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Fracture resistance of root filled premolar teeth restored with direct composite resin with or without cusp coverage

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Abstract

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Aim To evaluate the fracture resistance and fracture patterns of root filled maxillary first premolar teeth (with mesio–occlusal cavity preparation) restored with several composite restoration designs.

Methodology One hundred extracted sound human maxillary first premolars were randomly divided into five groups. Group 1 remained untreated (negative control). Conventional root canal treatment with additional mesial–occlusal cavity preparation was carried out on teeth in groups 2–5. In group 2, the teeth were restored intra-coronally with direct composite resin (positive control). In group 3, the palatal cusps of the teeth were reduced, and the cavities were restored with composite resin covering the palatal cusp (partial coverage). In group 4, the buccal and palatal cusps along with the distal marginal ridges were reduced; the cavities and cusps were restored with composite resin (conventional full coverage). In group 5, the buccal and palatal cusps were reduced but the distal marginal ridges were conserved. The cavities and the cusps were restored with composite resin (modified full coverage). All teeth were subjected to a progressive compressive loading parallel to their longitudinal axis until fracture. Fracture resistance was analysed using the one-way ANOVA and Fisher's LSD test. Fracture patterns were analyzed with chi-square test. The significance level was set at 0.05.

Results The fracture resistance (mean ± SD) of groups 1–5 was 1131 ± 207*N*, 904 ± 184*N*, 927 ± 224*N*, 1095 ± 289*N* and 1085 ± 243*N*, respectively (groups 1, 4, 5 > groups 2, 3; $P = 0.004$). Cusp fractures were recorded as the fracture pattern in 20 (100%), 19 (95%), 16 (80%), 8 (40%) and 12 (60%) premolars in groups 1–5, respectively (groups 1, 2 > groups 4, 5; group 3 > group 4; $P < 0.001$).

Conclusions When direct composite resin was used to restore root filled maxillary first premolar teeth involving a proximal surface, those restored with full-coverage designs had greater fracture resistance.

Keywords: composite, cusp coverage, endodontic, fracture resistance.

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Introduction

Extra-coronal restorations such as crowns have been recommended for root filled posterior teeth to prevent fractures and to minimize coronal leakage (Chu *et al.* 2005). Aesthetic crowns with appropriate labial profile in maxillary first premolars often require substantial tooth reduction. Edelhoff & Sorensen (2002) reported that conventional full crown preparations with buccal shoulders (1.4 mm) and lingual chamfers (0.7 mm) removed substantial amounts (75.6%) of tooth structure. In clinical practice, the remaining coronal tooth structure and functional requirements are important

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for the dentist to determine the optimum type of restoration (Faria *et al.* 2011). Caries, cavity preparation and subsequent endodontic procedures often necessitate post insertion. To conserve more tooth structure, Mannocci *et al.* (2002) suggested using direct composite restorations to restore teeth following root filling. This was supported by Plotino *et al.* (2008) who found similar fracture resistance of root filled teeth with direct or indirect composite restorations. The benefits of composite resin restorations include conservation of both tooth structure and the aesthetics of the buccal surface. In addition, the adhesive property of composite resin restoration allows minimal cavity preparation and provides intra-coronal reinforcement (Hilton & Broome 2006, Soares *et al.* 2008).

Studies suggest cusp coverage along with composite restorations minimize tooth fracture (Soares *et al.* 2008, Mondelli *et al.* 2009, ElAyouti *et al.* 2011). These studies investigated fracture resistance of premolars with mesial–occlusal–distal (MOD) cavity preparations. Nevertheless, there are circumstances when the cavity preparation involves only one proximal surface, but there are few studies that have investigated premolars with mesio–occlusal (MO) or disto–occlusal (DO) cavity design. Extrapolation of the results from MOD to MO/DO cavity design cannot be justified because the marginal ridge has a substantial influence on tooth strength (Shahrbaf *et al.* 2007). Thus, it is prudent to study the fracture resistance of root filled teeth with MO/DO cavities. The aim of the study was to evaluate the fracture resistance and fracture patterns of root filled maxillary premolars teeth (with MO cavity preparation) restored with several composite resin restoration designs. The null hypothesis tested was that there is no difference in the fracture resistance or fracture patterns of root filled maxillary premolar teeth restored with different composite resin restoration designs.

Materials and methods

Human first maxillary premolars with single fused roots extracted for orthodontic reason on patients below 18 years old were collected. Parents of the patients were informed of the purpose of the study and consented to donate the extracted premolars for research purposes. The extracted teeth were cleaned with a curette to remove attached periodontal tissue, calculus and plaque. They were examined under a 10× stereo-microscope, and teeth with caries, cracks or significant development defects such as extensive enamel hypoplasia were excluded. Sound teeth with fully developed roots were selected. The root length and the mesio–distal width of the crown were measured with a vernier calliper (Beijing Precision Instrument Co., Ltd, Beijing, China). They were stored in 0.5% chloramine T solution at 23 °C and used for this study within 3 months.

One hundred stored premolars were chosen and randomly assigned to five groups (n = 20). The roots of the teeth were covered with a 0.2 mm layer of vinylpolysiloxane (VPS) impression material (Virtual; Ivoclar Vivadent, Schann, Lichtenstein) and embedded in acrylic resin (Shanghai Medical Instruments Co., Ltd, Shanghai, China) up to 2 mm below the cementoenamel junction (CEJ) to simulate the periodontal ligament and alveolar bone (Nothdurft *et al.* 2008). Group 1 was unaltered, which served as the negative control. Teeth in the other four groups (group 2–5) underwent conventional root canal treatment. The endodontic access cavities were prepared, and the pulp was extirpated. Size 10 K files (Mani Inc., Tochigi, Japan) were inserted until their tips could be seen at the apical foramen. The working length was determined by subtracting 0.5 mm from this length. The canals were prepared using a step-back technique with sodium hypochlorite (5.25%) solution being used as the irrigant. Size 30 K files (Mani Inc) were used as the master apical file. Subsequently, size 35 and 40 K files were inserted 1 mm shorter than the preceding files. Finally, the coronal one-third of the canals was flared with Gates–Glidden drills from size 1–3 (Mani Inc). After drying the canals with paper points (Diadent, Chongju City, Korea), the prepared canals were filled with cold lateral compaction using gutta-percha points (Diadent) and a zinc oxide eugenol based sealer (Endomethasone, Septodont, Saint Maurdes Fosses, France).

Slit design MO cavity preparations (Gonzalez-Lopez *et al.* 2006) were prepared in groups 2–5. The buccolingual width was 4 mm and the proximal gingival margin was 1 mm above the CEJ (Fig. 1). Group 2 had MO cavity preparations and served as the positive control. Group 3 had MO cavity preparations with 2 mm reduction on the palatal cusps (partial coverage). Group 4 had MO cavity preparations with 2 mm reduction on both buccal and palatal cusps along with distal marginal ridge (conventional full coverage). Group 5 had MO cavity preparations with 2 mm reduction on both buccal and palatal cusps but conserved the distal marginal ridge (modified full coverage). The teeth were mounted on a stable platform and prepared with coarse grit diamond burs

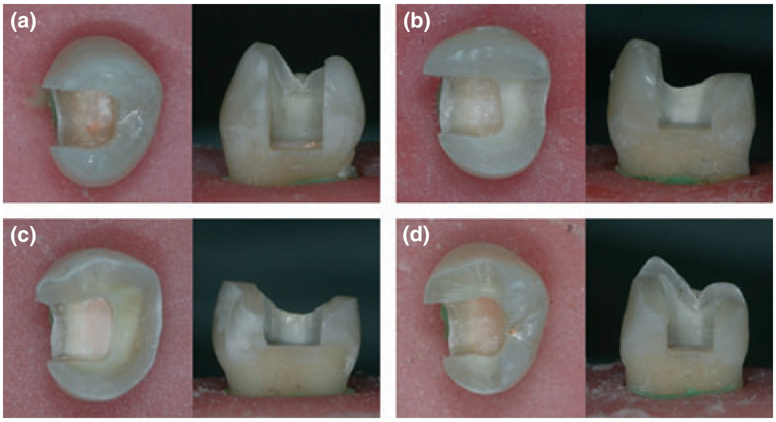

Figure 1 Preparation designs of the root filled premolars. (a) Group 2, mesio–occlusal (MO) cavity preparation, conventional intracoronal restoration; (b) Group 3, MO cavity preparation, partial coverage; (c) Group 4, MO cavity preparation, conventional full coverage; (d) Group 5, MO cavity preparation, modified full coverage.

(TR12; Mani Inc), in turbine handpiece under water coolant. The intended 2 mm cuspal reduction was marked with an oil based marker pen before preparation. All the measurements were taken with a vernier calliper (Beijing Precision Instrument Co., Ltd).

Gutta-percha was removed to the depth of 1 mm below the proximal gingival margin, and resin-modified glass ionomer cement (Fuji II LC capsule; GC, Tokyo, Japan) was used as the base material. An etch-and-rinse three-step adhesive (Scotch Bond Multipurpose; 3M ESPE, St. Paul, MN, USA) was applied. Nanohybrid composite with low shrinkage and shrinkage stress

Figure 2 The fracture resistance test.

(Tetric-N Ceram; Ivoclar Vivadent) was used to restore the teeth using a layering technique. Proximal contact areas and occlusal surfaces were restored using prefabricated VPS indices. The restorations were finished using superfine diamond points (SF102R; Shofu, Kyoto, Japan) and polished using silicone points (Silicone Midi; Shofu).

The teeth were stored in distilled water for 1 week to allow the endodontic sealer to set completely. Fracture resistance was tested as described by Reeh *et al.* (1989) and Mondelli *et al.* (2009). The teeth were mounted in a customized fixture and subjected to axial compressive loading with cross-head speed of 0.5 mm min^{-1} (Model 3367; Instron, Canton, MA, USA). The vertical loading force was applied through an 8 mm-diameter stainless steel ball parallel to the tooth axis. The contact points were approximately half way up the cusp triangular ridge (Fig. 2). Fracture resistance was recorded at the peak of the load-displacement curve. In addition, the fracture patterns were recorded using a simplified classification of cracked tooth syndrome proposed by the American Association of Endodontics (2008). The fracture patterns recorded were type 1 fracture – fractured cusp – which may extend to the cervical third of the crown or root (restorable) and type 2 fracture – fractured tooth – which includes cracked tooth and split tooth (nonrestorable). Fracture resistance of premolars between the five groups was compared using the ANOVA/Fisher's LSD test. Fracture patterns of the five groups were analysed with the Pearson chi-square test. Pairwise comparison was carried out to calculate the odds ratio. The significance level was set at 0.05.

Results

The results were summarized in Table 1. There was no statistically significant difference between the root length and crown width of premolars amongst the five groups. The mean fracture resistance for groups 1–5 were 1131 ± 207*N*, 904 ± 184*N*, 927 ± 224*N*, 1095 ± 289*N* and 1085 ± 243*N*, respectively. The fracture resistance of premolars in groups 1, 4 and 5 were significantly higher than that of groups 2 and 3 ($P = 0.004$). Fractured cusps were observed in 20 (100%), 19 (95%), 16 (80%), 8 (40%) and 12(60%) premolars in groups 1–5, respectively. Multiple comparisons found groups 1 and 2 had more fractured cusps than groups 4 and 5, and group 3 had more than group 4 ($P < 0.001$). The odd ratios (confidence interval) of fractured tooth of groups 4 and 5 to group 2 were 28.5 (3.2–257.5) and 12.7 (1.4–114.4), respectively. In group 2, 18 of 19 cusp fractures were adhesive failures, 14 of them occurred along the palatal–adhesive interface. In group 3, 12 of 16 cusp fractures were adhesive failures, and 10 of them occurred along the buccal–adhesive interface.

Discussion

Many factors such as the amount of residual tooth structure, the polymerization stresses of composite resin, the occlusion and opposing dentition contribute to the achievement of clinical success with direct posterior composite restorations (Deliperi & Bardwell 2008). This study allowed standardized assessment of the tooth fracture resistance in a laboratory environment. Fracture resistance could also be affected by the use of fibre posts and ceramic restorations. However, this study aimed to investigate and to compare the fracture resistance with several composite restoration designs.

A concern of composite resin restorations is polymerization shrinkage and shrinkage stress, which is affected by cavity design or the C-factor. Dos Santos *et al.* (2009) suggested that the C-factor played an essential role in gap formation in composite restorations, which could be reduced by using an incremental light-curing protocol during composite resin placement. However, *in vitro* (Duarte *et al.* 2007) and *in vivo* (Van Dijken 2010) studies have reported no significant difference in marginal integrity between horizontal incremental placement technique and oblique incremental technique with a high C-factor. There is also disagreement on the use of flowable composites or compomers to improve the marginal seal (Van Dijken 2010). In a recent study, Chuang *et al.* (2011) reported teeth using flowable composite lining and increased cusp depth may aggravate cusp flexure. This may affect the fracture resistance of the tooth and should be noted when restoring the tooth with composite resin. Nanostructured dental composites can have superior mechanical properties such as increased elastic modulus, strength or resistance to fatigue fracture that can easily be tuned by small modifications of their constituents (National Institute of Dental and Craniofacial Research 2010). The new generation of composite resin might also contribute in maintaining tooth strength by reducing the stress developed in the tooth (Mondelli *et al.* 2009). Thus, in this study, a standardized horizontal laying technique and the same nanostructured composite resin were adopted, and no flowable composite resin was used as lining material in any group.

In this study, the fracture resistance of restored premolars with various designs was different, and thus, the null hypothesis was rejected. It was apparent that conventional or modified full-coverage designs significantly strengthened the teeth, and this is in agreement

Table 1 Root length, crown width, fracture resistance and fracture type according to treatment group

Group (n = 20)	Root length/mm (SD)	Crown width/mm (SD)	Fracture resistance/*N* (SD)	Fractured cusp/*n* (%)	Favourable fracture/*n* (%)
1	13.9 (1.3)	7.7 (0.4)	1131 (207)	20 (100)	18 (90)
2	15.1 (6.6)	7.7 (0.4)	904 (184)	19[a] (95)	4 (20)
3	13.4 (1.4)	7.7 (0.4)	927 (224)	16[b] (80)	6 (30)
4	13.5 (0.9)	7.6 (0.3)	1095 (289)	8 (40)	4 (20)
5	13.1 (1.3)	7.7 (0.4)	1085 (243)	12 (60)	7 (35)
P value (multiple comparison)	0.302	0.69	0.004 (Gp1,4,5 > 2,3)	<0.001	<0.05

[a]18 were adhesive failures, and 14 of them occurred along lingual adhesive interface.
[b]12 were adhesive failures, and 10 of them occurred along buccal adhesive interface.

with other studies (Mondelli *et al.* 2009, ElAyouti *et al.* 2011). This finding suggests that composite resin restoration should cover both buccal and lingual cusps (full coverage), to reinforce root filled premolar teeth. The modified full coverage design is preferred because the distal marginal ridge is conserved and less tooth reduction is required.

The fracture resistance of the full coverage composite resin restorations in this study was almost the same as the intact teeth. Previous studies reported that fracture resistance of MOD restorations could be improved by full coverage design, but was significantly lower than the intact teeth (Soares *et al.* 2008, Mondelli *et al.* 2009). Reeh *et al.* (1989) reported that loss in tooth stiffness was related to loss of marginal ridge integrity. They reported loss of one and two marginal ridges weakened the tooth by 40% and 60%, respectively. Thus, conserving the marginal ridge and proximal wall is imperative to preserve tooth strength. Shahrbaf *et al.* (2007) reported that tooth strength could be maintained substantially when at least 1 mm of the marginal ridge thickness was kept. Similar results were also found in this study by saving/reducing the distal surface and marginal ridge coincidentally. As shown by this study, reducing the height of the marginal ridge by 2 mm had no significant effect on tooth strength as there was no significant difference in the fracture resistance of the restorations with conventional and modified full-coverage designs.

Teeth *in vivo* are subjected to short but large occlusal loads during chewing, and acute occlusal stress is distributed throughout the entire tooth (Eliguzeloglu *et al.* 2010). The axial compressive loading applied in this study was a repeatable and robust test. Intracoronal restorations and partial coverage restorations frequently fractured at the adhesive interface, probably because failure of the tooth–restoration interface is more likely than failure of the composite material. Thus, intra-coronal restorations and partial coverage restorations had more cusp fractures than full coverage restorations. This is in agreement with previous studies (Fennis *et al.* 2005, Mondelli *et al.* 2009). This study showed most intra-coronal restorations had adhesive failures on the palatal cusps. The load on the occlusal surface might cause stress concentration in the palatal cusp, and the restoration thus fractured at its weakest link. Fractures on restorations with partial coverage occurred primarily on the buccal cusps, because the buccal adhesive interface was the weak link under loading. In restorations with full cuspal coverage, fractures might occur in other locations where stress was concentrated. Many full coverage composite restorations in this study had tooth fractures, but intact tooth exhibited coronal fractures when they failed with compressive loading. Seow *et al.* (2008) reported full-coverage restorations demonstrated that stress built up along the intercuspal fissure under loading. This might explain why more tooth fractures were observed in restorations with full cuspal coverage. It should be emphasized that despite an increased mean fracture load, the full coverage restorations had an enhanced risk of nonrestorable fractures.

In this study, the intraoral ageing factors were not taken into consideration. This laboratory study also did not completely mimic the occlusal force during mastication. Similar to all laboratory studies, there were limitations, and the results should be interpreted with care. According to the results of this study, conventional or modified full coverage of composite restorations are preferred for root filled teeth. Further studies should be conducted to evaluate the effect of cyclic loading and ageing on tooth strength. With the advancement of computer technology, finite element analysis study can be used to study stress distribution on teeth. The three-dimensional finite element model allows us to study the load direction and can indicate the distribution of stress and displacement. Furthermore, finite element stress analysis studies can help to improve the designs of full-coverage composite restorations.

Conclusion

When direct composite resin was used to restore root filled maxillary first premolars involving a proximal surface, teeth restored with full or modified full-coverage designs had higher fracture resistance than intra-coronal or partial coverage design. The modified full-coverage design is preferred because the distal marginal ridge is conserved and less tooth reduction is required.

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