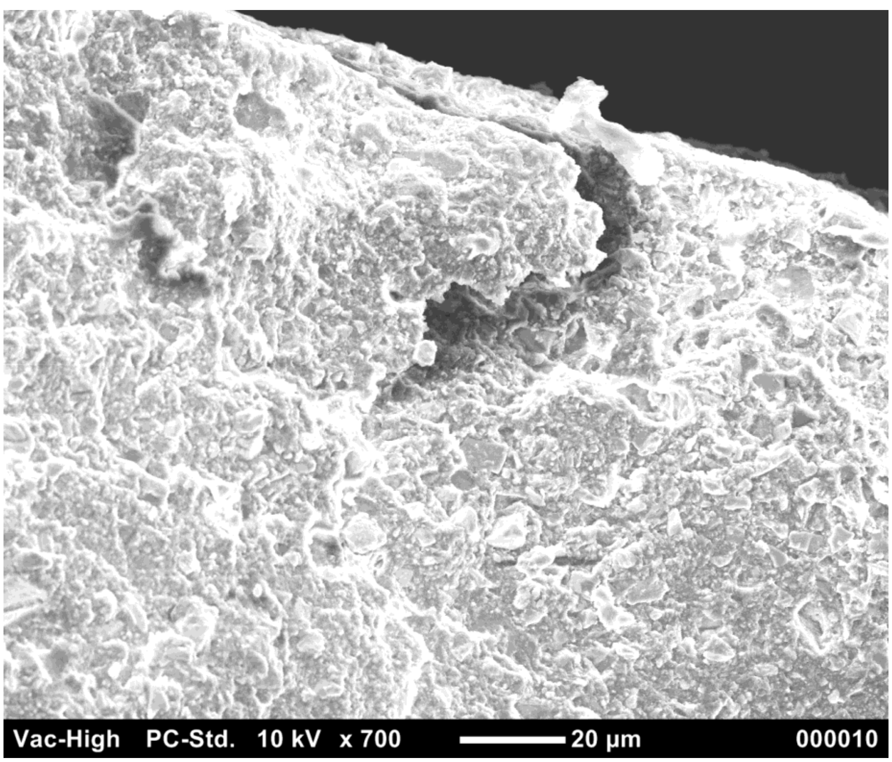


Illustration 19 – Incisial edge of Lava Ultimate restoration after compression testing.

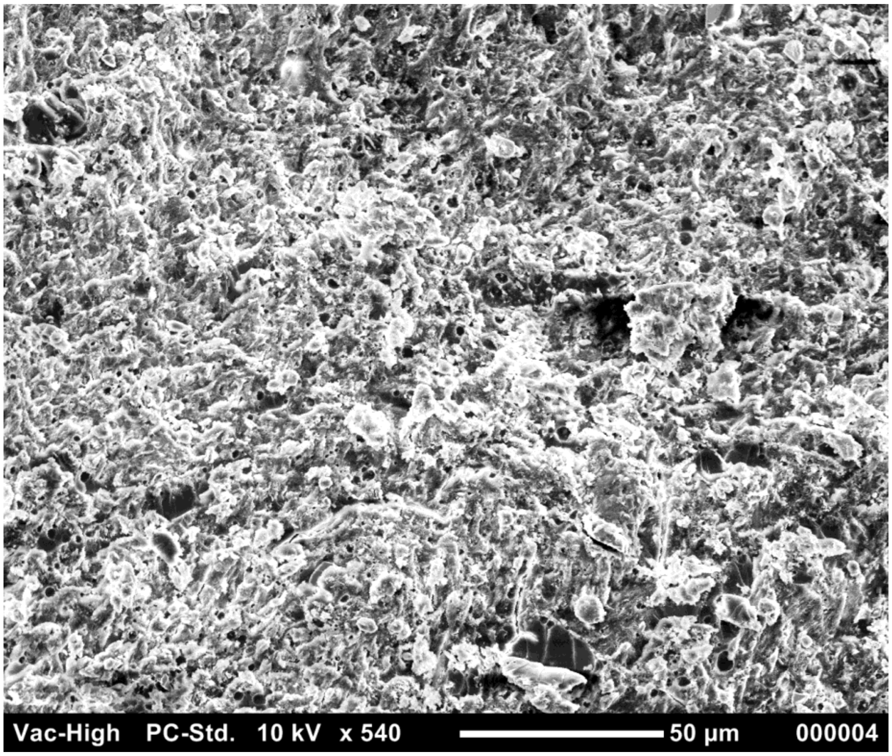


Illustration 20 – Intaglio surface of restoration

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