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Joggle lap shear testing of deep occlusal composite restorations lined with Dycal, Dycal LC, conventional or resin-modified glass ionomer

Testiranje spojnog smicanja dubokih okluzalnih kompozitnih restauracija postavljenih preko podloge od Dycal, Dycal LC, konvencionalnog ili smolom modifikovanog glas-jonomer cementa

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Abstract

Background/Aim. The longevity of a dental restoration may be predicted to some degree by its adhesive ability, and this, in turn, can be measured by bond strength testing between restorative materials and tooth structure. The aim of this study was to test an innovative joggle lap shearing jig that integrates the tooth and the entire biomechanical unit into testing, to compare the shear bond strengths of Class I occlusal composite restorations in deep cavity preparations lined with Dycal, Dycal LC, conventional glass ionomer or resin-modified glass ionomer. The mode of failure (adhesive, cohesive, mixed) after debonding was determined by stereomicroscopy. **Methods.** A total of 150 standardized occlusal cavities were prepared and divided into five groups. The group I cavities (n = 30) were coated with adhesive (ExciTE®F) and filled directly with composite (TetricEvoCeram). The group II and III cavities were lined with Dycal (n = 30) or Dycal LC (n = 30) before placing composite. The groups IV and V specimens were based with Fuji IX (n = 30) or Fuji II LC (n = 30). Shear bond strengths were determined with a universal testing machine and fractured bonding sites were analyzed under stereomicroscope. The mean bond strengths were analyzed using one-way ANOVA test ($p < 0.05$) and the means between the groups were analyzed with Student's *t*-test. **Results.** The shear bond strength (MPa) of composite restorations in cavities without base (23.91 ± 4.54) was higher than cavities lined with Fuji II LC (17.45 ± 2.74), Fuji IX (8.76 ± 2.57), Dycal LC (13.07 ± 1.84) or Dycal (6.12 ± 1.28). The results using the jogged lap shearing jig were consistent with the literature. **Conclusion.** The shear bond strength of occlusal composite restorations in deep cavities without liners was greater than cavities lined with Fuji II LC > Fuji IX > Dycal LC > Dycal.

Key words:
biomechanics; dentin-bonding agents; adhesives; dental cements; calcium hydroxide; materials testing; in vitro.

Apstrakt

Uvod/Cilj. Trajnost zubnih nadoknada može se donekle predvideti vstom adhezivne sposobnosti materijala i može se meriti testiranjem snage adhezije restorativnih materijala i zubnih struktura. Cilj ove studije bio je da se da se testira preklapanje spoja koji povezuje zub i biomehaničku jedinicu i da se uporedi jačina veze okluzalnih kompozitnih ispuna postavljenih u duboke kavitete preko podloge od Dycal, Dycal LC, konvencionalnog ili smolom-modifikovanog glas-jonomer cementa. **Metode.** Ukupno 150 standardizovanih okluzalnih kaviteta bilo je podeljeno u pet grupa (n = 30): I – kaviteti premazani adhezivom (ExciTE®F) i direktno ispunjeni kompozitom (TetricEvoCeram); II i III – kaviteti sa podlogom od Dycal ili Dycal LC pre postavljanja kompozitnog materijala; IV i V – uzorci sa bazom od Fuji IX ili Fuji II LC (n = 30). Jačina vezivne snage određena je pomoću univerzalne mašine, a način neuspeha (adhezivna, kohezivna, mešovita fraktura) određen je stereomikroskopom. Srednje vrednosti su analizirane pomoću ANOVA testa ($p < 0,05$), a značajnost razlika između grupa analizirana je Student-ovim *t*-testom. **Rezultati.** Jačina vezivne snage (MPa) kompozitnih ispuna u kavitetima bez podloge (23,91 ± 4,54) bila je veća u poređenju sa ispunima postavljenim preko Fuji II LC (17,45 ± 2,74), Fuji IX (8,76 ± 2,57), Dycal LC (13,07 ± 1,84) ili Dycal (6.12 ± 1.28). **Zaključak.** Smicanje ili pomaknuće okluzalnih kompozitnih ispuna u dubokim kavitetima bez lajnera je veće nego u kavitetima postavljenim preko Fuji II LC > Fuji IX > Dycal LC > Dycal.

Ključne reči:
biomehanika; dentin, vezivna sredstva; adhezivi; zub, cement; kalcijum hidroksid; materijali, testiranje; in vitro.

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Introduction

The longevity of a dental restoration may be predicted to some degree by its adhesive ability, and this, in turn, can be measured by bond strength testing. However, bond strength values are at best, gross assessments of the efficacy of bonding restorative materials to dentin as there is no direct clinical correlation to predict their clinical performance [1–4]. The International Standards Organization (ISO) Technical Specification No. 11405 provides some guidelines for testing the adhesive bond between restorative materials and tooth structure [5]. However, there is currently no universal test that will accurately predict the clinical performance of a specific material [6, 7].

Macro-bond strengths can be measured by shear, tensile, or push-out tests [8]. In a shear bond test, two materials are connected *via* an adhesive agent and loaded in shear until fracture occurs. Though macrotests are known for their simplicity, they have their shortcomings [7, 9]. Factors influencing bond strength testing include issues related to the dentin substrate, composite, and bonding area [10], storage conditions of the bond assemblies, and test design [11]. Another source of variability is the method used to apply the shear force, which includes wire loops, points, and knife edges [12].

In tensile bond tests, load will be exerted on either side of the test specimen, which can be held by active or passive gripping methods [13]. Stresses are far more homogeneous across the interface than in shear and, therefore, maximum principal stress values are much closer to the nominal strength [9, 14]. To pull a bond, however, requires the substrate and interconnect to be gripped. In these cases, a set of accurately formed and aligned tweezer tips with precision control of their opening and closing is likely to make the difference between success and failure [1]. Specimen alignment is also critical to avoid uneven stress distribution upon the specimen during loading.

Shear bond strengths highlight the strength at the bonded interface. When the shear device applies load forces on larger contact areas such as with the wire loop [15], stainless steel tape [16] and the Ultradent device [17], higher shear bond strength values are expected due to a more even distribution of shear forces. Nevertheless, specimen size [18], loading length [19], adhesive layer thickness [20], loading site [17] have been reported to affect the bond strength values and failure modes. In comparison to a knife edge, the use of a wire-loop seems to reduce the stress concentration magnitude adjacent to the adhesive interface, but finite element analysis has shown that this method results in grossly underestimated bond strength values [12].

Microtensile bond testing has also been used widely to assess bond strengths. However, the method is not easily applied to enamel due to its brittleness and the stresses generated during specimen preparation can lead to fracture of the enamel-resin interface [15]. The lack of standardization among microshear bond testing studies has resulted in considerable discrepancies in bonding data [21]. Furthermore, microtensile bond testing is also subject to the influence of cross-section shape and surface area, [22, 23] cutting speed [24], and geometry of the specimens, as well as the mode of fixation and the devices used for testing [25]. The shear load must also be applied precisely at the bonded interface to avoid subjecting the cylinder to rotation or bending rather than shear tension [21].

A relatively thicker adhesive layer in microshear tests, among other reasons, concentrates stresses highly influencing the maximum load, thereby rendering microtensile tests less accurate than macrosshear tests in representing shear bond strength [1]. Moreover, none of these laboratory tests take into account the overall response of a restored tooth while being loaded under the same shear forces, as the tests focus specifically on the adhesive layer between the tooth substrate and restorative material and not on the whole biomechanical unit.

Normal tooth structure transfers external biting loads through enamel into dentin as compression, which are distributed over a large internal volume of tooth structure and thus local stresses are lower. A restored tooth tends to transfer stress differently than an intact tooth, and in turn, differently from cross-sections of teeth that are subject to evaluation by current testing methods. Any force on the restoration produces compression, tension or shear along the tooth/restoration interface, leading to complex stress distributions, a combination of compressive, tensile and shear stresses (Figure 1) [26]. Since the process of mastication is one of indentation, basically a shearing phenomenon, the true nature of adhesive strength of the materials at the interface is depicted by the shear bond strength.

Ultimately, the quality and efficacy of bonding of adhesive materials will be reflected in their mode of failure – either cohesive, adhesive or mixed. With increasing bond strengths, the number of cohesive failures within the dentinal substrates is expected to increase [26]. A more ideal clinical correlation, however, would consider the whole biomechanical unit which includes not only the restorative material, but the tooth structure and the interface between the restoration and the tooth, as well. The restorative material may be strong enough to resist fracture, but the interface or tooth structure may not be.

Most restorations are designed to distribute stresses onto sound dentin, rather than to enamel. The process of stress transfer to dentin becomes more complicated when the amount of remaining dentin is thin and the restoration must bridge a significant distance to seat on to thicker dentin with the use of liners and bases. A test that relates the line of action of shear force more directly to the adhesive layer as it occurs within the tooth and to the actual restoration would more realistically depict how the material would resist debonding under shear forces during mastication.

Therefore, the aim of the study was to test an innovative joggle lap shear testing jig compare the shear bond strengths of class I occlusal composite restorations in deep cavity preparations lined with Dycal, Dycal LC, conventional glass ionomer or resin-modified glass ionomer, by centering the line of action of the applied shear force at the location of the dentin-liner or dentin-adhesive layer as it occurs in the tooth and within an actual restoration. The specified liners were chosen for this study, as the literature contains an abundance of data

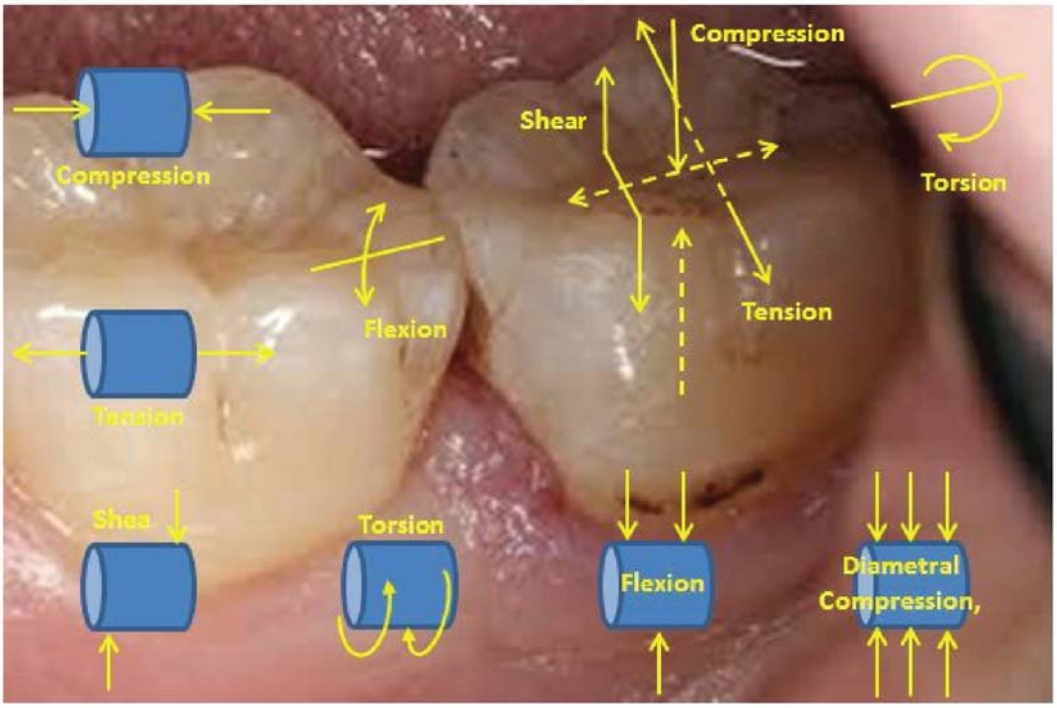

Fig. 1 – Normal tooth structure transfers external biting loads through enamel into dentin as compression, which are distributed over a large internal volume of tooth structure. A restored tooth tends to transfer stress differently than an intact tooth, and any force on the restoration produces compression, tension or shear along the tooth/restoration interface, leading to complex stress distributions; a combination of compressive, tensile and shear stresses.

related to their shear bond strengths to serve as the basis for comparison.

Methods

This *in vitro* study was approved by the Macedonian Ministry of Health Research and Ethics Committee and the Institutional Review Board of Sts. Cyril and Methodius University. A total of 150 non-carious mandibular third molars, extracted for orthodontic reasons with similar crown size were selected, cleaned and stored in a solution of 0.5% chloramine-T at 4°C until used. Bond strengths were measured no more than six months *post* extraction as *per* ISO technical specification 11405 [5].

To ensure that the teeth were free of cracks, defects or caries they were examined at × 10 magnification by means of an optical microscope (SZ-TP Olympus; Tokyo, Japan). To facilitate cavity preparation, the cusp tips of each tooth were reduced with a double-faced diamond disc No. 7011 (KGSorensen Ind. Com. Ltd), producing a flattened occlusal dentin surface. The prepared dentin surfaces were then polished with 180, 320, and 600 grit wet silicon carbide paper for 60 s.

Standardized cavity preparations were created in each tooth by mounting each specimen in plaster within a metal mold and using a variable-speed electric drill (Dremel, Model 232-5, Emerson Electric Co, Racine, WI) mounted on a drill press apparatus to facilitate uniform preparation of cavities and accurate cavity depth dimensions [27]. The occlusal cavity preparations, 3 mm (length) × 3 mm (width) × 3.0 mm (depth), followed a rectangular outline drawn on the occlusal surface of the tooth and were made with a #110/010 diamond bur (Dentsply, York, PA, USA). Cold water spray was delivered to the tooth and bur during cavity preparation to minimize heat. To standardize surface roughness, a new diamond bur was used for each preparation.

The teeth were then randomly divided into 5 groups *per* 30 teeth, each based on the restorative materials tested as follows: the group I (control group) specimens (n = 30) were treated with a complete adhesive system: etched with 37% H_3PO_4, coated with ExciTE® adhesive (IvoclarVivadent, Amherst, NY, USA) and filled directly with TetricEvoCeram composite (IvoclarVivadent). Group II and III specimens were first lined with either self-cured Dycal (Dentsply) (n = 30) or light-cured Prisma® VLC Dycal® (Dycal LC) (Dentsply) (n = 30) calcium hydroxide liners, respectively, then etched, coated with ExciTE adhesive and filled with Tetric Evo Ceram composite. Group IV and V specimens were first lined with either conventional Fuji IX (GC, Tokyo, Japan) (n = 30) or resin modified Fuji II LC glass ionomer (GC Fuji LINING LC PASTE PAK; GC, Tokyo, Japan) (n = 30), then etched, coated with adhesive and filled with composite.

After the cavity preparations were filled according to the manufacturer's recommendations (Table 1), tygon tubing was attached to the occlusal surface of each restoration and filled with composite. The tygon tube was removed after curing, resulting in cylinders of resin composite with cross-sectional diameter and height of 3 mm respectively.

Table 1

Materials and Application Protocols

Material	Application Protocol
Dycal	Equal volumes of the base and catalyst paste (1.17 g:1.00 g) were extruded onto a mixing pad and stirred immediately using a Dycal applicator for 10 sec until a uniform color was achieved. After drying the cavity preparation, the mix was placed in the cavity with the Dycal applicator and spread over the floor to a depth of 1 mm before setting starts (setting time: 2 ½–3 ½ min at room temperature). Any excess set material was removed from margins with a sharp spoon excavator.
Prisma® VLC Dycal® Visible Light Cured Calcium Hydroxide Base/Liner	The cavity preparations were rinsed with water and gently dried with a cotton pellet to avoid dessication. The Prisma® VLC Dycal® Liner was dispensed on a parchment paper pad. Using a ball-pointed Dycal® Liner applicator, the Prisma® VLC Dycal® Liner was placed directly only on the deepest portion of the cavity dentin in a thin layer, not exceeding a thickness of 0.8–1 mm. Care was taken to avoid placing Prisma® VLC Dycal® Liner on enamel or the margins of the cavity, leaving the rest of the cavity surface free for bonding. The ball of the instrument is approximately 0.7 mm in diameter which can be used as an indicator for the thickness of the material being placed. The material was light cured at 470 nm, with minimum light output at least 300 mW/cm^2 exposure for at least 20 s. Any material excess from retention areas, enamel, and/or margins was removed with a sharp spoon excavator. The adhesive and restoration was then placed into the cavity preparation following manufacturer's directions.
GC Fuji LINING LC PASTE PAK	GC Fuji Lining LC Paste Pak is a radiopaque, light cured resin-modified glass ionomer lining cement available in paste-paste form. The Paste Pak cartridge was loaded into the Paste Pak Dispenser after sitting at room temperature for 30 min. The cartridge was bled in order to prevent the incorporation of air bubbles into the material. After dispensing onto a mixing pad, the material was incorporated and spread out in a thin layer on the mixing pad using a plastic spatula. The pastes were mixed thoroughly, with lapping strokes, for 10 seconds, with care not to incorporate air bubbles. The working time is 2 minutes 15 s from the start of mixing at 23°C (73.4°F). The tooth preparations were washed and dried but not dessicated. The cement was transfered to the preparation using a syringe, covering dentine up to a depth of 1 mm, and light cured with a halogen light curing device which was placed as closely as possible to the cement surface for 20 sec.
ExciTE® F	ExciTE® F is a light-curing, nanofilled, fluoride-releasing, single-component adhesive for dentin and enamel bonding in conjunction with the total-etch technique. After ensuring a dry operating field, areas in deep cavities close to the pulp were selectively coated with a calcium hydroxide liner. A 37% phosphoric acid gel was applied (Total Etch, IvoclarVivadent) to the prepared enamel and flowed onto the prepared dentin. The etchant was left to react on the enamel for 15–30 s and on the dentin for 10–15 s. Following this, all etchant gel was removed with a vigorous water spray for at least 5 s. Excess moisture was removed with an air gun, leaving the dentin surface with a glossy wet appearance (wet bonding) not to over dry the dentin. The first step in applying Excite is to etch the enamel for 15 s and the dentin for 10 seconds with Total Etch, a 37% phosphoric acid etchant. The etchant is removed with thorough rinsing and the tooth structure is lightly dried with air or blot dried. Excite Adhesive is generously applied to the tooth structure using a scrubbing motion for 10 s, gently air dried for 3 seconds, and light activated for 20 s. The restoration is then placed using standard techniques.
TetricEvoCeram	TetricEvoCeram is a light-curing, radiopaque, nanohybrid composite for direct restorative therapy. The cavity preparations were cleaned and carried out according to the requirements of the adhesive technique with care to avoid preparing sharp, internal edges or additional undercuts. Any sharp enamel edges were rounded with finishing diamonds (25–40 μm). Subsequently, all residue in the cavity was removed with water spray and dried with water- and oil-free air. Only very deep areas close to the pulp with a calcium hydroxide material with care not to cover other cavity walls, since they can be used to support the bond with an enamel/dentin adhesive. Conditioning and application of the bonding agent was performed according to the Instructions and recommendations of the manufacturer using ExciTE® F (with phosphoric acid etching) . TetricEvoCeram was applied at room temperature in layers of max 2 mm thickness and adapted with a suitable instrument (e.g., OptraSculpt). Excess material was removed with suitable finishers (e.g., Astropol® F) or fine diamonds after polymerization. TetricEvoCeram was cured with light in the wavelength range of 400–500 nm (blue light) with a high intensity quartz tungsten halogen lamp (Astralis 10, (IvoclarVivadent) at High Power Program Regime, at 40 s exposure time, and 1200 mW/cm^2 light intensity, holding the tip of the light (8 mm) about 3mm above the restoration.

All the specimens were then thermocycled 500 times at 5°C and 55°C water with a one-minute dwell time. The specimens were then stored in distilled water for 24 h at 37°C to simulate the conditions of the oral cavity and subjected to shear bond strength testing in a universal testing machine (ADMET eXpert 1000 servo-hydraulic mechanical testing machine, ADMET, Norwood, MA) at a crosshead speed of 0.5 mm/min. The shear bond strenght megapascals (MPa) was calculated as ratio of maximum load recorded at failure in Newtons to surface area of the bonded restorations in mm^2.

The specimens were arranged in the mounting jigs of the testing machine. An *ad hoc* assembly of two vertical joggled lap metal holders was manufactured with holes on the ends to serve as holders for all dental elements. With the bevels parallel and facing away from each other, each tooth specimen was locked into one holder, while the composite button on the occlusal surface of the restoration engaged a 3 mm hole that was machined in the other holder. After fixing both tooth and button in place with orthodontic resin, the samples were subjected to shear force (plane stress) on the adhesive interface by stretching vertically on the specimen from both directions until the restorations failed (Figure 2).

Self-tightening vise grips were used to prevent slipping. The metal holders were aligned so that the centerline of the grip assembly was aligned with the adhesive bond at the bottom of the cavity preparations. Proper alignment was achieved with vice grips by adjusting the grip inserts from side to side so that the center line of the upper and lower grips passed through the dentin-adhesive layer. The teeth were then fixed to the metal holders with orthodontic resin to provide additional retention to avoid any sliding during the tests. All the procedures were conducted at room temperature.

Shear force was applied to each specimen by the servo-hydraulic mechanical testing machine (ADMET, Norwood, MA, USA) at the crosshead speed of 0.5 mm/min until failure occurred. Shear bond strength was then calculated in units of MPa after measuring the cross-sectional area at the site of fracture according to the formula: $\tau = F/A$ ($N/mm^2 = MPa$). Mean shear bond strengths and standard deviations were calculated for each group and statistically analyzed using a one-way ANOVA analysis of variance ($p < 0.05$). Comparison of the means between the groups was conducted with Student's *t*- test.

Failure modes were evaluated by a single operator under a dissecting microscope (SZ-TP Olympus; Tokyo, Japan) and classified as: adhesive failure (occurring purely at the restoration-dentin interface); cohesive failure (occurring within the material or within dentin); mixed adhesive/cohesive failure (combination of the adhesive or any of the cohesive modes). Calcium hydroxide and glass ionomer cements had been leveled off flush with the surface of the cavity preparation prior to the composite resin placement. Any deficiency in the cement surface was categorized as a cohesive failure within the material. If the surface of the two materials remained flat, this represented adhesive failure of the bond, and positive elevations on the cement surface represented a cohesive failure in the composite resin.

Schematic representation of biting loadstransfer is given in Figure 3.

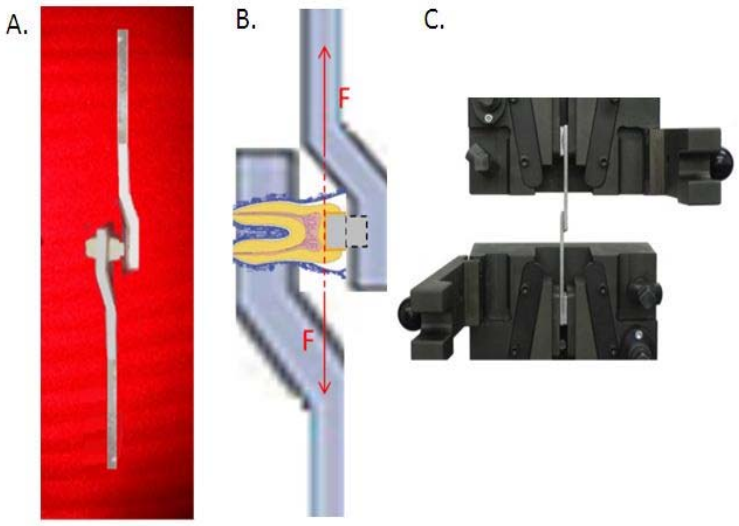

Fig. 2 – (A) An *ad hoc* assembly of two vertical joggled lap metal holders with holes on the ends serve as holders for all dental elements. With the bevels parallel and facing away from each other, each tooth specimen is locked into one holder, while the composite button on the occlusal surface of the restoration engages a 3 mm hole that is machined in the other holder. (B) After fixing both the tooth and the button in place with orthodontic resin, the samples were subjected to a shear force (plane stress) on the adhesive interface by stretching vertically on the specimen from both directions until the restorations failed. (C) Self-tightening vise grips were used to prevent slipping. The metal holders were aligned so that the centerline of the grip assembly was aligned with the adhesive bond at the bottom of the cavity preparations. Proper alignment was achieved with vice grips by adjusting the grip inserts from side to side so that the center line of the upper and lower grips passed through the dentin-adhesive layer. The teeth were then fixed to the metal holders with orthodontic resin to provide additional retention to avoid any sliding during the tests.

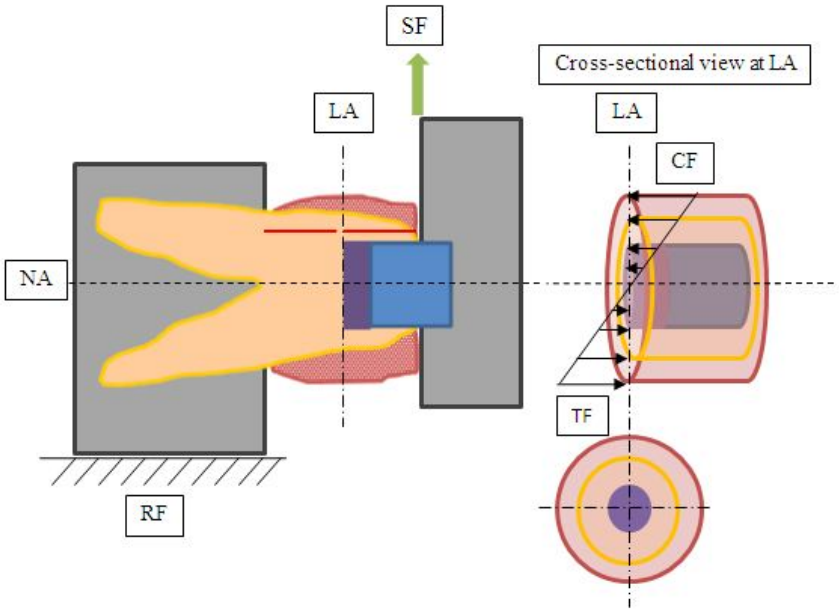

Fig. 3 – Applying tensile force accurately along the plane gives rise to configurations that minimise distortion away from the plane. Each end of the sample is held by vice grips and pulled apart at the controlled rate, and the force applied is expressed proportionally to the total adhesive surface area, or shear area. The joggled lap metal holders suspend the restored teeth bucco-lingually in a horizontal position and center the line of action to the specified adhesive layer as it relates to the restored tooth, while two fulcrums create a moment and subsequent torque to more closely simulate load under lateral excursions during mastication.
Red area – Enamel; Yellow area – Dentin; Blue area – Composite; Purple area – Baseliner; Gray areas –Test fixtures; RF – Rigid fixture (not moving); SF – Shear force application moving fixture; CF – Compression internal-forces; TF – Tension internal forces; LA – Line of action; NA – Neutral axis.

Results

The mean and standard deviation of shear bond strength for each group are presented in Table 2. The shear bond strength of composite restorations in cavities filled directly with complete adhesive system (37% H_3PO_4 etch, ExciTE adhesive and TetricEvoCeram composite) was higher than the shear bond strength of restorations in cavities lined with either of the calcium hydroxide bases (Dycal and Dycal LC) or glass ionomer cements (Fuji IX and Fuji II LC) (Figure 2). The difference in mean shear bond strength values between the control group and cavities lined with either calcium hydroxide or glass ionomer bases was significant ($p < 0.001$). The adhesive strength of restorations bonded directly to dentin-enamel was approximately four times greater than cavities lined with conventional Dycal and twice as high as the light-cured Dycal group. The adhesive strength of restorations in the control group was 2.7 times greater than the conventional glass ionomer group and 1.4 times greater than the resin-modified glass ionomer group.

Comparison of mean shear bond strengths between composite restorations in cavities lined with Dycal or Dycal LC (Table 2) showed significant differences ($p < 0.001$). The shear bond strength of the restoration over light-cured Dycal was twice (213.58%) as strong or 113.5% better than with conventional Dycal (6.12 MPa vs 13.07 MPa), though half as strong as composite bonded directly to hard tooth structure (13.07 MPa *vs* 23.91 MPa).

The differences in the mean shear bond strength values between composite restorations in the group III and IV cavities lined with Fuji IX or Fuji II LC glass ionomer were also significant ($p < 0.001$). The strength of adhesion of composite res-

Table 2

Comparative analysis among groups

Group		Average shear bond strength (MPa)	Standard deviation (SD)	Student's *t*-test	ANOVA F-test	*p*
I	Control	23.91	4.54			
II	Dycal	6.12	1.28	11.827	139.91	< 0.001
III	Dycal LC	13.07	1.84	7.197	52.04	< 0.001
IV	Fuji IX	8.76	2.57	9.732	92.33	< 0.001
V	Fuji II LC	17.45	2.74	4.113	18.22	< 0.001

torations over modified resin glass ionomer was two times (199.2%) greater than conventional glass ionomer and 33.5% greater than light-cured Dycal (13.07 MPa *vs* 17.45 MPa).

The resin-modified glass ionomer lined composite restorations reached higher shear bond strengths than the remaining liner groups. The GC Fuji LC cement showed superior bond strengths than all the other materials tested, except for the control group which had notably higher mean shear bond strength. Composite restorations in cavities lined with conventional Dycal showed the lowest shear bond strength rate and were inferior to resin-modified cement.

The distribution of fracture modes observed with a dissecting microscope × 20 magnification is shown for all the groups in Table 3. The principle mode of failure in group I (control group) was adhesive at the composite-dentin interface. The mode of failure in the groups II and III was mainly cohesive, principally at the composite resin-Dycal or Dycal LC interface. The failures within the Fuji IX glass ionomer group IV were mainly cohesive, unlike the GC Fuji Lining LC group V which showed 50% adhesive failure. Superior results were observed with resin-modified cement (17.23 MPa). The failure observed was mainly within the cement.

In lap shear (tensile) testing, adhesion is tested by pulling bonded layers apart along the plane of adhesion. The result can be a clean breakaway of the adhesive layer from the substrate, or more likely a breakdown in the cohesion of either the substrate or the adhesive layer, or both. Applying tensile force accurately along the plane gives rise to configurations that minimize distortion away from the plane. Each end of the sample is held by vice grips and pulled apart at a controlled rate, and the force applied is expressed proportionally to the total adhesive surface area, or shear area. In this study, jogged lap metal holders suspended the restored teeth buccolingually in a horizontal position and centered the line of action to the specified adhesive layer as it relates to the restored tooth, while two fulcrums created a moment and subsequent torque to more closely simulated load under lateral excursions during mastication.

The offset jig fixture allows for the entire composite cylinder to fit completely into the metal holder and flush with the restoration's occlusal surface. The opposite fixture mounted the tooth in a configuration that mimics the emergence of the cementoenamel junction (CEJ) from the alveolus. With both fixtures separated an equal distance from the

Table 3

Failure modes of all test groups

Description	Adhesive (%)	Cohesive (%)	Mixed (%)
Control (Excite + Tetric Ceram)	100		
Dycal + (Excite + Tetric Ceram)		80	20
Dycal LC + (Excite + Tetric Ceram)		80	20
Fuji IX + (Excite + Tetric Ceram)	10	70	20
Fuji II LC + (Excite + Tetric Ceram)	50	20	30

Discussion

As many variables can affect the efficacy of any shear bond strength testing method, it is important to justify the experimental model. The choice of testing assembly has great influence on stress distribution. Traditional shear testing with a knife or round surface contact have several limitations, including high stress point loading in which load is concentrated and not distributed to the surrounding composite or natural tissue structures. Furthermore, knife-edge shearing can only produce compression loading from the contact force. The use of a knife-edge chisel causes more severe stress concentration at the load application area than wire loop [9, 12] and stainless steel tape allows more uniform stress distribution at the bond interface [28]. The distance between the point of load application and the bonded interface in shear tests also affects stress distribution [18].

In contrast, the novel shear test distributes loading throughout the composite and tooth as it incorporates into testing the entire biomechanical unit. Distributed loading produces tension and compression loading within the entire composite, which is integrated into material and tissue structures. This was achieved by aligning the line of action to the floor of the restoration which may more closely simulate shear as seen clinically during mastication.

restoration floor, the weakest point in the restoration, the line of action being centered the novel test produces a shear and moment force coupled with tension and compression forces.

The viability of this jig was then tested by measuring bond strengths of a composite restoration in deep occlusal cavities lined with different bases. These studies have been limited. Therefore, a comparative *in vitro* analysis of composite restorations in deep occlusal cavity preparations lined with self-cured and light-cured CaOH and conventional and resin-modified glass ionomer would also be of further value [29, 30].

Many authors have measured shear bond strength *in vitro* with values ranging from 13.7 MPa to 26.84 MPa [31]. Khatry et al. [32] found mean values of adhesion to hard dental tissue with conventional composite and nanocomposite to be 21.04 MPa and 20.78 MPa, respectively. In general, they all show that maximum adhesive strength is achieved with direct bonding between hard dental tissues and adhesive systems [33, 34]. The current study determined that mean shear bond strength of a composite restoration bonded directly to dentin in occlusal cavity preparations (group I) was 23.91 MPa, which is consistent with the literature.

Sano et al. [22] reported that for specimens with rectangular bonding areas between 0.25–11.65 mm^2, tensile bond strength to dentin was shown to decrease as bonding area in-

creased, following a logarithmic function. A similar trend was noticed in shear bond strengths where smaller surface areas had significantly higher values when compared with those of larger areas [35]. The ISO/TR 11405 does not identify a specific value for bond area but it mentions a clear delimitation of the bonding area as an important requirement and shows a diagram of a split mold with a 3-mm diameter hole.[5] When considering that the resin composite in this study was bonded to four axial walls as well as the dentinal floor with an area of 9 mm^2 and that the shear bond strength was still in the upper end of values reported in the literature, our results cannot be correlated to the conclusions of the Sano et al. study [22].

Thermal cycling has been used as a technique to simulate clinical conditions and was used in this study as well. Thermal cycling may not have a significant effect on shear bond strength, but it can lead to spontaneous debonding of specimens and significantly reduce the shear bond strengths of dentin [36–38]. Miyazaki et al. [39] found that dentin bond strengths significantly decreased after 30,000 thermal cycles. A short thermal cycling regimen of 500 cycles was therefore, used in this study as recommended by ISO-TR 11450 [5].

Other investigations have found that the shear bond strength can be affected by the shrinkage of the composite material, which causes separation of the composite material from the dentin and, consequently, results in microleakage [40, 41]. According to Davidson et al., [42] the strength after polymerization contraction on a three-dimensional model is about 20 MPa. Munksgaard et al. [43] reported that a shear bond strength of 17 MPa was enough to counter shrinkage during composite polymerization to maintain the bonded interface.

Using liners in deep cavities can further affect the adhesion between hard dental tissues and composite materials [44]. Although calcium hydroxide as a base has desirable antibacterial effects and protects the pulpal tissue [33], it does not have notable adhesion capacity [30, 45]. Light-cured calcium hydroxide, on the other hand, has better chemical properties compared to self-cured calcium hydroxide and some investigators have reported good composite adhesion over Dycal LC [46]. The current study applied both Dycal and Dycal LC to the dentin of cavity preparations and found that the strength of adhesion of Dycal LC was significantly higher ($p < 0.001$).

The study determined that the shear bond strength of a composite resin over conventional glass ionomer Fuji IX or resin-modified glass ionomer Fuji II LC in an occlusal restoration was 8.76 MPa and 17.45 MPa, respectively. Although the mean shear bond strength of the light-cured Dycal group was twice (213.58%) as strong and 113.5% better than the conventional Dycal group (6.12 MPa *vs* 13.07 MPa), the strength of adhesion with modified resin glass ionomer was two times (199.2%) greater than conventional glass ionomer and 33.5% greater than light-cured Dycal (13.07 MPa *vs* 17.45 MPa). Assuming that the minimum strength of adhesion of a composite restoration to the cavity must be 17 MPa to maintain a good bond [43], the strength of adhesion achieved with modified resin glass ionomer equalled or slightly surpassed the minimum requirements. The results observed with resin-modified cement (17.23 MPa) are probably due to the superior cohesive strength of the cement and due to the chemical bonding between the resin bonding agent and the non-reacted resinous phase of the glass ionomer cement. The study indicates that a composite restoration in a deep occlusal cavity lined with modified resin glass ionomer would resist shear forces better than a composite restoration in a cavity lined with conventional glass ionomer or both self-cured and light-cured calcium hydroxide liners.

These results concur with other investigators who have explored the strength of adhesion between conventional and LC glass ionomer and have found that LC glass ionomers demonstrate better adhesion [47–50]. In a retrospective clinical study comparing direct composite materials with an indirect sandwich technique using resin modified glass ionomer as a base, Opdam et al. [51] found that direct composite restorations lasted longer. This might be due to resin-modified glass ionomer penetrating demineralized dentin better than conventional glass ionomer [34].

Nonetheless, both calcium hydroxide and glass ionomer liners can reduce the bonding surface available to composites, which can further contribute to reduced bond strength [29, 52–54]. Although the current study found that composite restorations in deep occlusal cavities lined with Fuji II LC resisted debonding better than the composite restorations over the other tested liners, the strength of the bond was not ideal.

As with any alternative test, the results of the *in vitro* study cannot be extrapolated directly to clinical situations. The complex intraoral environment prevents perfect duplication in *in vitro* conditions. Nevertheless, the *in vitro* information has to be considered along with the fact that to date, no single testing condition *in vitro* has proven superior over any other. The results of this study are comparable with the results achieved by other testing methods and show that the joggled shearing jig is a viable option that merits further investigation. It also provides a model that takes into account the whole biomechanical unit during testing.

Conclusion

The study shows that joggled lap shear testing may be a viable tool to measure strengths of dental materials while integrating the entire biomechanical unit into testing. A composite restoration in deep cavities lined with modified resin glass ionomer resisted debonding better than cavities lined with conventional glass ionomer or both self-cured and light-cured calcium hydroxide liners, satisfying a minimum adhesive strength of 17 MPa often cited as required to maintain composite marginal integrity. Shear bond strength of occlusal composite restorations in deep cavities without liners as measured by a joggled lap shear testing jig was greater than cavities lined with Fuji II LC, Fuji IX, Dycal LC and Dycal. The results concur with studies using other testing methods. The resin-modified glass ionomer lined composite restorations reached higher shear bond strengths than the remaining liner groups. The GC Fuji LC cement showed superior bond strengths than all the other materials tested, except for the control group which had notably higher mean shear bond strength. Composite restorations in cavities lined with conventional Dycal showed the lowest shear bond strength rate and were inferior to resin-modified cement.

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Disclosure statement

The authors declare no conflict of interest.

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