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RESEARCH AND EDUCATION

Survival rate and load to failure of premolars restored with inlays: An evaluation of different inlay fabrication methods

Marília Pivetta Rippe, DDS, MSc, PhD,[a] Carlo Monaco, DDS, PhD,[b] Taiane Missau, DDS, MSc,[c] Vinícius Felipe Wandscher, DDS, MSc, PhD,[d] Lucia Volpe, DDS, MSc,[e] Roberto Scotti, MD, DDS,[f] Marco Antonio Bottino, DDS, PhD,[g] and Luiz Felipe Valandro, DDS, MSc, PhD[h]

ABSTRACT

Statement of problem. Studies that evaluate the survival rate and load to fracture of premolars restored with inlays produced using different methods are lacking.

Purpose. The purpose of this in vitro study was to compare the survival rate and fracture load of premolars restored with inlays fabricated using different methods.

Material and methods. Thirty maxillary premolars were selected, embedded, and prepared to receive inlays fabricated using different methods (n=10): LaCom-digital scanning with Lava C.O.S. scanner (3M ESPE), followed by milling of composite resin block (Lava Ultimate; 3M ESPE) in a milling unit; CeCom-digital scanning with Cerec 3D Bluecam scanner (Dentsply Sirona), followed by milling of a Lava Ultimate block in Cerec (Dentsply Sirona); PresDis-impression with polyvinyl siloxane, inlay made using the lost wax technique, and IPS e.max Press (Ivoclar Vivadent AG) pressed ceramic (lithium disilicate). A dual-polymerizing resin cement system was used to lute the inlays. Inlays were mechanically cycled (2 Hz, 10^6 mechanical pulses, 80 N) after 24 hours, and the specimens were stored in distilled water at 37°C for 11 months. Then, a fatigue test was conducted using a 10-Hz frequency and 400-N load on the inner inclines of the cusps. The test was complete when the specimen fractured or when the specimen reached 1.5×10^6 cycles. The specimens that survived fatigue testing were submitted to a single-load fracture test in a universal testing machine and analyzed using a stereoscope for failure classification. Survival rates were estimated using the Kaplan-Meier method and log-rank test (Mantel-Cox). Fracture load data were analyzed using 1-way ANOVA (α=.05).

Results. No significant differences were detected among the groups for the survival rate (*P*=.87) or for the load to fracture (*P*=.78). Most failures were longitudinal, catastrophic fractures.

Conclusions. Premolars restored with inlays fabricated using the tested methods had similar survival rates and loads to fracture. (J Prosthet Dent 2019;121:292-7)

The longevity of a dental restoration is affected by long-term esthetics, resistance to fracture, and marginal adaptation,[1] all of which depend on the type of impression, restorative material, and production method of the restoration. Both laboratory and chairside computer-aided design and computer-aided manufacturing (CAD-CAM) systems have become popular and have been evaluated for different variables, including accuracy of the intraoral digital scanning,[2-5] manipulative characteristics between digital and conventional methods,[6] and repeatability of digital and conventional impressions.[7] However, in vitro studies evaluating the survival rate after the cyclic loading and load to fracture of premolars restored using inlays produced using different methods are lacking.

The survival rate is an important outcome in determining the performance of inlay-restored premolars. The adhesive interface of these restorations may deteriorate if the cusps deflect during the intermittent cyclic loading from mastication.[8,9] Also, the restoration may undergo

[a]Adjunct Professor, Prosthodontics Unit, Faculty of Odontology, Federal University of Santa Maria (UFSM), Santa Maria, Brazil.
[b]Assistant Professor and Researcher, Department of Biomedical Sciences and Neuromotor, Division of Prosthodontics, Alma Mater Studiorum, University of Bologna, Bologna, Italy.
[c]Graduate student, Prosthodontics Unit, Faculty of Odontology, Federal University of Santa Maria (UFSM), Santa Maria, Brazil.
[d]Adjunct Professor, Prosthodontics Unit, Faculty of Odontology, Franciscan University Center, Santa Maria, Brazil.
[e]Master student, Department of Biomedical Sciences and Neuromotor, Division of Prosthodontics, Alma Mater Studiorum, University of Bologna, Bologna, Italy.
[f]Professor, Department of Biomedical Sciences and Neuromotor, Division of Prosthodontics, Alma Mater Studiorum, University of Bologna, Bologna, Italy.
[g]Professor, Dental Materials and Prosthodontics Unit, São Paulo State University (UNESP), São José dos Campos, Brazil.
[h]Associate Professor, Prosthodontics Unit, Faculty of Odontology, Federal University of Santa Maria (UFSM), Santa Maria, Brazil.

Clinical Implications

Premolars restored with composite resin inlays produced from a digital scan with computer-aided design and computer-aided manufacturing presented the same survival rates as teeth restored with lithium disilicate inlays produced from a conventional impression and the lost wax technique.

catastrophic fracture after the growth of microscopic cracks in stress-concentrated areas under repeated loading. The propagation of these cracks leads to catastrophic fracture, which occurs when the final mechanical load exceeds the capacity of the material or the restorative complex.[10]

Different materials are available for inlays, including lithium disilicate and feldspathic ceramics, composite resins, and interpenetrating network ceramic composite resins, which can then be milled with CAD-CAM systems. Indirect posterior composite resin restorations have ideal anatomic form, good marginal adaptation, appropriate proximal contact and contour,[11] and good wear properties,[12] and they produce acceptable restorations with minimal tooth reduction.[13] For instance, a manufacturer of one CAD-CAM composite resin (LAVA Ultimate; 3M ESPE) reports that the material is 80% (by weight) nanometer ceramic, silica, and zirconia nanoclusters.[14] This material can be milled with a chairside CAM system and does not require a furnace for crystallization.

The clinical outcome of inlay-restored premolars may be affected by the elastic modulus of restorative material as it influences the stress concentration at the bonded interface between the tooth and restoration.[15] Different inlay materials and cement thickness may also affect the dentin-restoration bond,[16] and the occlusal cement thickness has been shown to influence the failure loads of feldspathic ceramic crowns because of the polymerization shrinkage of the cement layer.[17]

Therefore, the purpose of this study was to compare the survival rates and loads to fracture of inlay-restored premolars produced by different methods. The null hypothesis was that the different inlay production methods would not affect survival rate or load to failure.

MATERIAL AND METHODS

This study was approved by the Ethical Committee of the Federal University of Santa Maria. Thirty human maxillary premolars without visible cracks or carious lesions and with similar buccal-lingual dimensions were selected for the study. Teeth were numbered and then randomly allocated to 3 groups (n=10) by using a computer program (www.randomizer.org) (Table 1).

Premolars were embedded between 2 molars in a polyvinyl siloxane matrix (Elite HD; Zhermack) filled with polyurethane resin (F16 Polyol; Axson Technologies) to simulate the proximal contact of the inlay with the adjacent teeth. The occlusal surface of each tooth was fixed to an adapted surveyor (B2; BioArt) with the crown perpendicular to the x-axis (ground) to position the teeth in the resin. The polyurethane resin was mixed and poured into the matrix up to 3 mm below the cement-enamel junction.

Standardized inlay cavities (Fig. 1) were prepared in the premolars by using a tapered diamond rotary instrument with rounded angles (#3131 bur; KG Sorensen). The rotary instruments were mounted on a high-speed handpiece (Extra Torque 605C; Kavo Dental GmbH) and fixed to a standardized preparation device according to the method of Rippe et al.[5] Preparations were made as parallel as possible to the long axis of the tooth with a convergence of 10 degrees and the following dimensions: buccal-lingual width of 3 mm; occlusal box depth of 3 mm; and rounded internal line angles (Fig. 1). Each diamond rotary instrument was used to prepare 5 teeth, and all preparations were finished with a fine-grit (25 μm) diamond rotary instrument with the same geometry (#3131FF bur; KG Sorensen). Impressions were made, and inlays were fabricated as shown in Table 1.

Inlays were seated on the prepared teeth, and the interproximal contacts were adjusted with the aid of 21-μm-thick occlusal marking tape (AccuFilm II; Parkell Inc). The resin inlays were adjusted and polished with a 25-μm-grit diamond rotary instrument (#3216 bur; KG Sorensen) at 6000 rpm and the lithium disilicate inlays with a 40-μm-grit diamond rotary instrument (#3216 bur; KG Sorensen) at 30 000 rpm.

Before cementation, the intaglio surfaces of the inlays were etched with 10% hydrofluoric acid (IPS Ceramic Etching; Ivoclar Vivadent AG) for 20 seconds, rinsed with water for 20 seconds, and air dried for 20 seconds. A silane coupling agent (Monobond S; Ivoclar Vivadent AG) was applied to the etched surface and left for 60 seconds. A self-etching primer (Multilink Primer A and Primer B; Ivoclar Vivadent AG) was applied to the prepared tooth, both enamel and dentin. The cement (Multilink automix; Ivoclar Vivadent AG) was mixed and applied to the intaglio surface, and the restoration was seated with a 7.5-N load for 60 seconds, using a standardized device (Peso Padrão; SPLabor Laboratory Equipment). Excess cement was removed, and the cement was photopolymerized (Radii-cal; SDI) for 20 seconds on each tooth surface.

After the specimens were cemented, they were stored in distilled water at 37°C for 24 hours and subjected to mechanical cycling (Erios ER-11000; Erios Equipment Ltd) for 10^6 cycles.[18] The specimens were placed in the metal base of the mechanical cycling

Table 1. Experimental design

Group	Model	Scan or impression Technique	Inlay Fabrication	Material	Main Composition	Modulus of Elasticity*
CeCom	Chairside	Bluecam intraoral dental scanner	Milling: Cerec MC XL	Composite resin (Lava Ultimate; 3M ESPE)	~80% weight nano-ceramic and ~20% resin weight	12.77 GPa
LaCom	Labside	Lava C.O.S intraoral dental scanner	Milling center	Composite resin (Lava Ultimate; 3M ESPE)	~80% weight nano-ceramic and ~20% resin weight	12.77 GPa
PresDis	Labside	Conventional impression one-step technique with polyvinyl siloxane	Lost wax technique with injected ceramic	Lithium disilicate (IPS e.max Press; Ivoclar Vivadent AG)	SiO_2 57-80; Li_2O 11-19; K_2O 0-1; 3 P_2O_5 0-11; ZrO_2 0-8; ZnO 0-8; Al_2O_3 0-5; MgO 0-5; Coloring oxides 0-8 (in% by weight)	95.5 GPa

*Information provided by manufacturers. CeCom, chairside CAD-CAM system; LaCom, laboratory CAD-CAM system; PresDis (control group), conventional fabrication.

machine in distilled water at 37°C, and an axial force of 80 N at a frequency of 2 Hz was applied with a 6-mm-diameter actuator (cylinder actuator with round edges milled from stainless steel) to the occlusal surface of the restored premolars.

After mechanical cycling, the specimens were stored in distilled water at 37°C for 11 months and fatigue tested in an electrodynamic testing machine (ElectroPuls E3000; Instron). The specimens were placed on a metal platform attached to the machine, and an axial load of 400 N was applied to the cusps of the restored premolars at a frequency of 10 Hz in water at room temperature by using a 6-mm-diameter piston. Occlusal marking film (AccuFilm II; Parkell Inc) was used to ensure that the piston did not contact the inlay. The fatigue tests were considered complete when the specimen fractured and the number of cycles was recorded or when the specimen reached 1.5×10^6 cycles. Specimens that survived fatigue testing were subjected to a monotonic test.

For the monotonic test, each specimen was positioned on the same device, and a load was applied along the long axis of the tooth, taking care that the piston did not touch the restoration. A universal testing machine (DL-1000; Emic) and the same point that was used for fatigue testing was used to apply a constant load at a crosshead speed of 1 mm/min until failure occurred.

Fracture analysis was performed after fatigue and monotonic testing, using stereomicroscopy (Stereo-Discovery V20; Carl Zeiss Meditec Co) at ×10 magnification and classified as Mode I, indicating small fractures in the tooth or inlay; Mode II including one or more fractures of the cusp above the cement-enamel junction; or Mode III, showing longitudinal fracture damaging the tooth integrity. Modes I and II were considered reparable failures, and Mode III was considered a catastrophic failure.

Data analysis for survival rates was estimated using the Kaplan-Meier method. Differences among survival rates based on the study groups were analyzed using the log-rank (Mantel-Cox) test (α=.05). For the monotonic fracture load data, the Shapiro-Wilk test showed a normal distribution, and the Levene test demonstrated data homogeneity. One-way ANOVA (α=.05) was consequently used to analyze the monotonic fracture load data.

Table 2. Mean ±standard deviation cycles for failure of fatigue test and mean ±standard deviation load for failure (N) after monotonic test

Group	No. of cycles for failure	No. of specimens which survived fatigue test	Load to fracture
CeCom	1 500 000 $\pm0^A$	8	1581.1 $\pm541.4^a$
LaCom	1 389 204 $\pm94\,430^A$	8	1519.6 $\pm398.9^a$
PresDis	1 384 055 $\pm109\,313^A$	8	1687.3 $\pm423.6^a$

Similar uppercase superscript letters indicate no statistical differences between number of cycles for failure according to log rank. Similar lowercase superscript letters indicate no statistical differences between load for failure after monotonic test according to 1-way ANOVA. CeCom, chairside CAD-CAM system; LaCom, laboratory CAD-CAM system; PresDis (control group), conventional fabrication.

RESULTS

One specimen from the PresDis group failed during the mechanical cycling, with small fractures in the tooth. Therefore, this specimen was not counted in the statistical analysis of this group.

For the number of cycles to fracture, log-rank (Mantel-Cox) revealed no significant differences among the tested groups (P=.877) (Table 2). Survival rates for the experimental groups were 0.8 for LaCom and CeCom groups, meaning that the probability of the premolars from these groups to exceed 1.5 million cycles without showing failure (event/primary outcome) was 80%; 0.88 for PresDis, so the probability of the premolars of this group to exceed 1.5 million cycles without failure was 88%. Five specimens fractured before or at 1.5 million cycles: 2 failures occurred in the LaCom group (498 428 and 1 393 614 cycles), 2 failed in the CeCom group (both at 1 500 000 cycles), and 1 failed in the PresDis group (456 503 cycles). Considering the failure analysis from this test (survival test), most were Mode III failures (Table 3, Fig. 2).

For the monotonic testing, 1-way ANOVA showed no statistically significant differences among the groups (P=.78) (Table 2). Most of the failures were Mode III (Table 3, Fig. 2). The results of the fracture analysis from Table 3 were only valid after the survival test.

DISCUSSION

Survival rates of the digital intraoral scanning and CAD-CAM systems were similar to those of the conventional impression and press ceramic techniques, regardless of

Table 3. Number of failure modes for specimens

Group	Mode I	Mode II	Mode III	Total Failures
During Fatigue Test				
CeCom	0	0	2	2
LaCom	1	0	1	2
PresDis	0	0	1	1
Total	1	0	4	5
During Monotonic Test				
CeCom	1	2	5	8
LaCom	1	2	5	8
PresDis	1	0	7	8
Total	3	4	17	24

Mode I, small fractures in tooth or inlay; Mode II, 1 or more fractured cusps above cement enamel junction; Mode III, longitudinal fracture damage to tooth integrity. CeCom, chairside CAD-CAM system; LaCom, laboratory CAD-CAM system; PresDis (control group), conventional fabrication.

Figure 1. Experimental tooth arrangement.

the type of scanner, inlay production method (chairside or laboratory), or material; thus, the null hypothesis was accepted. The 2 scanners had different working principles and different light sources. The BlueCam scanner works on the principle of strip light projection combined with active triangulation through short-wavelength blue light (BlueCam Scanner; Sirona Scientific Documentation 2015). The Lava C.O.S. scanner is based on the principle of active (optical) wavefront sampling, which obtains 3D information from a single-lens imaging system by measuring depth based on the defocus of the primary optical system (Lava Chairside Oral Scanner C.O.S.; 3M ESPE technical datasheet 2009). Ender and Mehl[4] reported that the precision of impressions digital scans (CEREC Bluecam and Lava C.O.S.) was similar to that of conventional impressions when a powder coat spray was applied before both Lava C.O.S. and CEREC scanning, as in the present study.

However, Neves et al,[2] evaluating marginal adaptation of lithium disilicate crowns manufactured from different CAD-CAM systems of either microcomputed

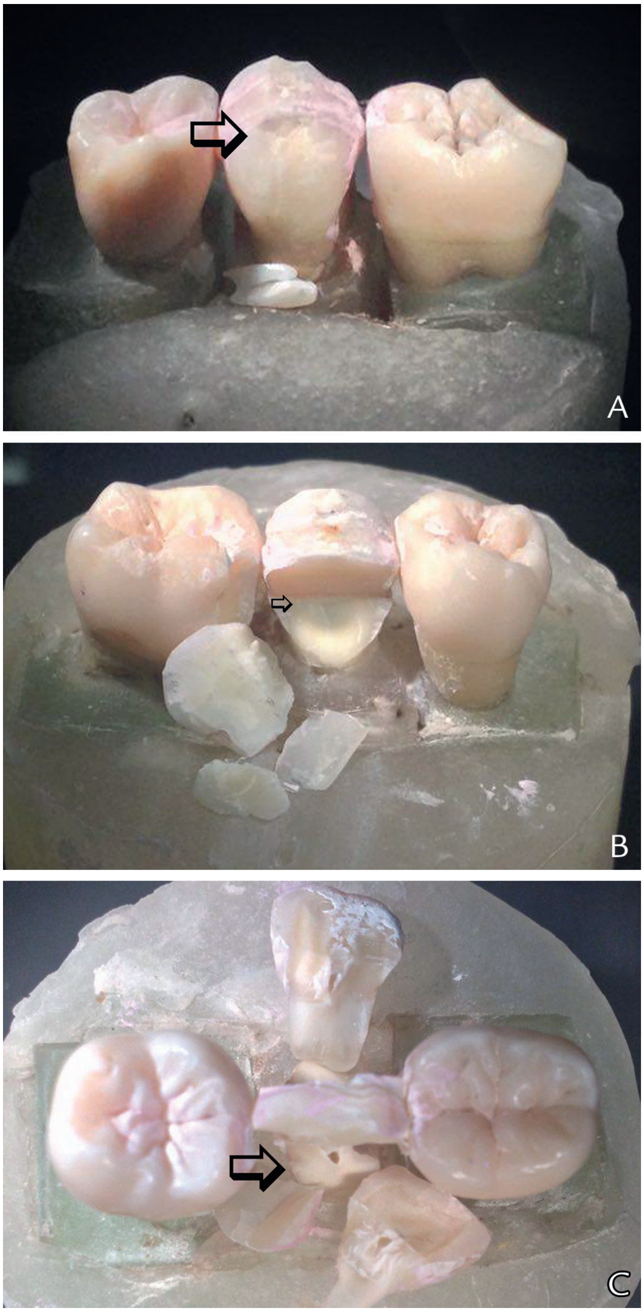

Figure 2. Representative images of failures occurring during fatigue test and after single-load fracture test. A, Mode I, small fractures in tooth or inlay. B, Mode II, 1 or more fractured cusps above cement enamel junction. C, Mode III, longitudinal fracture damage to tooth integrity.

(CEREC or E4D) or ceramic pressed technique, reported that crowns manufactured from lithium disilicate using the CAD-CAM Cerec Bluecam 3D scanner system or injection technique had significantly lower marginal leakage than crowns manufactured using a laser scanner system/CAM E4D CAD. Rippe et al[5] found no statistical differences for marginal misfit for similar comparisons of the current research; however, the Lava C.O.S. presented worse internal fit at the axial wall than the CEREC system with composite resin, even though these 2 groups were similar to pressed ceramic. Additionally, there were no differences among the different inlay production methods when the pulpal wall was considered. They reported that comparable cement film thicknesses were used for each group, except for the axial wall in LaCom and CeCom; however, in the current study, this difference in thickness did not influence the survival rate. Furthermore, despite differences regarding the type of impression, scan, and production methods leading to restorations with different marginal accuracy, according to present study, these outcomes seem to have no effect on the survival rate of the inlays, regardless of the material (composite resin or lithium disilicate).

The mechanical behavior of inlay-restored premolars may be affected by the elastic moduli of the material because an inlay with a lower elastic modulus would lead to lower stress concentrations at the bonded interface.[15] Furthermore, the different inlay materials may also affect dentin-restoration bonding.[16] However, according to Zamboni et al,[9] adhesively bonded restorations decrease cuspal deflection during mechanical cycling and appear to increase cuspal reinforcement, regardless of the material type.

In the current study, an indirect resin was used for inlay fabrication, which is more practical than a ceramic, as it does not need a sintering furnace after milling. Furthermore, these composite resin blocks are industrially manufactured and postpolymerized, which can improve the mechanical properties.[11] Additionally, the CAD-CAM composite resin blocks have good wear properties,[12] are less fragile than porcelain, and can be used in thinner preparations, allowing for conservative preparation designs and more resistant restorations.[13] In the laboratory-fabricated group, pressing was used to make the lithium disilicate inlays, because this system is generally more popular in commercial dental laboratories.

The present study used a laboratory test that attempted to simulate the clinical situation through accelerated fatigue, considered a better predictor of clinical performance than a simple load-to-failure test.[18] Kujis et al[18] reported that specimens failed only after more than 1 000 000 cycles under moderate loading, an assumption supported by the present study. Most specimens that resisted the fatigue test fractured at a high load (Table 3).

Limitations of this study include the limited number of specimens and limited number of inlay systems tested; consequently, results should be interpreted with caution. Another limitation was that the test equipment did not stop at the exact moment that the specimen failed in the CeCom group, as the machine recorded 1.5×10^6 cycles in the 2 specimens that failed in the survival test. However, the failures probably occurred close to 1.5×10^6 cycles. Nevertheless, this discrepancy does not influence the survival rate of this group, as only failure or survival is considered in the Kaplan-Meier test. Because the present study was carried out in vitro, clinically important differences among the groups would only be known through in vivo studies.

Further studies should be carried out to compare other types of materials indicated for inlay production and include clinical trials. Also, other types of scanners with or without powder should be evaluated and whether these different inlay production methods influence bond strength should be assessed.

CONCLUSIONS

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

1. Premolars restored with inlays fabricated by the evaluated methods did not present statistically significant differences in survival rates and loads to failure.
2. The tested scanning methods had no influence on the outcomes.
3. Intraoral scanning methods behaved similarly to the conventional production method.

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Corresponding author:
Marília Pivetta Rippe
Prosthetic Dentistry Unit, Federal University of Santa Maria
Floriano Peixoto, 1184
Santa Maria, RS, 97015-372
BRAZIL
Email: mariliarippe@mail.ufsm.br

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