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Marginal ridge strength of tunnel-prepared teeth restored with various adhesive filling materials[1]

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Abstract

This study evaluated the load required to fracture the marginal ridge of tunnel-filled teeth restored with various adhesive filling materials. Five test groups, each consisting of 20 extracted maxillary premolars, were filled with either composite resin or a conventional, a cermet, or two brands of resin-modified glass ionomer (polyalkenoat) cements. The tunnels were prepared with the occlusal access placed in the mesial fossa, leaving a relatively thin approximal wall. The teeth were subjected to incremental dynamic forces. A maximum absorbed energy index, quantifying the fracture resistance of the teeth, showed no statistically significant differences between the test groups with regard to marginal ridge strength, even though the elastic moduli of the materials varied. None of the adhesive materials restored the teeth to the strength of sound teeth.

Keywords: Glass polyalkenoat cement; Composite resin; Operative dentistry; Fracture resistance

The tunnel preparation technique has been introduced as an alternative to the traditional Class II amalgam restoration [1–5]. The preparation consists of removing approximal caries tissue through the occlusal surface via a tunnel (Fig. 1). One of the main objections is that this technique entails undermining the marginal ridge, increasing the risk of fracture [6]. In a recent three-year clinical study, 14 % of the tunnel restorations were replaced due to marginal ridge fracture [7].

Two factors may affect the marginal ridge strength of teeth with tunnel restorations: the size and position of the preparation, and the properties of the restorative material used. It has been shown that a conservative tunnel restoration situated 2 mm from the marginal ridge does not significantly weaken an otherwise intact tooth [8–10]. Most dentists, however, seem to prepare tunnels with a narrower approximal wall [11,12]. By placing the access closer to the marginal ridge, the quality of caries removal appears to be better [13]. Less tooth substance is removed, and, if necessary, the conversion to a conventional Class II preparation is facilitated.

Use of adhesive materials appears to be appropriate when restoring tunnel-prepared teeth. Glass ionomer cement (glass polyalkenoat cement) [14,15] is the most frequently used material because it adheres to both dentin and enamel [16], releasing fluoride [17] and probably exerting a cariostatic effect. There are several types of glass ionomer products. In the cermet cements, silver particles are sintered to the glass particles during manufacture [18]. The addition of resins to conventional glass ionomer cement converts it into a dual-cured cement [19], termed resin-modified glass-ionomer cement [20]. The use of composite resin, i.e. a polymer matrix with stiff inorganic inclusions, has also been suggested for restoration of tunnel-prepared teeth [8]. A composite resin restorative material may attach the unsupported marginal ridge to the acid-conditioned tooth structure, thus strengthening it [21–23].

The aim of the present laboratory study was to investigate the ability of various types of adhesive materials to influence the marginal ridge strength of tunnel-prepared teeth when they were subjected to intermittent forces.

1. Materials and methods

114 extracted maxillary premolars without restorations or macroscopic defects were stored in 2% benzalkonium-chloride. After removal of the periodontal tissue, the teeth were divided into small, medium, and large sizes according

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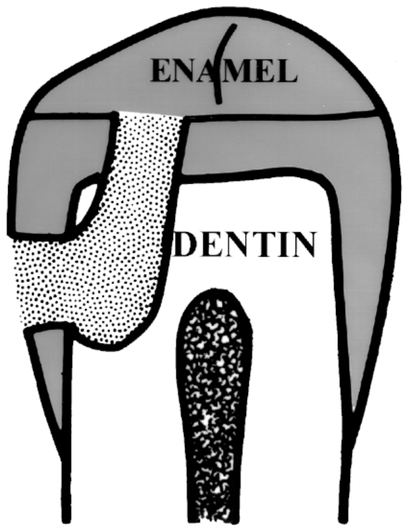

Fig. 1. Schematic illustration of the tunnel restorative technique.

to the buccopalatinal width. The teeth were divided into 5 test groups of 20 teeth each, with an equal ratio of small, medium, and large teeth in each group, and a control group of 14 teeth. On the mesial surfaces, a 1.5-mm deep cavity was prepared with a high speed round bur (009) in a direction perpendicular to the long axis of the tooth, 2 mm below the marginal ridge. The bur was angled approximately 45° in the buccal and palatinal direction to create a cavity in the dentin.

2. Tunnel restoration

The teeth were mounted to a level 1 mm below the cementoenamel junction in a block of acrylic resin. The block was mounted in a vice with a universal ball-joint, enabling the tooth to be aligned as desired. A drill-stand, with a straight hand piece held by a clamp, enabled a vertical drilling procedure to be performed. A round bur (012) was fastened in the hand piece and drilling commenced with a water spray by lowering the hand piece. Entry was made through the mesial occlusal fossa. The tunnels were extended in a buccal and palatinal direction by moving the drill clamp in a buccopalatinal direction. With this device, standardized tunnels were prepared with an approximately 1.7-mm buccopalatinal dimension. The mean width of the remaining marginal ridge was afterwards measured to 1.1 mm (range 0.9–1.3 mm) with a digital Image Analyzer (Cue-2, version 4.0, 1992, Galai Production Ltd., Migdal Haemek, Israel). The five groups of preparations were filled with restorative materials that were handled according to the manufacturers' instructions.

- *Group 1:* Tunnels filled with the conventional glass ionomer cement *Baseline*, (DeTrey/Dentsply, Konstanz, Germany). The preparations were gently dried, and material from a capsule was applied with a Centrix syringe with a plastic nozzle. Two layers of varnish were applied.
- *Group 2:* Tunnels filled with the resin-modified glass ionomer cement *Fuji II LC* (GC Corporation, Tokyo, Japan). The conditioner was applied for 10 s. the preparations were rinsed for 30 s and gently dried. The material (powder/liquid ratio 3.0 g:1.0 g) was applied with a Centrix syringe with a plastic nozzle and light-cured in two layers. Two layers of varnish were applied.
- *Group 3:* Tunnels filled with the glass ionomer cermet cement *Ketac Silver* (Espe, Seefeld, Germany). The preparations were rinsed and gently dried. The material was applied from a capsule supplied with a plastic tip (Pipen, Piteå, Sweden). Two layers of varnish were applied.
- *Group 4:* Tunnels filled with the composite resin *Z100* (3M Co, St. Paul, MN, USA). A bonding agent (Scotchbond Multi-Purpose Adhesive) was used to bond the restoration to the tooth structure. The preparations were etched with maleic acid for 15 s, rinsed, and dried. The primer was applied and gently dried. A thin resin layer was applied and light cured for 10 s. The restorative material was injected from a preloaded syringe, packed into the tunnel, and light-cured in two layers from the occlusal surface.
- *Group 5:* Tunnels filled with the resin-modified glass ionomer cement *Vitremer* (3M Co, St. Paul, MN, USA). The primer was brushed on the preparation for 30 s, dried, and light-cured. The material (powder/ liquid ratio 2.5 g:1.0 g) was applied with a Centric syringe with a plastic nozzle and light-cured.
- *Group 6:* Control group of intact teeth.

The tunnel-restored teeth were stored for 2 weeks in water prior to testing.

3. Mechanical testing

The strength of the marginal ridges was tested in a servohydraulic mechanical testing machine (MTS 810, MTS systems Corp., Minneapolis, MN, USA) using a stepwise, dynamic loading procedure. The tooth in the acrylic block was placed in saline solution, and load was transferred to the ridge by a steel plunger (Fig. 2). The rod was notched to avoid contact with the occlusal part of the filling, and to prevent it from sliding off the ridge during testing. The tip diameter of the rod was 1 mm. The ridges were subjected to sine-shaped dynamic forces with a frequency of 2 Hz, initially varying between 50 N and 100 N for 500 cycles. The peak forces were then incremented by 50 N and another 500 cycles applied. The peak load was incremented by 50 N until failure occurred. The load level and the number of cycles were recorded at the time of failure. A maximum energy index (MEI), indicating the maximum energy that the ridges could endure, was calculated according to the expression:

$$MEI = L_1 \cdot N + L_2 \cdot N + L_3 \cdot N + \ldots + L_{max} \cdot N_{failure}$$

where MEI is the maximum energy index. L_1 is the first load level (100 N), L_2 the second load level (150 N), and so forth (increments of 50 N) up to L_{max}, which is the load level at failure. N is the number of cycles (500), and $N_{failure}$ is the number of cycles endured at L_{max} before failure occurs (Fig. 2).

4. Measurement of elastic modulus

In order to assess the rigidity and the potential ability to mechanically support tooth substance, measurements of the elastic modulus were undertaken for each material. Cylindrical specimens (5 × 3 mm, n = 10) from each product were produced in polytetrafluoroetylene molds. The materials were handled as described previously. After 2 weeks of water storage, the specimens were subjected to compressive testing (0.02 mm/s). The elastic modulus, expressed in gigapascals (GPa), was computed from the resulting stress-strain curve based on the initial, nearly straight portion of the curve.

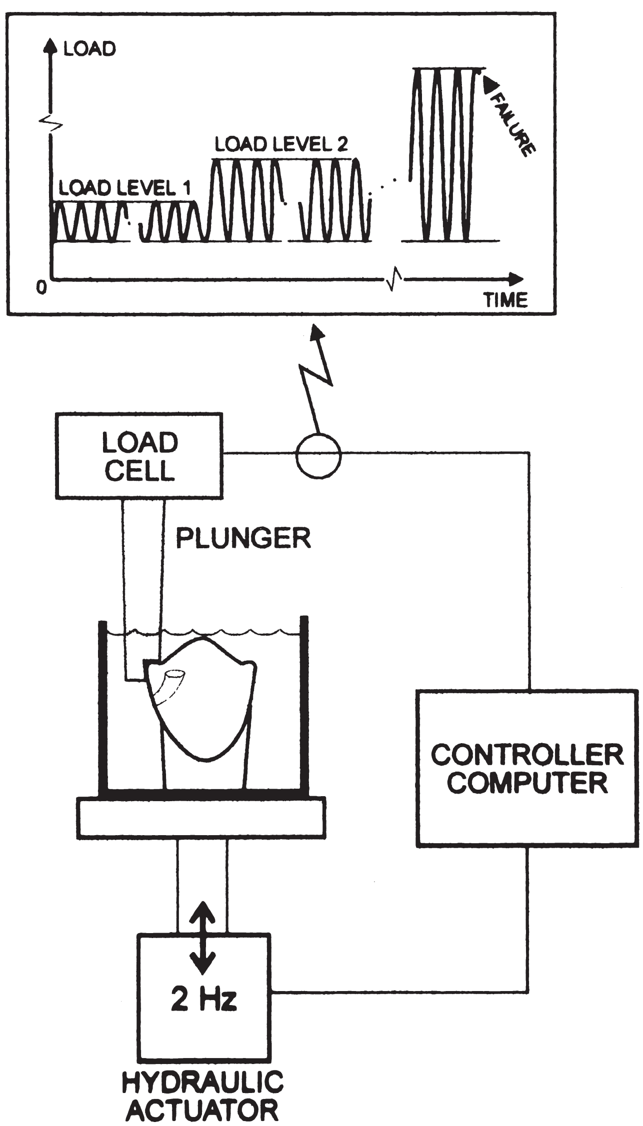

Fig. 2. Schematic illustration of the testing procedure of tunnel restored teeth subjected to a stepwise, dynamic loading procedure.

5. Statistical analysis

Median values and quartiles (Q_1 and Q_3) were used to express the average and the variation of the measurements. The Kruskal-Wallis test was used to test the overall difference in medians between groups, revealing a p-value of 0.005. The Mann-Whitney test was then used to test for significant differences between individual pairs of observations. The chosen level of significance ($\alpha = 0.05$) was adjusted according to the number of paired comparisons.

6. Results

With the median strength of intact teeth set at 100%, it was possible to achieve approximately 47%–62% of this strength in the restored teeth (Table 1). The statistical analysis revealed that there was no significant difference between the test groups concerning resistance to marginal ridge fracture. Each of the test groups, however, differed significantly from the control group.

Fracture patterns in each group were similar. The fracture was generally triangular in shape with the apex of the triangle at the marginal ridge and the base at the approximal exit of the tunnel. Repairing the fractured teeth with a traditional class II preparation would not necessitate significant alterations.

Results from the measurements of elastic moduli revealed that the composite resin *Z-100* had the highest elastic modulus (7.15 GPa), while one of the resin-modified glass ionomers, *Fuji II LC*, displayed the lowest (3.50 GPa) (Fig. 3).

Table 1
Medians and quartiles (Q_1 and Q_3) of the energy required to fracture the teeth for each group

	MEI (%)*			Lmax (N)*
		Quartiles		
	Median*	Q_1	Q_3	Median*
Ctr	732,400 (100)	516,888 (71)	997,175 (136)	400 N
Baseline	454,475 (62)	235,500 (32)	594,763 (81)	325 N
Vitremer	409,250 (56)	238,875 (33)	869,913 (119)	300 N
Fuji II LC	391,700 (53)	145,850 (20)	594,063 (81)	300 N
Ketac Silver	352,475 (48)	235,563 (32)	568,600 (78)	275 N
Z-100	342,025 (47)	241,750 (33)	558,362 (76)	275 N

* Median of intact teeth = 100%; MEI = maximum energy-index; Lmax = absolute load level in newtons (N) at failure.

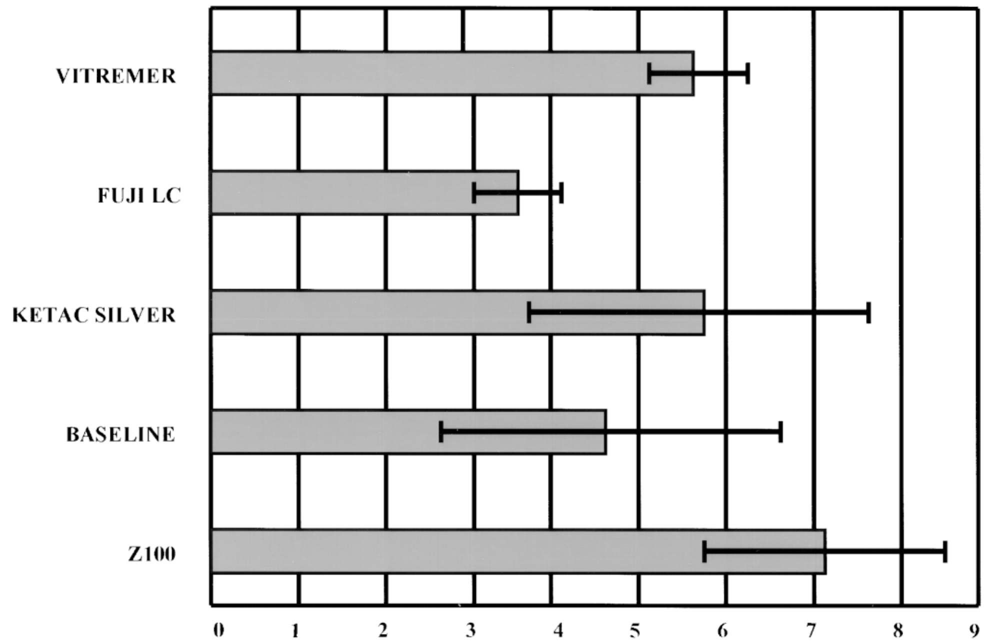

Fig. 3. Elastic moduli for each product. Mean and standard deviation in gigapascals (GPa).

7. Discussion

This study, which evaluated the load required to produce marginal ridge fracture in tunnel-restored teeth, showed that there was no significant difference between the various adhesive materials in their ability to strengthen the restored teeth. There was a difference, however, between the restored teeth and the sound teeth.

The location and dimension of the tunnel preparations corresponded with the design preferred by clinicians, i.e. with the occlusal access in the fossa and a remaining marginal ridge thickness of approximately 1 mm [12,13]. It can be assumed that a rigid filling material could offer better support for the marginal ridge than a more flexible one. Even though the elastic moduli of the present materials differed by a factor of about two, there was no correlation between the elastic moduli and the strength of the ridge of the filled teeth. The elastic moduli of the materials were lower than for dentin or enamel [24].

A main factor affecting the strength of the approximal wall is probably the bonding ability of the restorative material. By etching the enamel, a mechanical interlock between the composite resin and the treated enamel surface is obtained [25]. It has been difficult to achieve the same effect with dentin, but restorative resins may bond to dentin via recent bonding agents that penetrate into conditioned dentin [26]. One major disadvantage of composite resin materials is their inherent polymerization shrinkage. This shrinkage is capable of damaging tooth structure [27], especially when efficient bonding agents are used with composite resins that possess a high modulus of elasticity [28,29]. It is therefore possible that the material, due to contraction, might create cracks that may cause fractures.

The adhesion of glass ionomer cements to tooth structure is believed to be a diffusion-based adhesion resulting from chemical bonding that involves penetration of both dentin and enamel [30]. Conventional chemical setting glass ionomer materials have been reported to shrink 3–4% in volume, but slow setting may permit stress relief within the restoration, which limits the forces exerted on the surrounding tooth structure [31]. Bond strength is reported to be low [32], but the adhesive strength is difficult to measure because the cement tend to fail cohesively [33,34]. The cohesive properties are not improved by the addition of silver particles [35]. Apparently, a material with improved cohesive strength would be advantageous. This has been achieved in the case of the resin-modified glass ionomer materials [36]. Bond strength is reported to be greater than conventional materials [37]. Two types of setting reactions take place in these materials: a conventional glass-ionomer reaction between fluoroaluminosilicate glass and polycarboxylic acid, and a light-activated free radical polymerization of pendant methacrylate groups. Resin-modified glass ionomer cements exhibit a rapid setting contraction through the polymerization of the polymer component [38]. Moreover, light-curable glass-ionomers absorb water on exposure to aqueous environments and swell due to strongly hydrophilic components [39]. After an initial inward pull on the approximal wall, these properties could cause outward pressure, which may further increase the risk of fracture.

Comparison of the results obtained with destructive testing should be interpreted carefully because they vary with the methods used [40]. This study sought to emulate a clinical situation, as tooth fracture is most likely caused by the progression of small cracks during dynamic, repeated loading [41]. The results are in accordance with those reported by Fasbinder et al. and Purk et al., who showed that a narrow approximal wall will weaken the marginal ridge beyond the ability of the glass ionomer material to reinforce it [42,43]. While Purk et al. showed that conventional glass ionomer cement restored the tooth to a higher strength than composite resin when tested at the marginal ridge, a similar compressive study showed that composite resin strengthened the marginal ridge to a greater degree than did cermet glass ionomer [44]. It has also been shown that the cermet materials have reduced adhesion to tooth substance compared with the conventional cements [45].

Preservation of the approximal enamel wall is the main objective of the tunnel restoration [46]. Clinical studies have shown that marginal ridge fracture is a problem with tunnel restorations [7,47]. Nevertheless, our results confirm earlier findings [10] that the remaining marginal ridge should be of some thickness to withstand the occlusal forces. The opening should therefore be positioned more centrally than is generally preferred by clinicians. Dentin, with its elasticity, rigidity, and toughness, provides a firm foundation for tooth reconstruction and the impact of mastication. Regardless of the properties of the present filling materials, it appears that none of the tested materials could adequately replace the functional aspects of dentin.

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