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ORIGINAL ARTICLE

Effect of thickness and CAD-CAM material on fatigue resistance of endodontically treated molars restored with occlusal veneers

Mayara dos Santos Noronha DDS, MSC, PhD[1] | **Marco Aurélio de Carvalho DDS, MSC, PhD**[2] | **Anh Quynh Do DDS**[3] | **Vitaliano Gomes de Araújo Neto DDS, MSC, PhD Student**[1] | **Camila Heitor Campos DDS, MSC, PhD**[4] | **Marcelo Giannini DDS, MSC, PhD**[1] | **Pascal Magne DDS, MSC, PhD**[5]

[1]Department of Restorative Dentistry, Piracicaba Dental School, University of Campinas, São Paulo, Brazil

[2]Department of Oral Rehabilitation, School of Dentistry, University of Anápolis, Anápolis, Brazil

[3]Advanced Endodontics, Herman Ostrow School of Dentistry, University of Southern California, Los Angeles, CA

[4]Department of Oral Rehabilitation, School of Dentistry, Federal Fluminense University, Nova Friburgo, Brazil

[5]Division of Restorative Sciences, Herman Ostrow School of Dentistry, University of Southern California, Los Angeles, CA

Correspondence
Mayara dos Santos Noronha, DDS, MSC, PhD, Department of Restorative Dentistry, Piracicaba Dental School University Campinas, Av. Limeira, 901, Piracicaba, Sao Paulo 13414-903, Brazil.
Email: mysnoronha@gmail.com

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Abstract

Purpose: To evaluate the influence of the thickness and type of computer-aided design and computer-aided manufacturing (CAD-CAM) material on the fatigue resistance and failure mode of endodontically treated teeth (ETT) restored with occlusal veneers (OV).

Materials and methods: Seventy-five (N = 75) ETT were restored with Herculite XRV in the endodontic access. Five experimental groups (n = 15) were tested. Four groups had two different thicknesses (0.6-0.7 mm or 1.4-1.6 mm) and two different CAD-CAM materials: zirconia-reinforced lithium-silicate (LS/Celtra Duo) and composite resin (RC/Cerasmart). The fifth group (control) did not have occlusal veneers. All the specimens were subjected to accelerated fatigue (5 Hz frequency) with an occlusal load increasing up to 1800 N and 131,000 cycles. The number of cycles was recorded when the machine stopped or at the completion of the test. Fatigue resistance was analyzed using the Kaplan-Meier survival test (95% significance level, log-rank post hoc pairwise comparisons). The samples were categorized according to failure mode. The CAD-CAM materials were examined through scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS).

Results: No differences were found between the thicknesses, regardless of the type of the CAD-CAM material. The thick LS OV outperformed the RC and control groups. The thin RC OV and control groups showed a higher percentage of repairable and possibly repairable failures than the other groups. LS was more homogeneous under SEM, and the EDS analysis detected Si and Zr, but not Li.

Conclusions: A larger thickness did not improve the resistance of the CAD-CAM materials. Thick LS showed a higher cumulative survival rate to fatigue than the RC and control groups. The direct composite alone (control) survived similarly to the experimental groups, except for the thick LS.

KEYWORDS
CAD-CAM, occlusal veneers, fatigue resistance, ceramics, composite resins

Once a tooth is endodontically treated, its mechanical properties are compromised[1] and significantly decreased, as compared to vital teeth.[2,3] The physical changes of the non-vital tooth occur mainly due to all the procedures involved in endodontic treatment,[4] leading to volumetric loss of dental structure,[2,5–8] which compromises the mechanical, chemical, and physical properties of the endodontically treated teeth (ETT).[1] Preparation depth, isthmus width, and cavity configuration are highly critical factors that could decrease tooth stiffness and increase the risk of fracture[9] owing to the loss of reinforcing structures.[5] Consequently, the conservation of its structure and preservation of the biomechanical integrity of the restored tooth,[10,11] which reduces the risk of failures and enhances the longevity of the tooth, are crucial when dealing with nonvital teeth.[12,13]

Minimally invasive preparations and partial restorations can be a good alternative to restore ETT[12,14] instead of full crowns.[13] Strategies such as keeping margins in enamel,[15] supporting tooth structure, preserving the marginal ridge,[16] using appropriate core build-up procedures,[17] and adequate marginal sealing and adhesion[18,19] can improve the strength of ETT. Among the partial coverage preparations, nonretentive overlays or occlusal veneers can cover dental cusps, increase the resistance of larger restorations, and reduce the risk of tooth fractures. Additionally, they are effective in occlusal wear protection[20,21] and increase the mechanical resistance of the teeth.[22–25]

The clinician's choice for an effective oral rehabilitation includes various semi-direct and indirect prosthetic options. Modern adhesive approaches include ceramics and composite resin[9,10,26] that are processed by computer-aided design and computer-aided manufacturing (CAD-CAM) restorations.[27–29] They comprise glass-, resin-matrix-, and oxides-ceramics.[30] Currently, zirconia-reinforced lithium silicate glass-ceramic (LS, Celtra Duo, Dentsply Sirona, Hanau, Germany) and resin-based composite (RC, Cerasmart, GC Corporation, Tokyo, Japan) are the two types of CAD-CAM materials widely used owing to their esthetic and mechanical properties as well as their easy processing, milling, and quick polishing without sinterization.[31,32]

When choosing a minimally invasive approach, such as full mouth rehabilitation of bio-corroded dentitions, with partial adhesive indirect restorations,[33] all the aforementioned material's advantages are challenged by the limited restoration thickness.[29,34,35] Thin occlusal veneers could present reduced occlusal loading resistance, and the selection of the material, as well as type of preparation, may significantly affect their performance.[36] In vitro testing, such as accelerated fatigue, has been widely used to simulate stress mechanisms[37,38] and predict clinical performance.

Scientific studies evaluating the fatigue resistance of occlusal veneers using different CAD-CAM materials with different thicknesses are lacking, and there is no consensus on the best restorative material for posterior ETT. Thicknesses lower than those recommended by manufacturers are often required clinically, but they have not yet been studied. This study aims to compare two types of material (lithium silicate and resin-based composite CAD-CAM blocks) in thin (0.6-0.7 mm) and thick (1.4-1.6 mm) posterior occlusal veneers (overlays) to a direct composite resin, and evaluate their influence on the biomechanical behavior of the ETT. The null hypotheses were that (1) the two occlusal veneer CAD-CAM restorative materials and (2) the two different thicknesses could not influence the accelerated fatigue resistance of ETT when compared to a direct composite resin without cuspal coverage.

MATERIAL AND METHODS

This study was approved by two ethics committees, Piracicaba Dental School - University of Campinas (number: 2.177.28) and Herman Ostrow School of Dentistry (number: HS-20-00051). Seventy-five sound upper human molars were kept in a saturated thymol crystal solution (Tymol Crystal, Merck KGaA, Darmstadt, Germany) before being selected for the study.

Endodontic treatment and access restoration

Seventy-five noncarious and intact extracted molars were endodontically treated. The access cavity was prepared using high-speed diamond burs under irrigation with a saline solution. Each tooth was scouted with # 10 and # 15 K-files (Dentsply Sirona, Hanau, Germany) to create a glidepath. The working length (1 mm from the visual apex) was measured after inserting a size 15 K-file into the canal. The canals were prepared with three sizes larger than the file to bind. Each canal was chemically prepared and debrided using rotary files (Vortex Blue 0.06 rotary; Dentsply Sirona), sodium hypochlorite (5.25%), and 17% EDTA. The canals were then dried using paper points. Canal obturation was completed with a warm vertical technique using a gutta-percha and Therma Seal Sealer (Dentsply Sirona), and the teeth were stored.

After the obturation of the root canal, a 1-mm-thick glass ionomer barrier (GI) (Fuji Triage, GC Corporation, Tokyo, Japan) was used to cover the gutta-percha. The endodontic access was then reprepared with a cylindrical diamond bur (1012HL KG Sorensen) to remove the GI excesses and standardize the cavity shape, and then washed and gently air-dried. Enamel and dentin were etched with 37% phosphoric acid (Ultra-Etch, Ultradent Products Inc., South Jordan, UT for 30 and 15 seconds, respectively, washed vigorously for 30 seconds, cautiously air-dried before primer application with a brush for 15 seconds, followed by air-drying for 5 seconds, and adhesive resin application (OptiBond FL; Kerr Corp., Orange, CA). All materials and adhesives were applied in accordance with the manufacturer's instructions. The adhesive resin was light-activated for 20 seconds (Valo Ultradent, 1000 mW/cm2) and the access was filled with composite resin (Herculite XRV, Enamel Shade A2, Kerr Corp.) in increments of 2 mm. Each increment was light-activated for 20 seconds and the last increment was covered with an air-blocking gel (KY Jelly; Johnson & Johnson Inc., New Brunswick, NJ) before an additional 10 seconds of light activation. All restorations were polished (Jiffy Composite Polishing Brush; Ultradent Products Inc.) and stored in water for 24 hours prior to preparation.

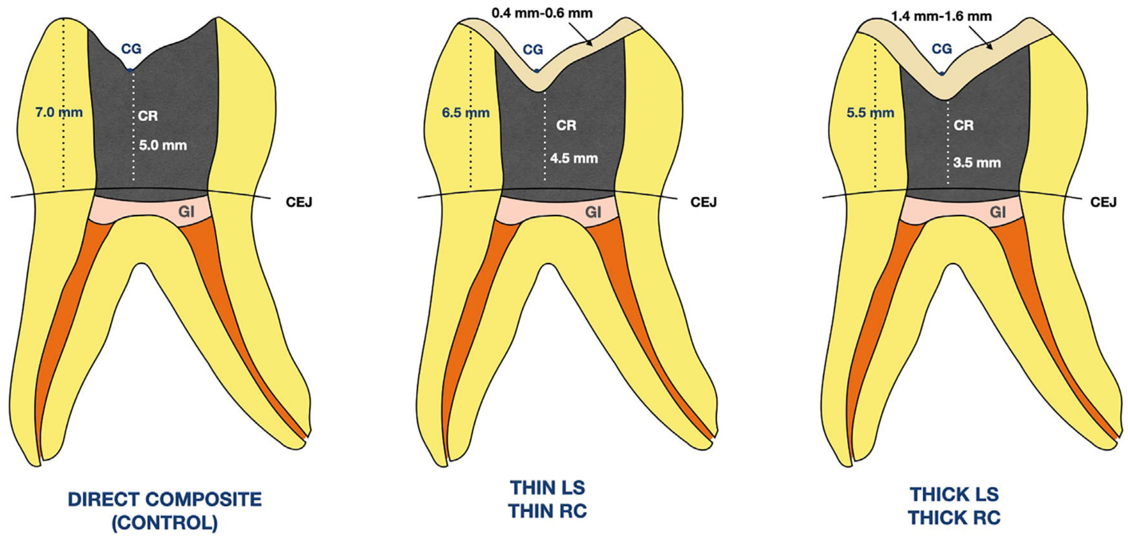

FIGURE 1 Experimental groups according to the type of preparation and restoration (n = 15). CG, Central Groove; CR, Composite Resin (Herculite, XVR); CEJ, Cementoenamel junction; and GI, Glass Ionomer cement. G1 – Thick LS; G2 – Thin LS; G3 – Thick RC; G4 – Thin RC; and G5 – Control (direct composite resin restoration without cuspal coverage). LS, lithium silicate and RC, resin-based composite.

Specimen preparation

An acrylic resin (Palapress; Kulzer GmbH, Hanau, Germany) was used to obtain a holding base for the fatigue test, with teeth roots embedded 3 mm beneath the cement enamel junction (CEJ). The teeth were randomly divided into 5 groups (n = 15). The control samples were not additionally prepared for occlusal veneer, but they were kept with direct composite resin restoration only. The remaining four experimental groups consisted of standardized occlusal veneer preparations with two different thicknesses: a 0.6 to 0.7 mm (thin) reduction and 1.5 to 1.6 mm (thick) reduction, using round end diamond burs with rounded end of 0.6- or 1.5-mm diameter (3195 and 3195FF, for thin group; 3139 and 3139F for the thick groups, KG Sorensen, Cotia, SP, Brazil). The preparation was polished with fine grain diamond burs and a polishing instrument (W16Dg, W16Dmf, and W16D, EVE Ceram Diapol, Germany). Standardized heights from the CEJ to the cusp tips (7.0, 5.5, and 6.5 mm) and to the central groove (5.0, 4.5, and 3.5 mm) were set for the control, thick, and thin groups, respectively (Fig 1).

Immediately after tooth preparation, immediate dentin sealing was applied, and fresh dentin was etched for 15 seconds, washed, and gently dried. The primer (Optibond, FL) was applied with a slight brushing motion, followed by gentle removal of the excesses for 5 seconds with air. The adhesive was applied and left unpolymerized for approximately 10 seconds prior to photoactivation for 20 seconds. A glycerin gel was applied to air-block the superficial layer, and additional light-activation for 10 seconds was conducted. The adhesive and restorative materials used in this study are listed in Table 1.

Design and milling of CAD-CAM occlusal veneers

Specimens were restored using a Cerec 3 CAD-CAM system (Sirona Dental Systems GmbH, Bendheim, Germany). The preparations were powdered and scanned, and the minimal thickness was adjusted according to each group (thin or thick). The upper third molar, individual biogeneric, and "Onlay mode" were selected. Design tools (Cerec v3.6, Sirona Dental Systems) were used to align cusp tips, and the preparation was checked and adjusted when necessary, to be parallel to the occlusal surface. The software proposal was checked for precise thickness using measurement tools and again after the milling process with a caliper. Sixty CAD-CAM blocks of two different types of materials (Table 1) were milled (n = 15): LS, zirconia-reinforced lithium silicate glass-ceramic (Celtra Duo, Dentsply Sirona) and RC, a resin-based composite (Cerasmart, GC Corporation, Tokyo, Japan). All occlusal veneers were inspected for possible defects and polished according to the manufacturer's recommendations. The fit of each restoration was confirmed.

Adhesive luting of the occlusal veneers

The intaglio surface treatment of the restorations was performed according to the manufacturer's instructions for each type of material. For the LS groups, the occlusal veneers were etched with hydrofluoric acid (10%, Ultradent Products Inc.) for 30 seconds, rinsed for 20 seconds, ultrasonically cleaned for 1 minute, and dried for 5 seconds. For the RC group, air-abrasion with aluminum oxide particles was performed (50 μm for 10 seconds at 0.2 MPa), washed for 20 seconds

TABLE 1 Adhesive and restorative materials used in this study, their composition, and batch number

Materials	Composition	# Batch number
Primer Optibond FL	10-30%: 2-hydroxyethyl methacrylate, Ethanol, 2-[2-(methacryloyloxy) ethoxycarbonylM] benzoic acid. 5–10% Glycerol phosphate dimethacrylate	35266
Adhesive Optibond FL	30-60%: Glass, oxide, chemicals; 10–30%:2-hydroxyethyl methacrylate, Ytterbium trifluoride; 5–10%: 3-trimethoxysilylpropyl methacrylate, 2-hydroxy-1,3-propanediyl bismethacrylate; 1–5%: Alkali fluorosilicates (Na)	35266
Silane	>50 ≤100%: Isopropyl Alcohol; >2.5 ≤100%: Silane	D07Q8
Herculite XRV	5-10%: 7,7,9(or 7,9,9)-trimethyl-4,13-dioxo-3,14-dioxa-5,12-diazahexadecane-1,16-diyl bismethacrylate; Poly(oxy-1,2-ethanediyl), α, α'-[(1-methylethylidene) di-4,1-phenylene]bis[ω-[(2-methyl-1-oxo-2-propen-1-yl)oxy]-; 1,6-hexanediyl bismethacrylate; 2,2'-ethylenedioxydiethyl dimethacrylate; Hexamethylene diacrylate; 3-trimethoxysilylpropyl methacrylate	6709675
Celtra Duo	Lithium Silicate Glass-Ceramic with 10% of Zirconium Oxide	18027273
Cerasmart	Nano Ceramic Filler, Bis-MEPP, UDMA, DMA	1603091

*According to manufacturer supplied data.

followed by ultrasonic cleaning for 1 minute, and air-drying for 5 s. For both materials, a silane coupling agent (Silane, Ultradent Products Inc.) was applied for 1 minute, gently air-dried for 5 seconds, and heat-dried at 100°C for 1 minute in a photothermic oven (DI500 oven; Coltene AG, Alstätten, Switzerland). Finally, Optibond FL adhesive was applied to the intaglio surface of the occlusal veneers, but it was not light-activated.

Tooth preparations were cleaned with water and pumice prior to air-abrasion and etching with phosphoric acid for 30 seconds, rinsing, drying, and wetting with Optibond FL adhesive resin, but not polymerized. A composite resin (Herculite XRV, Enamel A2 Kerr) was preheated at 68°C inside the Calset warmer (AdDent, Danbury, CT) and applied to the intaglio surface of the restoration to provide better seating.[20]

The correct restoration position was secured while the composite resin excess was carefully removed before light activation for 20 seconds at each surface (60 seconds). The margins were covered with an air-blocking barrier and light-activated for an additional 10 seconds per surface. All margins were controlled, and the surfaces were polished with diamond-impregnated ceramic polishers (Jiffy Composite Polishing Brush; Ultradent Products Inc.) and silicon-carbide-impregnated bristle brushes (Jiffy Composite Polishing Brush; Ultradent Products Inc.). All procedures were conducted using an optical microscope (Leica MZ 125; Leica Microsystems GmbH, Wetzlar, Germany) at 10× magnification for the preparation, control of occlusal veneer adaptation, crack detection, and polishing. The specimens were stored in distilled water at room temperature for at least 24 hours before the mechanical test.[18,19,33] The fatigue resistance of the following experimental groups was tested according to two thicknesses (thin: 0.4-0.6 mm and thick:1.4-1.6 mm, Fig 1), two types of CAD-CAM materials, and the direct composite restoration:

1. Thick zirconia reinforced lithium silicate glass-ceramic (Thick LS)
2. Thin zirconia reinforced lithium silicate glass-ceramic (Thin LS)
3. Thick resin-based composite (Thick RC).
4. Thin resin-based composite (Thin RC).
5. Direct composite resin without cuspal coverage (Control)

Mechanical testing

A fatigue-testing electromechanical system (Acumen 3, MTS Systems, Eden Prairie, MN) was used to mimic the masticatory forces. The teeth were positioned in a metal-mounting device and completely immersed in distilled water. Tuning procedures were conducted to determine the optimal movements and accuracy of the fatigue test.

Composite resin spheres (7 mm-diameter) were fabricated using composite resin (Filtek Z100, 3M Oral Care, St. Paul, MN) in a silicon mold and light-activated for 20 seconds on each side (40 seconds) and additional thermo-activation in a photothermic DI500 oven for 7 minutes. The resin sphere was resin bonded to the loading actuator. Tripodic contact was adjusted and set for all specimens (mesial-buccal, distal-buccal, and palatal cusps) and confirmed with occlusal paper markings to obtain an identical loading configuration for all teeth. [18,19,33]

Pilot studies were conducted to determine the fatigue-test profile. The profile consists of 12 progressive steps at a frequency of 5 Hz. The initial load (warm-up) was set at 200 N for 5000 cycles (step 1) to allow the progressive settling of the specimen and avoid stress concentrations at the beginning of the test. Subsequently, a 200 N load increase was applied for the next five steps (9000 cycles each) and a 100 N load increase was applied for the remaining steps: step 6 to 7 (9000 cycles), steps 8 to 10 (14,000 cycles), and step 11 to 12 (15,000 cycles), until 1800 N (total 131,000 cycles), or until any fracture occurred. Once the test ended, the number of endured cycles was compiled for the analysis (Table 2).

TABLE 2 Accelerate fatigue test profile according to steps, number of cycles (NC), and Load (in Newtons)

Steps	1	2	3	4	5	6	7	8	9	10	11	12
NC	5000	9000	9000	9000	9000	9000	9000	14000	14000	14000	15000	15000
Load (N)	200	400	600	800	1000	1200	1300	1400	1500	1600	1700	1800
I*	1	5001	14001	23001	32002	41001	50001	59001	73001	87001	101011	116010
F**	5000	14000	23000	32000	41000	50000	59000	73000	87000	101000	116009	131001

NC: number of cycles per step.
*I: Initial number of cycles.
**F: Final number of cycles.

Microscope evaluation

All the restored teeth were inspected after the accelerated fatigue test using transillumination (Microlux; Ad Dent, Inc.) at 10× magnification under an optical microscope (Leica MZ 125; Leica Microsystems GmbH; Wetzlar, Germany). The failure mode of each tooth was evaluated visually, photographed (Camera CANON SLR3, Tokyo, Japan), and categorized by calibrated examiners as follows: (1) repairable tooth fracture (cohesive chipping within the material or adhesive failure with fragment, but no loss or damage of underlying tooth structure), (2) possibly repairable (adhesive failure with fragment like chip or crack and minor damage of underlying tooth structure); (3) catastrophic, unrecoverable fracture that involves tooth/root fracture (below CEJ) and requires tooth extraction; and (4) survived with cracks, those that lasted until the end of the fatigue test, even with cracks and wear on the occlusal surface (Fig 2). Failure analysis was performed using representative specimens that were coated with gold and observed through scanning electron microscopy (SEM) (JSM IT 300, Jeol; Tokyo, Japan). Micrographs were obtained to observe the indirect material microstructures at 5000× magnification. For chemical composition determination, samples were fixed on a metal stub and sputter-coated using carbon (MED 010; Balzers Union; Balzers, Liechtenstein) before energy-dispersive X-ray spectrometry (EDS) using an X-ray detector (X-Act, Oxford Instruments, Abingdon, UK) coupled to an SEM equipment. Analyses were performed for 60 seconds (voltage 20.0 kV, dead time 20%-30%).

Statistical analysis

A Shapiro-Wilk's test ($p > 0.05$) was used to verify the normal data distribution. Fatigue resistance of all groups was analyzed using the Kaplan-Meier survival test for endured number of cycles followed by post hoc log-rank test (Mantel-Cox) for pairwise comparison. A life table analysis was performed to compare the fracture load step at which the specimen failed, followed by the Wilcoxon test. Statistical software was used for all statistical analyses (SPSS 22.0, SPSS Inc.), with a significance level set at 95%.

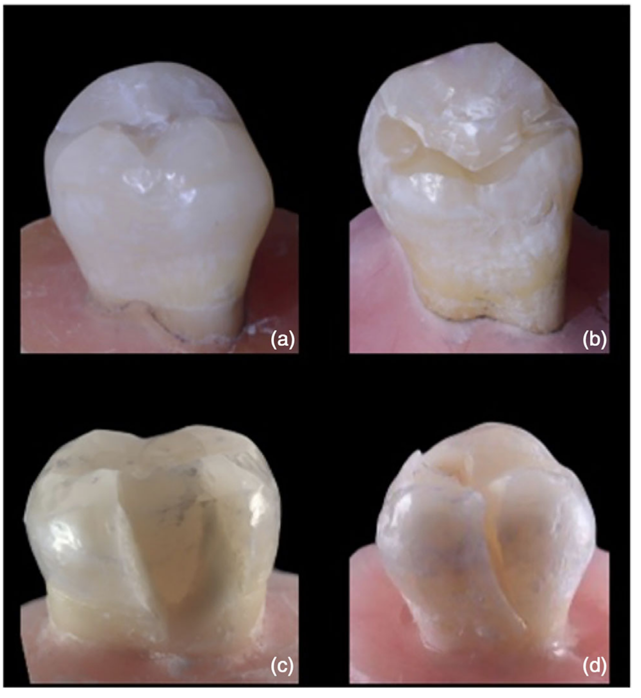

FIGURE 2 Representative failure images of tested groups. (a) Survived with cracks (Thick LS); (b) repairable failure (Thin LS); (c) possibly repairable failure (Thick RC); and (d) catastrophic failure (Thin RC). CEJ, cementoenamel junction; LS, lithium silicate; RC, resin-based composite.

RESULTS

The Shapiro-Wilk's test ($p > 0.05$) and visual inspection of their histograms, normal Q-Q plots, and boxplots showed that the data was normally distributed for all groups, with z-values between −1.96 and 1.96 for skewness and kurtosis. Figure 3 shows the fatigue resistance survival curves (Kaplan-Meier survival estimator) regarding the number of cycles (a) and life table curves for load at failure for each group (b). All the specimens survived until step 4 (first sample failure at 27,900 cycles/800 N, Table 2 and Fig 3a, b). The post hoc tests showed no differences for endured cycles (log rank) and load at failure (Wilcoxon-Gehan) between different thicknesses of the same CAD-CAM material ($p > 0.05$) for LS and RC.

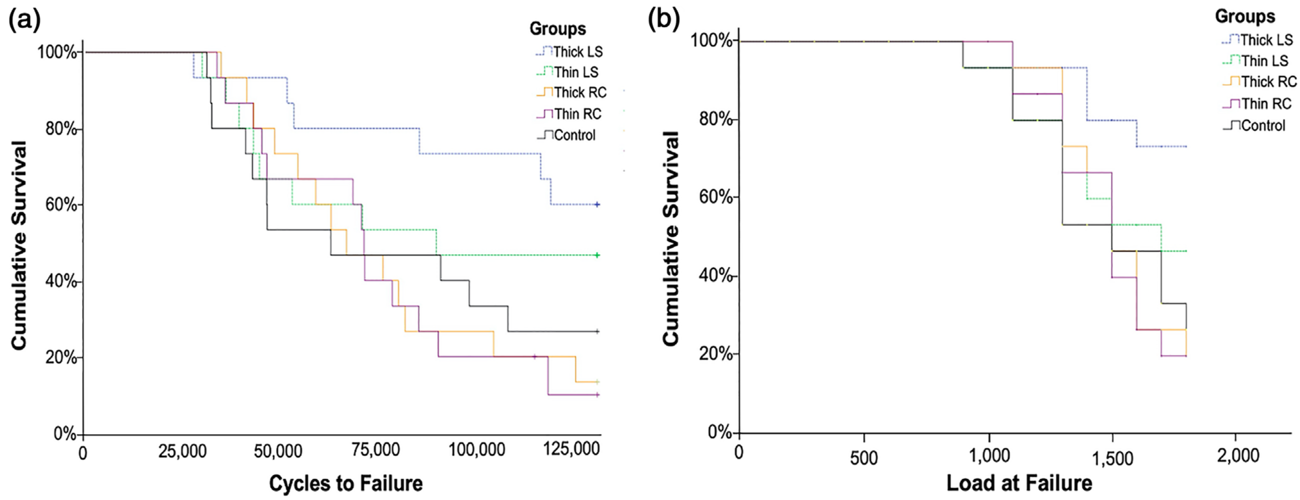

FIGURE 3 Kaplan-Meier survival curves for cycles (a), and life table curves of survived loads (b) for all groups. LS, lithium silicate and RC, resin-based composite.

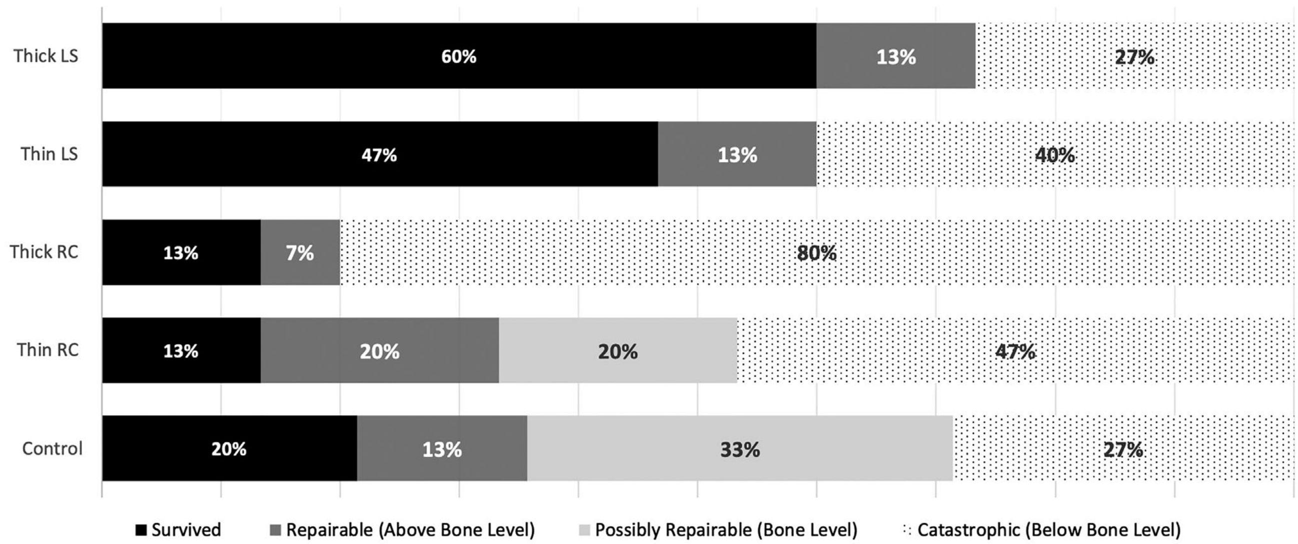

FIGURE 4 Failure mode distribution of tested groups. LS, lithium silicate and RC, resin-based composite.

TABLE 3 P-values of pairwise comparisons of all 5 groups

	Thin LS	Thick LS	Thin RC	Thick RC	Control
Thin LS	-	0.334	0.091	0.184	0.363
Thick LS	0.329	-	0.001*	0.006*	0.037*
Thin RC	0.365	0.008*	-	0.747	0.602
Thick RC	0.569	0.019*	0.705	-	0.736
Control	0.480	0.043*	0.883	0.817	-

Shaded cells, Kaplan-Meier followed by post hoc log-rank tests for cycles; clear cells, life table followed by post hoc Wilcoxon-Gehan test for load.
*Statistically significant difference between groups ($p < 0.05$) LS, lithium silicate; RC, RC-resin-based composite.

However, the thick LS differed between the RC and control groups ($p < 0.05$). Thin LS, RC (thick and thin), and control showed no statistically significant differences (Table 3).

Figure 4 presents the percentage of failure modes for each group. The thick LS showed a higher number of surviving samples (60%), whereas the thick RC had the highest percentage of catastrophic failures (80%). The thin RC and control showed the highest percentage of repairable and possibly repairable failures (40% and 46%, respectively).

Figure 5 shows the representative SEM images of the fractured areas of tested samples and the fractography of the samples are described in the caption of Figure 5. The microstructure of the CAD-CAM materials examined through SEM was more homogeneous for LS than RC, which showed small filler particles embedded by polymer matrix. EDS analysis identified the following chemical elements (wt%): for LS: O (62.1%), Si (24.3%), Zr (7.2%), P (2.7%), K (1.5%), and lower than 1% for Tb, In, H, S, and Ta; for RC: O (43.9%), C (31.6%), Si (12.4%), Al

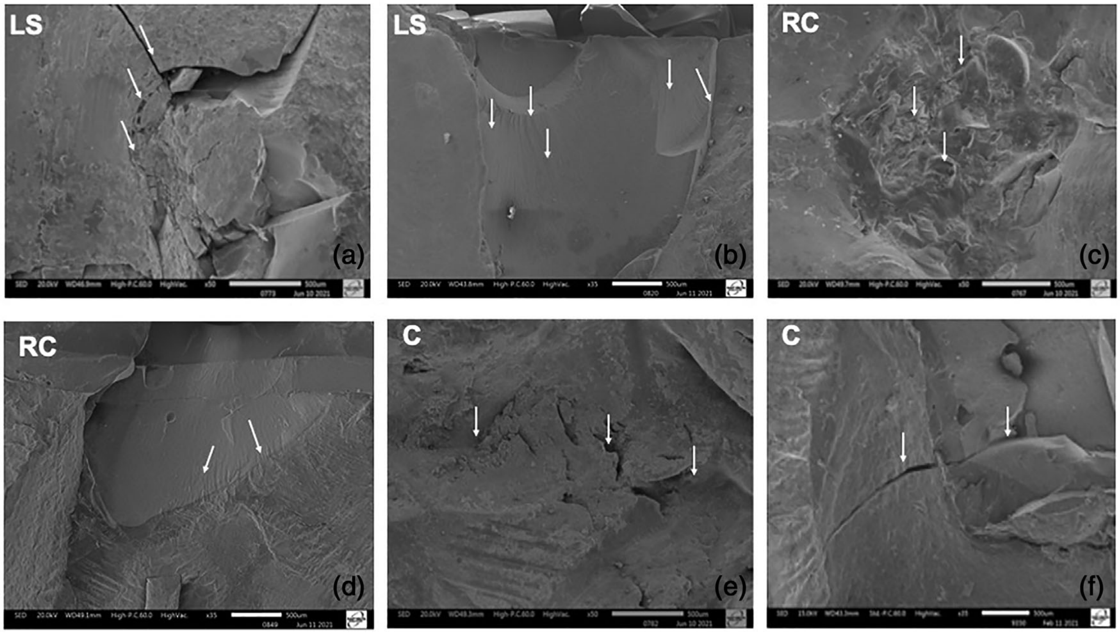

FIGURE 5 Representative SEM Images of two failure modes: "survived with cracks" and "repairable" of the three restorative materials. (a) LS group showing microcracks (white arrows) of one sample that survived the test. (b) LS group showing a repairable failure. White arrows indicate the direction of crack propagation (DCP). (c) RC group showing wear facets (white arrows) on its surface that survived the fatigue test. (d) RC group with a repairable failure. White arrows indicate the DCP. (e) Sample of Control group that survived the fatigue test. White arrows showing wear of the surface. (f) Repairable failure of Control group. White arrows indicate the DCP. The DCP of all groups seems to initiate from the oclusal surface towards to restoration margin. LS, lithium silicate; RC, resin-based composite; and C, control.

(6.1%), Na (3.3%), K (2.5%), and Ca (0.1%) were found (Fig 6).

DISCUSSION

The ETT were subjected to an accelerated fatigue test. The experimental groups consisted of occlusal veneers made of two different CAD-CAM materials (LS and RC) and two different thicknesses (thin groups: 0.4-0.5 mm, and thick groups: 1.4-1.6 mm). The first null hypothesis was rejected as differences were found among materials. The thick LS outperformed the RC groups and control. Conversely, the second null hypothesis was accepted as no differences were observed between the thicknesses, regardless of the CAD-CAM material. The control was a direct composite restoration without cuspal coverage, which represented the simplest restorative procedure.

The manufacturers (LS/Dentsply Sirona and RC/GC Corp.) recommend restoration of minimal thickness ranging from 1.0 mm (at restoration margins) to >1.5 mm (for wall thickness, pits, fissures, and cusp areas) for posterior restorations. In most cases, to obtain these restoration thicknesses, the removal of additional sound dental tissue is necessary, unless the vertical occlusal dimension is increased. However, this study revealed that both materials might be indicated for the conservative approach (thin occlusal veneers), as no differences were found for the same material using thin and regular thickness occlusal veneers (Table 3). This could be because thick occlusal veneers (potentially stronger) require more tooth preparation (more sound tissue removed), whereas the thin occlusal veneers (potentially weaker) allow more underlying tooth structure preservation and more enamel area for bonding. In addition, improvements in strength, fit, and processing technologies of CAD-CAM materials and systems[39] resulted in more accurate restorations with fewer internal flaws, which may have masked the effect of thickness.

However, in vitro fatigue studies should be interpreted with caution for clinical implications, and failure type evaluation is an important aspect because it indicates the next treatment possibilities (Figs 2 and 4). Thin LS restorations have more catastrophic failures than the thick restorations. Thin brittle materials can be more affected by mechanical in vitro tests owing to load configuration, stress concentration, presence of water, as well as the substrate type (enamel or dentin), which can induce crack propagation and material failure.[38,40–42] According to the manufacturer, LS is a high-strength glass-ceramic reinforced by zirconia (10%) indicated for crowns, anterior bridges, partial crowns inlays, onlays, veneers, and implant-supported restorations. Internally, it includes a large amount of fine-grained lithium silicate with a high glass content, which improves the optical and mechanical properties. Additionally, it is easy to polish and process quickly because it is already in a crystalline state. However, concerns regarding milling effects should be evaluated, specifically for glass-ceramics, and careful polishing should be indicated.[43]

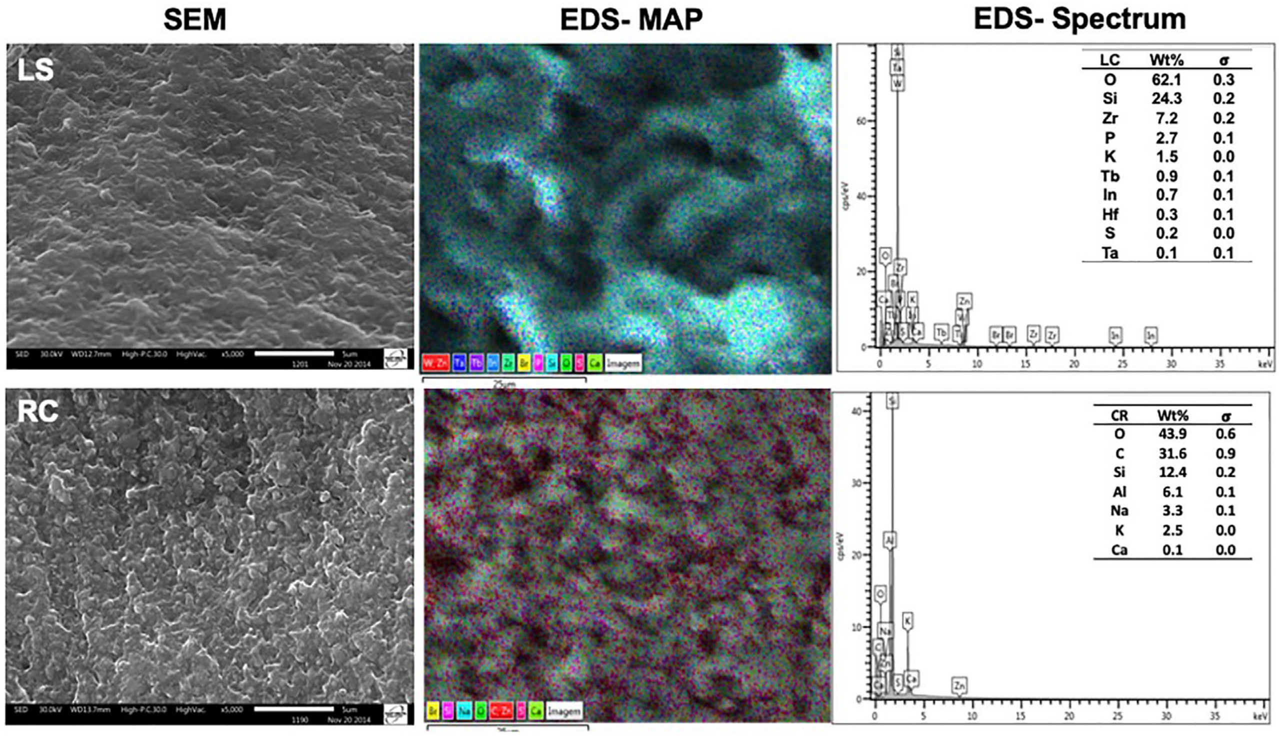

FIGURE 6 SEM images (at 5000× magnification) of CAD-CAM materials (left column), EDS mapping at 2000× magnification, and EDS spectrum (right column). LS, lithium silicate and RC, resin-based composite.

The RC showed an opposite trend, with more catastrophic failures observed for thick restorations (Figs 2 and 4). According to the manufacturer, RC is a hybrid material with a flexible resin matrix structure and nanoceramic fillers. Similar to LS, RC is indicated for posterior and anterior teeth, inlays, onlays, and implant-supported restorations according to the manufacturer's dimensions. It maintains its gloss over time and recovers its luster after roughening as stated by the manufacturer. In addition to its proper flexural strength,[44] a good mechanical performance of the material blocks is observed even after one year of water storage.[45]

The high strength of LS claimed by the manufacturer was observed in the cumulative survival analysis with respect to the thickness requirements, that is, using thick restoration. In contrast, the thin LS occlusal veneers were not superior to RC, and the initial cracks may propagate and overload the underlying tooth structure, leading to more catastrophic failures. A previous study demonstrated that the thin composite-based CAD-CAM occlusal veneers had lower crack propensity than thin ceramic ones[18] and the zirconia-reinforced lithium silicate should be indicated with caution for thin restorations.[46]

Different mechanical properties were observed for the two materials. The flexural strength of LS was approximately 300 MPa, whereas that of RC was 234 MPa. The major differences, however, are the elastic modulus, which is approximately 10 to 12 GPa for RC and 70 GPa for LS, and the hardness, which is 62.2 HV for RC and 463.5 HV for LS.[47] Flexibility is a crucial property that allows impact dispersion and stress distribution. Conversely, rigidity may explain the failure type differences and higher survival rate of the thick LS compared to the thick RC. LS is a more rigid material and its thickness is directly related to the ceramic tensile stress, which decreases as the thickness of the ceramic increases.[48]

Clinically, the presence of antagonistic teeth should be considered. RC restorations induce less antagonistic enamel wear and better preserve milling burs when compared to LS.[32,49,50] It is exactly the opposite of ceramics, which resist wear, but induce a substantial amount of antagonistic enamel wear.[50] A critical element for a material's choice is to identify whether the antagonistic dentition is a natural tooth, an existing composite resin, or ceramic restoration.[24] The main difference between the RC thin and thick groups was the higher possibility of repairable failures in the thin group (Fig 4). This is an important finding, specifically in ETT, which are more fragile and less resistant than the vital teeth[2] and failure can be related to the type of substructure.[40]

SEM analysis showed that the specimens that survived the complete fatigue test presented different surface topographies according to the CAD-CAM material. Crack formation was more frequent in the LS group, whereas the RC group presented more wear facets. The control samples appeared to have more wear than the RC groups. Moreover, in samples with repairable failures, it was possible to identify crack propagation from the loading area toward the margins (Fig 5). Additional SEM analysis was performed to evaluate the microstructures of the LS and RC CAD-CAM materials.

According to the microstructural analysis, LS appeared to be more homogeneous than RC. This may be owing to the small filler particles embedded in the polymer matrix found in the composite microstructures (Fig 6).

According to the EDS analysis (Fig 6), all the materials presented oxygen as the most common component. For LS, chemicals such as Si and Zr were detected, confirming the manufacturer's instructions. However, no Li was detected, which could be attributed to the complex microstructure associated with its low molecular weight. The same pattern and elemental composition can be found in other studies with lithium silicate glass-ceramics.[51–53] For RC blocks, higher amounts of C are explained by the content of methacrylate, such as Bis-MEPP, UDMA, and DMA. Si, Al, Na, and K can be explained by the structure of 71% silica and barium glass nanoparticles, as claimed by the manufacturers.

Moreover, all groups endured superior loads to maximum masticatory forces in humans.[54–57] The fatigue resistance of the control group was not significantly different from that of the experimental groups, except for the thick LS. Direct composite resin restorations restore ETT as a socio-economic alternative when sufficient remaining structure[58] and intact marginal ridges are present.[59,60] In this study, the same composite resin was used as a luting agent for the occlusal veneer groups, with the advantages of higher filler content, which improves the mechanical survival and fracture resistance,[60] unlimited placement time, easier positioning, decreased polymerization shrinkage,[61] less marginal degradation,[62] and similar film thickness of flowable material.[63]

The study used fresh ETT; however, the results might be different in clinical practice when the ETT are subjected to occlusal loading over the years. In addition, endodontic access was more conservative, preserving the marginal ridges with more supporting tooth structures, and simulating a clinical scenario of deep class I decay that reached the pulp and required root canal treatment. Standardized human teeth were used to avoid any discrepancy in morphology or amount of the remaining tissue that could affect the fatigue resistance.[64] Clinically, the standardization might not occur. The endodontic treatment could be associated with deep caries, and extension of caries removal and endodontic access. The majority of overlying restorations, supported by underlying restorations, affect more than 1/3 to 1/2 of the occlusal surface, and any clinical interpretation must consider the simulated clinical condition in this in vitro study.

Although the conventional restorative treatment for ETT involves full crown restorations, conservative approaches are important choices to fulfill the principles of minimally invasive dentistry because the integrity of coronal dentin interferes with its stress concentration and failure probabilities.[58,65] The CAD-CAM materials used in this study were chosen because they allowed the procedure to be implemented in one clinical session, reducing the time, cost, and risk of contamination, without the need for additional firing. From a practical standpoint, both materials selected for this study can be milled within less than 10 minutes and they can be quickly polished.[32,66] This is the first study to evaluate the fatigue behavior of two different CAD-CAM materials, LS (Celtra duo) and RC (Cerasmart), with two different thicknesses, using ETT as a substrate. However, further studies are needed to simulate different amounts of tooth reminiscence in ETT.

CONCLUSIONS

Within the limitations of this in vitro study, the following conclusions were drawn. Increased thickness did not improve LS (Celtra Duo) or RC (Cerasmart) ETT occlusal veneer fatigue resistance. The thick LS group exhibited better fatigue resistance than the RC and control groups. The direct composite restoration without cuspal coverage (control group) had the same fatigue resistance as both the RC and thin LS groups. A thick LS showed the best overall performance (fatigue and failure modes). The thin RC and control showed a higher percentage of repairable and possibly repairable failures. The thick RC had the highest rate of catastrophic failure.

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REGULATORY STATEMENT

This study was conducted in accordance with the Ethical Review Committee guidelines and policies.

DECLARATION OF COMPETING INTEREST

The authors do not have personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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