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Clinical Evaluation of Chairside CAD/CAM Nano-Ceramic Restoration: Five Year Status

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Disclosures

Dr. Fasbinder has received honoraria for educational programs and research funding for projects with 3M and the CEREC system from Dentsply Sirona. This research is sponsored by a research grant from 3M.

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Abstract

(1) Objectives: This investigation was a longitudinal, randomized clinical trial to measure the clinical performance of a nano-ceramic material (Lava Ultimate/3M) for chairside CAD/CAM fabricated restorations.

(2) Materials and Methods: 120 chairside CAD/CAM onlays were restored with a CEREC system randomly assigned to 60 leucite-reinforced ceramic (IPS EmpressCAD/Ivoclar) onlays and 60 nano-ceramic (Lava Ultimate/3M) onlays. Equal groups of onlays were cemented using a self-etch and a total etch adhesive resin cement. The onlays were recalled for a period of five years.

(3) Results: At one week post-operatively, 10% of the onlays cemented with both the self-etch and total etch adhesive resin cements were reported as slightly sensitive. However, all patients were asymptomatic by the 4th week without treatment. Four leucite-reinforced onlays and one nano-ceramic onlay fractured and required replacement.

(4) Conclusions: Adhesive retention with a self-etch or total etch cementation technique resulted in a similar clinical outcome with no reported debonds. The nano- ceramic onlays had a lower incidence of fracture compared to the leucite-reinforced ceramic onlays with both having a very low risk of fracture. Nano-ceramic onlays performed equally as well as glass ceramic onlays over five years of clinical service.

Clinical Significance

Ceramic materials have been a mainstay for chairside CAD/CAM restorations for the past 30 years and a new category of resilient ceramics with a resin matrix have been introduced reported to offer ceramic-like durability and esthetics with resin-like efficiency in handling. There is no long-term clinical studies on the performance of these materials. This is a five year randomized clinical trial on the performance of nano-ceramic onlays.

Key Words

Ceramic, Nano-ceramic, CAD/CAM, Onlays, CEREC

Introduction

Ceramic materials have been a mainstay for chairside CAD/CAM restorations for the past 30 years. They have very good wear resistance with the potential to induce some antagonist wear if the surface remains rough.[1,2] Ceramic restorations have good strength properties to resist compressive forces but may be at risk of fracture due to tensile stresses.[3,4] A number of high strength ceramic and more currently, full contour zirconia materials, have been marketed for chairside CAD/CAM application with the potential to prevent the risk of fracture. However, to achieve the high strength these materials offer, considerable time is devoted to post-milling processing using porcelain oven crystallization or oven sintering processes.

A new category of chairside CAD/CAM materials has been introduced that have a composite resin matrix and have been referred to as "hybrid ceramics" or "nano-ceramics". A broader name for this type of material is a resilient ceramic. These resilient ceramic materials include a resin matrix with a ceramic additive that are industrially processed into a preformed block. This category of resilient ceramic materials attempts to combine the desired properties of ceramics such as durability, enamel-like surface finish, good esthetics, and color stability with desired properties of composite resin such as high flexural strength, low abrasiveness, and ease of polishing. [5,6] Resin-based CAD/CAM materials are not as hard as ceramic materials and have been shown to be milled faster with less margin chipping and less milling tool wear.[7,8] These materials have the added advantage of being efficiently fabricated without the need of a post-milling oven firing cycle. Another possible advantage of resilient ceramic materials is that the adhesive resin cements may have a more similar wear rate compared to that of the restoration leading to improved margin integrity over time.[9,10]

One of the first of the resilient ceramic materials introduced was Lava Ultimate (3M). It is a nano-ceramic CAD/CAM material that contains 20 nanometer (nm) size silica particles, 4 - 11 nm size zirconia particles, and agglomerated nano-size particles of silica and zirconia, all embedded in a highly cross-linked polymer matrix with an approximately 80% ceramic load. The manufacturer states an advantage for the nano-ceramic material compared to CAD/CAM composite blocks is the ability to retain a high gloss surface finish over time.[11] The manufacturer also reports a flexural strength of 200 MPa for Lava Ultimate, that is greater than the flexural strength of the feldspathic and leucite reinforced porcelain blocks.[11] It is indicated for veneers, inlays, and onlays but not for crowns. Independent laboratory studies have reported flexural strength of 170 MPa for Lava Ultimate.[7,12]

Although resilient ceramic materials are recommended for efficient treatment while minimizing the risk of chipping or fracture of all-ceramic materials, there may be concerns with both the surface luster and occlusal wear of the material over time as well as a lack of color stability.[7] Although chairside CAD/CAM restorative materials have been studied for over 30 years, there are no long-term clinical studies using resilient ceramic materials. The purpose of this randomized clinical trial was to evaluate the longitudinal clinical performance of nano-ceramic and leucite-reinforced ceramic chairside CAD/CAM onlays over five years of clinical service. The study also evaluated the short-term post-operative sensitivity associated with the adhesive luting technique of onlays using a self-etch and total etch adhesive cement.

Methods and Materials

The Medical Sciences Institutional Review Board of the University of Michigan reviewed and approved the investigation protocol prior to initiation of the study. The patient population was selected from current patients under clinical treatment at the University of Michigan dental clinics. All patients signed a written informed consent document prior to enrolling in the study. All teeth were asymptomatic at the beginning of treatment. Patients received a maximum of two onlays. Each lesion or defective restoration exhibited sufficient size to extend at least one-half the intercuspal width of the tooth requiring an onlay restoration. The onlays did not include all cusps on the selected tooth so as to ensure there was some portion of an occlusal margin in the restoration. All teeth tested vital and were asymptomatic at the beginning of treatment. All restorations had opposing functional occlusion and at least one proximal contact with an adjacent tooth. There was no attempt to exclude patients with specific occlusal schemes or parafunctional habits.

Exclusion criteria included:

Devital or sensitive teeth

Teeth with prior endodontic treatment of any kind

Teeth with a history of direct or indirect pulp capping procedures

Patients with significant untreated dental disease

Pregnant or lactating women

Sixty onlays were placed using each of the two restorative materials (IPS EmpressCAD/Ivoclar and Lava Ultimate/3M). A random numbers table was generated for the study that randomly assigned 60 onlays to each of the two study groups. The sample size was according to the international standard represented by the criteria of the American Dental Association (ADA, Council on Scientific Affairs: Acceptance Program Guidelines “Restorative Materials”, March 1996)

All the onlays were prepared, fabricated, and delivered in a single treatment appointment by one of the two treating dentists. Prior to preparing the tooth, shade determination was made using a shade guide (Vita Classic) and the pre-operative status of the tooth was recorded with digital photographs. Cavity preparation for the onlays followed the manufacturer's recommended guidelines and was defect-oriented in design in that no specific attempt was made to create mechanical resistance in the preparation. There was at least 2.0 mm of occlusal reduction over functional cusps, at least 1.5 mm of reduction over nonfunctional cusps and in the central fossa, at least 1.2 mm of axial reduction, and no sharp internal angles. No bases or liners were used in any onlay preparation. An Isolite2 dryfield illuminator (Isolite Systems) was used for isolation of the quadrant during all clinical procedures.

The manufacturer's instructions were strictly adhered to in the imaging, design, and machining of the onlays using a CEREC 3D BlueCam system (Dentsply Sirona) with 4.0 version software. Following computergraphic design of the onlay, the operator opened the envelope with the random assignment of the prefabricated block to be used for the specific restoration. The restorations were milled in the MCX mill (Dentsply Sirona) from prefabricated blocks of IPS EmpressCAD (Ivoclar), a leucite-reinforced porcelain, or Lava Ultimate (3M), the test nano-ceramic.

Two different cements were used to cement the onlays. Half of the onlays (60 restorations equally distributed between the Lava Ultimate and IPS EmpressCAD restorative materials) were cemented with total etching and a dual cured resin cement (Variolink II/Ivoclar). The other half of the onlays were cemented with self-etching and a dual cure resin cement (RelyX Ultimate/3M ESPE). The internal surfaces of the IPS EmpressCAD onlays were etched for 60 seconds with 4.9% hydrofluoric acid gel, rinsed for 20 seconds, and then air dried with oil-free air. The internal surface was coated with silane coupler (Monobond Plus/Ivoclar) and lightly air dried. The internal surfaces of the Lava ultimate onlays were lightly air abraded with 30-micron silica (CoJet Sand/3M) in a microetcher, cleaned with alcohol, and then air dried with oil-free air. Scotchbond Universal Adhesive (3M) was applied to the prepared internal surface of the onlays and dried until there was no movement of the adhesive agent.

For the Variolink II cement group, the cavity preparation was cleaned and then total etched for 20 seconds with 37% phosphoric acid, rinsed thoroughly with water, and lightly air dried leaving a moist surface. A thin coating of Excite (Ivoclar) dentin bonding agent was applied and air thinned. The bonding agent was not light cured prior to placement of the cement. Equal parts of the Variolink II cement base and catalyst were mixed, loaded into a syringe, and injected into the cavity preparation. For the RelyX Ultimate cement group, the preparation was cleaned with a slurry of pumice and water and rinsed before actively applying Scotchbond Universal Adhesive (3M) for 20 seconds and subsequently air thinning until there was no movement of the bonding agent. The bonding agent was not light cured prior to placement of the cement. The RelyX Ultimate was injected directly into the cavity preparation with the automix tip. The onlay was inserted into the cement to complete seating and the excess cement removed. All onlays were light cured for 40 seconds from the facial, lingual and occlusal for a total cure of 2 minutes. A series of diamond finishing burs, rubber abrasive points and cups, finishing strips, and diamond polishing pastes were used for removal of excess cement, final contouring of the restoration, and adjustment of the occlusion.

Patients were contacted by telephone once a week after the initial appointment to evaluate the immediate post-operative sensitivity. A criterion-referenced rating scale was used to measure sensitivity. The telephone interview was used as a follow-up procedure to minimize recall loss as the patient was not required to return to the clinic. During the telephone interview a criterion-referenced rating was made of functional tooth sensitivity using the following scale. Patients were only asked to return for an evaluation if they were having continued discomfort or any indication of premature occlusal contact.

Sensitivity Criteria:

1= No sensitivity is experienced at anytime

2= Slight sensitivity is experienced occasionally but it is not uncomfortable

3= Moderate sensitivity is experienced intermittently and it is noticeably uncomfortable

4= Severe discomfort is noted routinely with cold or pressure stimulation

Two independent evaluators examined all restorations in the study. Clinical evaluations were made at baseline (onlay placement), six months, one year, two years, three years, and five years using written criteria based on modified USPHS criteria for margin discoloration, anatomical form, margin finish, margin adaptation, proximal contact, recurrent caries, surface finish and cuspal/tooth fracture (Table #1). Disagreements in evaluations were discussed between the evaluators and a consensus judgment was reached and recorded for every criteria.

Intraoral digital color photographs at a 1:1.5 magnification were taken to document pre-operative, cavity preparation, restoration try-in, and post-operative conditions. Facial and occlusal views of the tooth were documented for both the pre-operative and post-operative conditions.

A postcementation quadrant impression was made of each test restoration in a polyvinyl siloxane material and casts were poured in an epoxy die material. Casts were made at the baseline, 6 months, 1 year, 2 years, 3 years, and 5 years recall visits.

Results

Eighty-six patients were enrolled in the study; 30 males and 56 females. (Table #2) Each patient received a maximum of two test restorations with at least one proximal contact available for evaluation. Each test group consists of 30 onlays (4 groups of two cements and two materials).

One specific aim of the study was to evaluate the short-term post-operative sensitivity associated with the adhesive luting technique for onlays using self-etch and total etch adhesive cements. At one week post-operatively, patients described as slightly sensitive 10% of the onlays cemented with Variolink II and 10% of the onlays cemented with RelyX Ultimate. However, all patients were asymptomatic by the 4th week without treatment. No patient required treatment for sensitivity. No onlay was reported as sensitive at any other recall evaluation. (Table #3)

The fractures observed in the study were from both materials. Four EmpressCAD onlays fractured and required replacement; one at 10 months, one at 34 months, one at 37 months, and one at 40 months. (Figure 1, 2) One Lava Ultimate onlay fractured and required replacement at 19 months. Two Lava Ultimate onlays were lost due to fracture of the adjacent tooth structure at 38 months and 43 months and required replacement. (Figure 3) Two additional onlays showed evidence of surface chipping that did not require treatment; one Lava Ultimate onlay at 24 months and one EmpressCAD onlay at 24 months. Two teeth with Lava Ultimate onlays required endodontic treatment; one at 6 months and one at 25 months. (Figure 4A, 4B) Both onlays had the endodontic access preparations restored with direct composite restorations (Filtek Supreme Ultra/3M) and the onlays remained in the study recall with no further negative outcomes.

In summary, there was a total of 5 fractured restorations after 5 years of clinical service. The Kaplan-Meier probability for restoration fracture confirmed a small risk of fracture after five years. The Kaplan-Meier probability for fracture of EmpressCAD onlays was 0.068 (0.026; 0.171) and for Lava Ultimate onlays was 0.083 (0.036; 0.189). The probabilities were not statistically significantly different between materials (Table #4 and #5)

The USPHS criteria scores for color match, margin discoloration, surface finish, anatomic form, caries, margin adaptation, and surface gloss remained relatively unchanged at greater than 93% alpha over the five-year recall period for both groups of onlays. There was no measured difference in the performance of the two materials used for the onlays based on the cementation technique.

Discussion

The purpose of this study was to evaluate the clinical outcome of chairside CAD/CAM onlays fabricated from a nano-ceramic material (Lava Ultimate/3M) and a leucite-reinforced ceramic material (EmpressCAD/Ivoclar) after five years of clinical service. One specific aim of the study was to measure the post-operative sensitivity between using a self-etch technique and a total etch technique with a dual cure resin cement. There was no difference in the post-operative sensitivity between cementing techniques at one week post-operatively with 10% of the patients reporting slight sensitivity in the onlay. And by four weeks all patients were asymptomatic without treatment. No onlay was reported as sensitive at any other recall evaluation. Although self-etching is commonly considered an alternative to the use of total etching to decrease the risk of post-operative sensitivity, no difference in sensitivity was reported in this study. This lack of sensitivity is consistent with other chairside CAD/CAM clinical studies. Potential reasons for this may be related to a single appointment procedure as the preparation must be isolated to accurately digitally record it ensuring it can be isolated to adhesively bond the restoration. In addition, the ability to bond to the freshly prepared tooth structure has been shown to minimize post-operative sensitivity without the use of a provisional restoration.[13,14]

All-ceramic restorations generally have a fracture rate of 3% - 5% after 5 years due to their brittle nature. They may also be abrasive to the opposing dentition if allowed to have a rough surface.[15-17] Lava Ultimate has been reported to perform better under *in vitro* fatigue testing compared to several all-ceramic materials due to a difference in their elastic properties.[18] Lava Ultimate was reported to be less brittle and more flexible and had the best fatigue performance due to its greater resilience in enabling more stress absorption by deformation as the primary outcome.[18] All-ceramic materials had increased brittleness and cracking as the primary outcome.

There are very limited clinical studies on resilient ceramic materials since they are relatively new materials. One clinical study on Lava Ultimate included 42 onlays fabricated with the CEREC system and adhesively delivered with a dual cured resin cement (Variolink II/Ivoclar) for 30 patients.[19] Two onlays debonded within the first 12 months requiring replacement resulting in a success rate of 95.0%. There were 2 fractured onlays and 1 additional debonded onlay requiring replacement after 2 years of clinical function resulting in a cumulative success rate of 85.7%. No chipping fractures were reported. In the present study, there was one case of surface chipping for both of the materials that did not require treatment. Four of the leucite-reinforced onlays fractured (at 10, 34, 37, and 40 months) with only one of the nano-ceramic onlays fracturing (at 19 months). The three debonded restorations were a concern to the authors in that laboratory reports of bond strength indicate that the bond to nano-ceramics were lower than to all ceramic materials.[20] The authors reported that debonded restorations all had cement remaining on the tooth preparation as potential evidence of the weaker bond to the nano-ceramic partial crowns. This was not a finding for this study over five years. There were no cases of debonding using two different adhesive cementation techniques. The self-etch and total etch techniques both demonstrated equally good adhesive retention for defect-oriented onlay preparations. (Figures 5A-D, 6A-D) And the very low incidence of margin surface staining (3% of the onlays over 5 years) and no occurrence of margin stain pentration also is evidence of the stability of the adhesive retention over time. The use of microabrasion on the internal aspect of the onlays resulted in clinically good adhesive retention. It should be noted that the other study used calibrated dental students to place the restorations and the debond rate may have been related to the relative clinical inexperience of the operators.

A purported advantage of the nano-ceramic material is that it may wear at a similar rate to the resin cement maintaining good margin adaptation. The USPHS criteria for margin adaptation was refined to create descriptors with potentially finer discrimination to detect margin change over time. (Table #1) The alpha category was further divided to measure when margins became detectable prior to any crevice formation. A definite trend was noticed in the increase in detectable margins for both types of onlays with the nano-ceramic onlay margins be somewhat less detectable. (Table #6) This trend is consistent with results of other clinical research on ceramic onlays as the occlusal forces lead to margin cement wear over time. Generally, the trend is for the cement wear to stabilize as the exposed area of the cement becomes less susceptible to occlusal forces and may be protected by the adjacent enamel and restorative material at the margin. The amount of margin wear was only noticed due to the more refined criteria used for margin wear evaluation in this study compared to the typical USPHS criteria. All margins would usually be considered an alpha rating.

There is limited evidence on the polish retention of nano-ceramic materials. One *in vitro* study compared the surface roughness of materials using an automated tooth brushing machine.[21] The glass ceramic material (IPS emaxCAD/Ivoclar) had a limited surface roughness change after 8 years of simulated toothbrush abrasion. The authors reported an increase in surface roughness for polymer ceramic materials that was inversely related to the amount of filler load. They suggested that the greater amount of filler particles limited the area of resin matrix exposed to abrasive wear. A reasonable question for resin-based CAD/CAM restorations is the ability for the material to retain an esthetic, gloss surface over years of clinical service. This has been an appreciated property of all-ceramic materials as they have compatible wear with the opposing dentition. A recent study of Lava Ultimate partial coverage crowns reported that the surface gloss was stable with minimal surface abrasion after 12 months. However, after 24 months surface gloss deteriorated but occlusal wear continued to be similar to that of enamel.[19] In this study, there was no appreciable difference in the surface gloss between the two types of onlays with 91.6% (55/60) scored as alpha after five years. (Figures 7A-D, 8A-D) Of particular interest is the maintenance of the surface gloss for the onlays through five years of clinical service for Lava Ultimate. This is a critical feature for doctors to accept nano-ceramic as a replacement for conventional ceramics. The surface of Lava Ultimate has been comparable in smoothness and gloss to the leucite-reinforced ceramic restorations. Only by desiccating the surface of the restoration is it easier to differentiate between the two as the nano-ceramic results in a matte surface appearance when desiccated. (Figure 9A-D) There have been a limited number of onlays that developed broader wear facets over the five years of clinical service. (Figure 10A-D) These were occasionally detected on Lava Ultimate onlays but not the EmpressCAD onlays. This is consistent with the less abrasive nature of the nano-ceramic material compared to ceramic materials and could be considered an advantage in high wear cases to avoid surface chipping or fracture.

Conclusions

The following conclusions can be made based on the study outcomes.

There was no difference in the post-operative sensitivity of the onlays using a self-etching and total etching technique with a dual cured resin cement.

Adhesive retention with a self-etch or total etch cementation technique resulted in a similar clinical outcome with no reported debonds.

The resilient ceramic onlays had a lower incidence of fracture compared to the leucite-reinforced ceramic onlays with both having a very low risk of fracture.

Nano-ceramic onlays performed equally as well as glass ceramic onlays over five years of clinical service.

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Table #1: Modified USPHS criteria.

Category	Rating
Color Match	
Tooth and restoration have an ideal color match; can distinguish restoration with some difficulty	Alpha
Readily perceptible mismatch in color; general match	Bravo
Obvious mismatch in color between tooth and restoration; unacceptable	Charlie
Margin Discoloration	
No evidence of margin discoloration	Alpha
Surface stain along less than 50% of exposed margin	Bravo-1
Surface stain along greater than 50% of exposed margin	Bravo-2
Penetrating discoloration of exposed margin	Charlie
Surface Finish	
Smooth, highly polished to finely granular	Alpha
Gritty, moderate rough but uniform texture	Bravo
Rough or pitted, visible evidence of significant pits and voids	Charlie
Evidence of surface crazing with no loss of restoration or mobile pieces	Delta
Anatomic Form (general contour)	
Restoration is continuous with existing anatomic form	Alpha
Restoration is discontinuous with existing anatomic form, missing material is not sufficient in size exposing dentin	Bravo
Restoration is discontinuous with existing anatomic form and missing material sufficient in size to expose dentin	Charlie
Cusp/Tooth Fracture	
No evidence of cusp or tooth fracture	Alpha
Evidence of cusp/tooth fracture adjacent to the restoration margin without loss of tooth structure	Bravo
Complete fracture and loss of tooth structure adjacent to restoration	Charlie
Fracture of tooth not related to the restoration	Delta
Caries	
No evidence of caries	Alpha
Evidence of recurrent caries at crown margin; repairable without compromise to crown	Bravo
Evidence of recurrent caries at crown margin; not repairable, crown requires replacement	Charlie
Margin Adaptation (margin integrity)	
No visible evidence of crevice formation along cavosurface margin; explorer does not catch when drawn across the margin	Alpha-1
Margin is detectable along less than 50% of cavosurface margin; and less than 1 mm in depth	Alpha-2
Margin is detectable along more than 50% of cavosurface margin; and less than 1 mm in depth	Alpha-3
Evidence of crevice formation (penetrable) along less than 50% of cavosurface margin; greater than 1 mm in depth	Bravo-1
Evidence of crevice formation (penetrable) along greater than 50% of the cavosurface margin; greater than 1 mm in depth	Bravo-2
Evidence of crevice formation exposing dentin to the axial or pulpal floor	Charlie
Onlay Fracture	
No evidence of onlay fracture	Alpha
Evidence of onlay fracture confined to less than 50% of the occlusal isthmus width, pieces not mobile	Bravo
Evidence of onlay fracture extending more than 50% of the occlusal isthmus width, pieces not mobile	Charlie
Fracture of onlay with mobile pieces or restoration defect	Delta
Proximal Contact	
Firm resistance to passage of floss with ideal breadth of contact area	Alpha
Light resistance to passage of floss or notable variance in breadth of contact area; shim stock will pass through contact	Bravo
Contact visibly open with passage of one thickness of articulating paper	Charlie
Sensitivity	
No sensitivity is experienced at any time	Alpha
Slight sensitivity is experienced occasionally but is not uncomfortable	Bravo
Moderate sensitivity is experienced intermittently and is noticeably uncomfortable	Charlie
Severe discomfort is noted routinely with cold or pressure stimulation	Delta

Table #2: Distribution of onlay restorations.

Teeth	Premolars	Molars	Totals
Maxillary	29	30	59
Mandibular	9	52	61
Totals	38	82	120

Table #3: Post-operative sensitivity ratings

Post-Op Sensitivity		Lava Ultimate Variolink II	Lava Ultimate RelyX Ultimate	EmpressCAD Variolink II	EmpressCAD RelyX Ultimate
Number of Onlays	Rating	30	30	30	30
Sensitivity at 1 week	Alpha Bravo	27 3	26 4	27 3	28 2
Sensitivity at 2 weeks	Alpha Bravo	27 3	28 2	29 1	30
Sensitivity at 3 weeks	Alpha Bravo	29 1	29 1	29 1	30
Sensitivity at 4 weeks	Alpha Bravo	30	30	30	30

Table #4: Kaplan Meier Probability for fracture of EmpressCAD onlays.

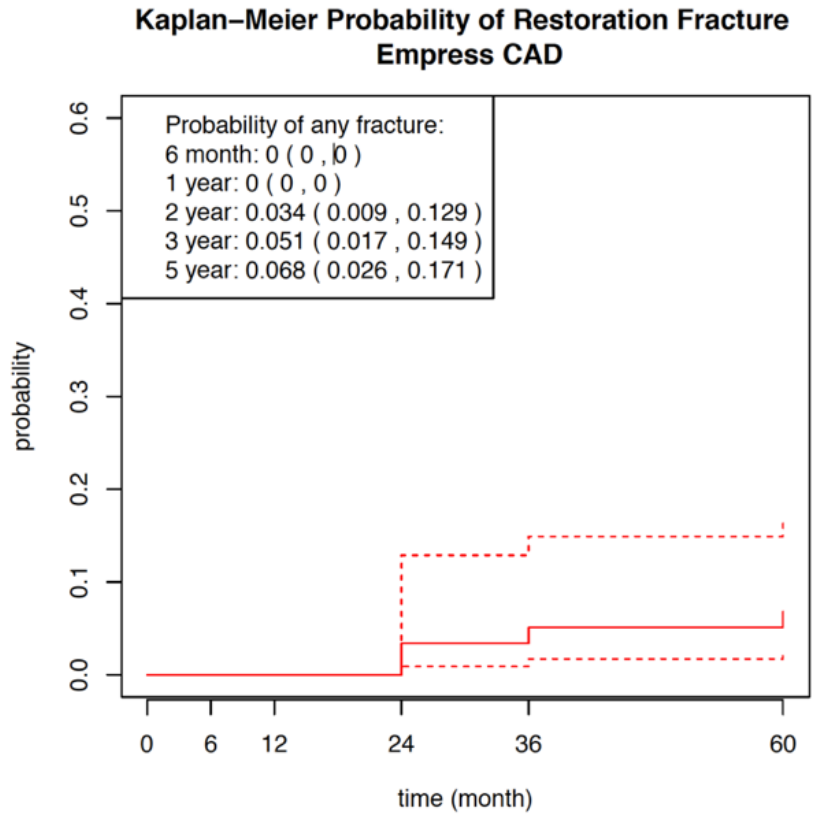


Table #5: Kaplan Meier Probability for fracture of Lava Ultimate onlays.

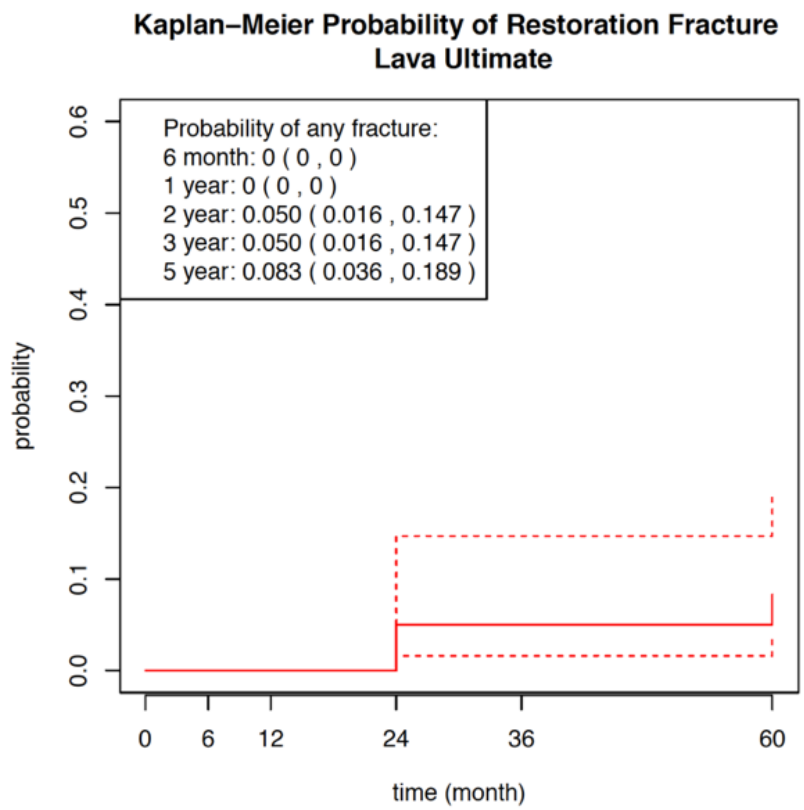


Table #6: The percentage of alpha and alpha-2 scores for margin adaptation over 5 years.

Material	Baseline		6 months		1 year		2 years		3 years		5 years	
	alpha	alpha-2	alpha	alpha-2	alpha	alpha-2	alpha	alpha-2	alpha	alpha-2	alpha	alpha-2
Lava Ultimate	100%	0%	61.7%	38.3%	49.2%	50.8%	30.4%	69.6%	22.8%	77.2%	23.2%	76.8%
Empress CAD	100%	0%	60.0%	40.0%	32.2%	67.8%	27.6%	72.4%	14.0%	86.0%	12.7%	87.3%

Figure Legends

Figure #1: Fractured leucite-reinforced onlay on the lingual cusp of #13 at 10 months.

Figure #2: Fractured leucite-reinforced onlay on the mesial marginal ridge of #14 at 34 months.

Figure #3: Fractured distal marginal ridge adjacent to nano-ceramic onlay #19 at 43 months.

Figure #4A, B: Nano-ceramic onlays on the first and second premolars at the 1 year and 3-year recall with the endodontic access in the onlay #4 restored with composite stable over time.

Figure #5A-D: Leucite-reinforced onlay tooth #30 with defect-oriented, adhesive preparation at 1 year, 3 years and 5 years of clinical service.

A: Preparation B: 1-year recall C: 3-year recall D: 5-year recall

Figure #6A-D: Nano-ceramic onlay tooth #30 with defect-oriented, adhesive preparation at 1 year, 3 years and 5 years of clinical service.

A: Preparation B: 1-year recall C: 3-year recall D: 5-year recall

Figure #7A-D: Leucite-reinforced onlay tooth #3 at 1 year, 3 years and 5 years of clinical service.

A: Preparation B: 1-year recall C: 3-year recall D: 5-year recall

Figure #8A-D: Nano-ceramic onlay tooth #5 at 1 year, 3 years and 5 years of clinical service.

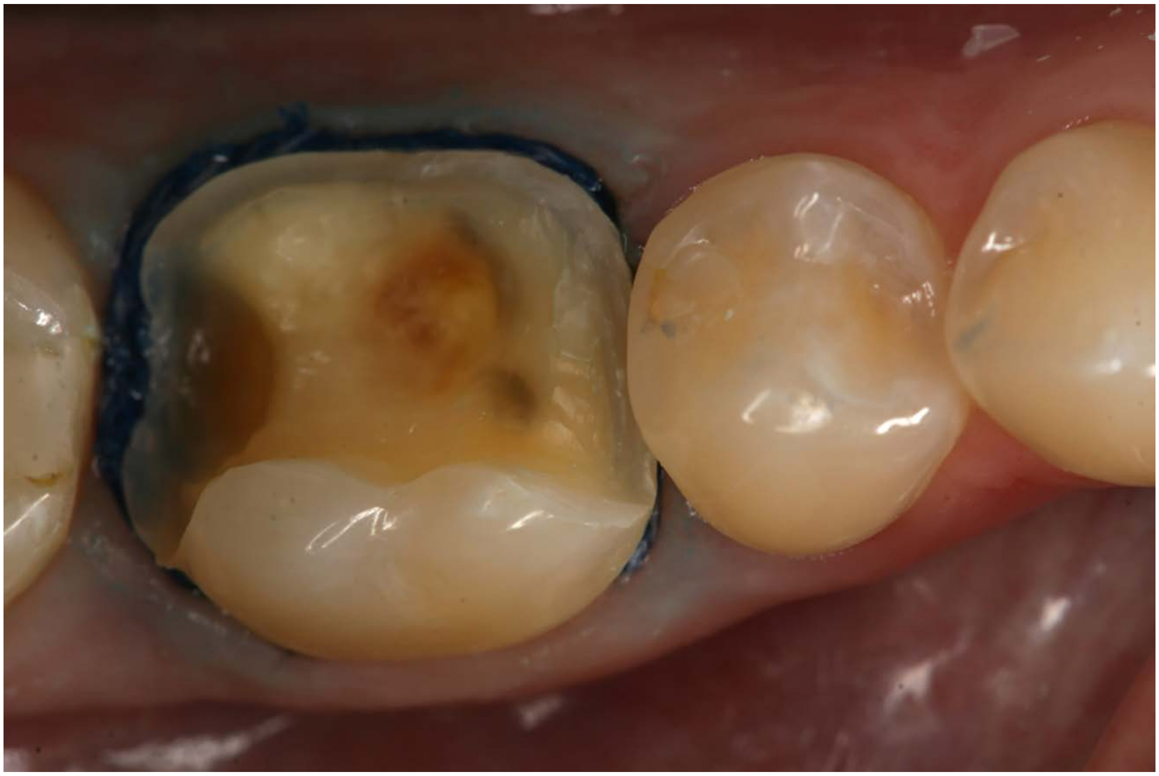
A: Preparation B: 1-year recall C: 3-year recall D: 5-year recall

Figure #9A-D: Nano-ceramic onlay tooth #14 at 1 year, 3 years and 5 years of clinical service. Note matte finish to onlay surface after desiccated with air.

A: Preparation B: 1-year recall C: 3-year recall D: 5-year recall

Figure #10A-D: Nano-ceramic onlay tooth #19 at 6 months, 3 years and 5 years of clinical service. Note wear facet development on the mid-facial cusp after 6 months.

A: Preparation B: 6 month recall C: 3-year recall D: 5-year recall



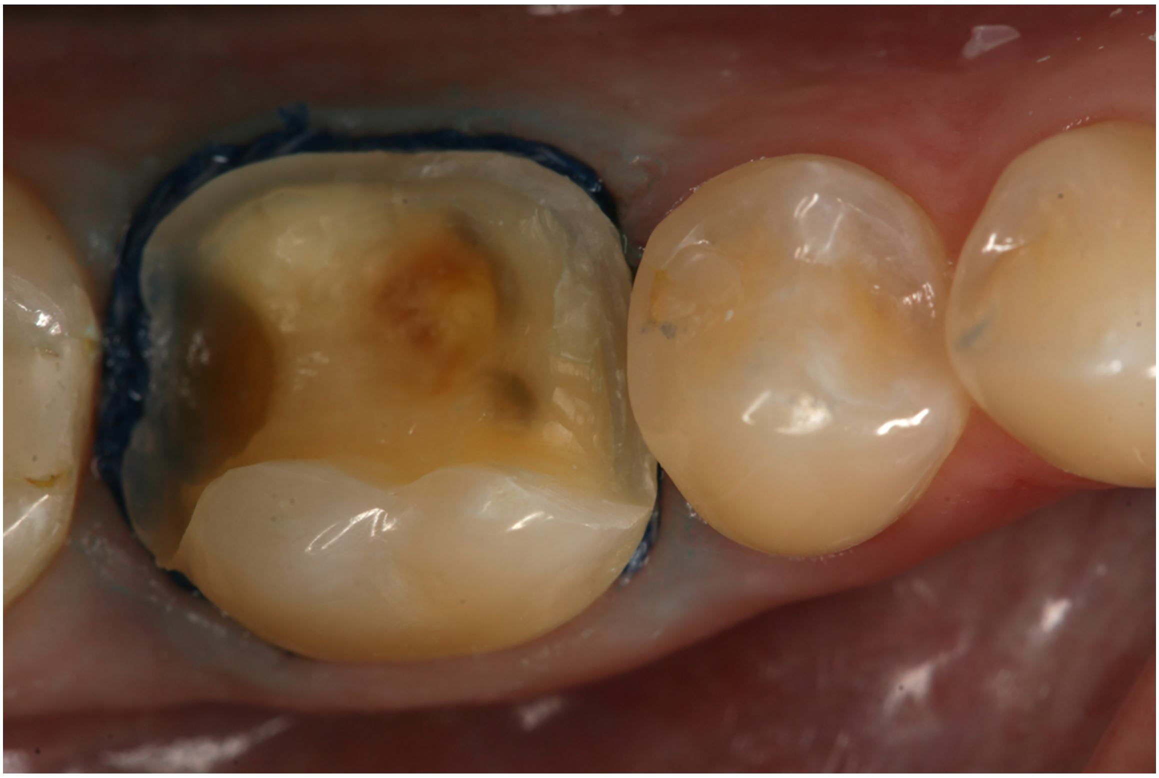
JERD_12516_Fig.1. Empress frac #13 10 mos.tif

JERD_12516_Fig.2 Empress frac #14 34 mos.tif

JERD_12516_Fig.3 LU frac #19 43 mos.tif

JERD_12516_Fig.4A LU RCT #4 comp 1 yr pot.tif

JERD_12516_Fig.4B LU RCT #4 comp 3 yrs pot.tif



JERD_12516_Fig.5A Empress #30 prep.tif

JERD_12516_Fig.5B Empress #30 1 yr pot.tif

JERD_12516_Fig.5C Empress #30 3yrs pot.tif

JERD_12516_Fig.5D Empress #30 5 yrs pot.tif

JERD_12516_Fig.6A LU #30 prep.tif

JERD_12516_Fig.6B LU #30 1 yr pot.tif

JERD_12516_Fig.6C LU #30 3 yrs pot.tif

JERD_12516_Fig.6D LU #30 5 yrs pot.tif

JERD_12516_Fig.7A Empress #3 prep.tif

JERD_12516_Fig.7B Empress #3 1 yr pot.tif

JERD_12516_Fig.7C Empress #3 3 yrs pot.tif

JERD_12516_Fig.7D Empress #3 5 yrs pot.tif

JERD_12516_Fig.8A LU prep.tif

JERD_12516_Fig.8B LU #5 1 yr pot.tif


JERD_12516_Fig.8C LU #5 3 yrs pot.tif

JERD_12516_Fig.8D LU #5 5 yrs pot.tif

JERD_12516_Fig.9A LU #14 prep.tif

JERD_12516_Fig.9B LU #14 1 yr pot.tif

JERD_12516_Fig.9C LU #14 3 yrs pot.tif

JERD_12516_Fig.9D LU #14 5 yrs pot.tif

JERD_12516_Fig.10A LU #19 prep.tif

JERD_12516_Fig.10B LU #19 6 mos pot.tif

JERD_12516_Fig.10C LU #19 3 yrs pot.tif

JERD_12516_Fig.10D LU #19 5 yrs pot.tif