Original Article

Fracture Resistance of Teeth Restored with Direct and Indirect Composite Restorations

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Abstract

Objective: Tooth fracture is a common dental problem. By extension of cavity dimensions, the remaining tooth structure weakens and occlusal forces may cause tooth fracture. The aim of this study was to evaluate and compare the fracture resistance of teeth restored with direct and indirect composite restorations.

Materials and Methods: Sixty-five sound maxillary premolar teeth were chosen and randomly divided into five groups each comprising thirteen. Fifty-two teeth received mesio-occluso-distal (MOD) cavities with 4.5mm bucco-lingual width, 4mm pulpal depth and 3mm gingival depth and were divided into the following four groups. G-1: restored with direct composite (Z-250, 3M/ESPE) with cusp coverage, G-2: restored with direct composite (Z-250) without cusp coverage, G-3: restored with direct composite (Gradia, GC-international) with cusp coverage, G-4: restored with indirect composite (Gradia, GC-International) with cusp coverage. Intact teeth were used in G-5 as control. The teeth were subjected to a compressive axial loading using a 4 mm diameter rod in a universal testing machine with 1 mm/min speed. Data were analyzed using one-way ANOVA and Tukey tests.

Results: The mean fracture strength recorded was: G-1: 1148.46N±262, G-2: 791.54N±235, G-3: 880.00N±123, G-4: 800.00N±187, G-5: 1051.54N±345. ANOVA revealed significant differences between groups ($p<0.05$). Tukey test showed significant difference between group 1 and the other groups. There was no significant difference among other groups.

Conclusion: Direct composite (Z-250) with cusp coverage is a desirable treatment for weakened teeth. Treatment with Z-250 without cusp coverage, direct and indirect Gradia with cusp coverage restored the strength of the teeth to the level of intact teeth.

Key Words: Tooth Fracture; Composite Resins; Bicuspid

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Received: 28 March 2013
Accepted: 23 June 2013

Journal of Dentistry, Tehran University of Medical Sciences, Tehran, Iran (2013; Vol. 10, No.5)

INTRODUCTION

Tooth fracture is a common dental problem. Many factors such as tooth anatomy contribute to cusp fracture; however, cavity preparation procedures seem to be the major cause of most cuspal fractures [1-4].

Lopes et al. (1991) have shown that large intracoronal mesio-occluso-distal (MOD) preparation in premolar teeth reduces cusp stiffness to one third of the level of sound teeth [5]. Extending cavity dimensions, the remaining tooth structure weakens and occlusal forces will cause more deformation in the cusps [6]. Studies that have used photoelastic analysis have demonstrated that occlusal coverage by onlays reduces the stress in the remaining tooth structure [7].

On the other hand, studies have shown that the weakening effect of preparation can be alleviated with the use of adhesive materials [8-11]. It has been suggested that the adhesive nature of composite has the ability to bind the cusps and decrease flexion, which is the main cause of fractures in teeth restored with amalgam [12,13].

Furthermore, composite has a lower elastic modulus than amalgam; therefore, more load is absorbed within the composite compared to amalgam. Composite, therefore, may transmit lesser load to the underlying tooth structure [14]. In an effort to overcome problems of primary polymerization shrinkage of direct restorations, various indirect techniques for producing composite restorations have been developed [15].

A new generation of composites is classified by Touati as second-generation laboratory composite, or ceramic optimized polymers (Ceromers) [16]. The manufacturers and research data claim that they provide enhanced flexural strength, increased elasticity and fracture resistance compared with that of direct composites [16-19].

Regrettably, specific information regarding the restoration priority of the large cavities with direct or indirect techniques is scarce; therefore, to substantiate the present data and also to investigate the new aspects of the subject, this study was conducted to compare the compressive fracture resistance of large cavities restored with cusp coverage using direct and indirect resin composite.

MATHERIALS AND METHODS

Selection and Preparation of Teeth

Sixty-five newly extracted (not more than two months) sound human maxillary premolars were used. Any calculus and soft tissue deposits were removed from the teeth using hand scaler (Gracey Curette, SG 17/18, Hu-Friedy, Chicago, USA). Each tooth was carefully examined under light microscope (X10) for any existing enamel fissure or fracture. The teeth were stored in 0.5% chloramine solution for 48 hours, and then transferred to distilled water until preparation. The dimensions of the teeth were measured and taken into consideration for grouping. In order to minimize the influence of size and shape variation of the teeth on the results, the height and width of each tooth was primarily measured bucco-lingually and mesio-distally with a digital caliper (Serial NO: 0026536, Mitotoya, Japan) with an accuracy of 0.01 mm and then the teeth were classified according to their size obtained from the following equations:

Tooth height = Buccal cusp edge to CEJ (Y1) + Palatal cusp edge to CEJ (Y2)/2

Tooth width = Mesiodistal width in height of contour area in palatal and buccal (X)

Tooth size = Tooth height/Tooth width

Subsequently, the teeth were distributed randomly into five groups of 13 each, and prepared as follows:

Group 1: Teeth restored directly with resin composite (Filtek Z-250, 3M/ESPE Co., St. Paul, MN, USA) with cusp coverage.

Group 2: Teeth restored directly with resin composite (Filtek Z-250, 3M/ESPE Co., St. Paul, MN, USA) without cusp coverage

Group 3: Teeth restored directly with resin composite (Gradia, GC-International) with cusp coverage

Group 4: Teeth restored indirectly with resin composite onlay (Gradia, GC-International)

Group 5: Intact teeth (Control)

Templates were made for the teeth undergoing cavity preparation, using bleaching tray material to serve as guidance during reconstruction of the occlusal surface of the prepared teeth in groups 1 to 4. MOD cavities were prepared with round line angles and in order to have equal dimensions in all teeth (Fig 1), they were repeatedly checked with a digital caliper with an accuracy of 0.01mm (Serial No: 0020536, Mitutoyo, Japan). In groups 1, 2 and 3 that received direct filling, the walls of the cavity were prepared parallel, while in group 4; the walls were prepared with 15° divergence.

Preparations were carried out with diamond cylindrical bur (No 837L/012, Tizcavan, Iran) and each bur was replaced after 5 preparations. All preparations were done under water cooling. Group 5 served as the unprepared control group. The composition of the materials that were used in this study are presented in Table 1.

Direct Restoration Procedures

In groups 1 and 2, the teeth were restored with Filtek Z-250 composite (shade A3). First, the teeth were etched with phosphoric acid for 15 seconds, rinsed (30 seconds) and then dried (10 seconds). Two layers of adhesive (Single Bond, 3M/ESPE Co., St. Paul, MN, USA) were applied and gently air dried for 2 seconds, and then light-cured for 10 seconds. The composite was placed using the incremental technique and each layer was cured for 20 second saccording to the manufacturer’s instruction. In group 3, G-bond (GC-International) was applied over the teeth, and then direct Gradia posterior composite (shade A3, Dentin) was placed. The adhesive was applied with mini-sponge and dried with high pressure of air flow as instructed by the manufacturer and cured for 10 seconds.

Table 1. Composition of the Material Used

Material	Company	Batch Number	Composition
Filtek Z-250	3M Dental Products, st. Paul, MN, USA	$1370A_3$	Filler: Zirconia, Silica (0.01-3.5 μ m), %60 Volume Matrix: BISGMA, UDMA, BISEMA
Single Bond	3M Dental Products, st. Paul, MN, USA	1105	Conditioner: Phosphoric acid %35. Silica thickner BISGMA: Self priming adhesive, HEMA A glycerolate dimethacrylate bisphenol dimethacrylate (HEMA-TMDI), Urethance Copolymer alcheonic acid, Ethanol, Water
Gradia, Direct	GC Dental products corp. 2-285 Torllmatsu-Cho, Kasugai, Aichi, Japan	002005	Filler: Silica, Pre-polymerized filler, Flouroaluminosilicate glass, %65 volume Matrix: UDMA, Ethylen dymethacrylate
G-Bond	GC Corporation 76-1 Hasunuma-cho,itabashi-KU, Tokyo, Japan	002277	Acetone, 4-Methacryloxyethyltrimellitic acid anhydride (4-META), Urethane Dimethacrylate (UDMA), Dimethacrylate component, Phosphoric acid ester, Water, Sillica Filler
GC Fuji Plus	GC Dental products corp. 2-285 torllmatsu-cho, lasugai, Aichi, Japan	001409	Powder: Flouroalumino silicate Liquid: Acrylic and maleic acid copolymer, HEMA, Water, Initiator Treating agent: citric acid (%10), Ferric chloride (%2) and water

Each layer of composite was light-cured for 20 seconds.

A matrix band was placed and then the restorative material was inserted in five layers as demonstrated in Fig. 2. Composites were polymerized with a halogen curing light (ARIALUX, Violet Spectrum Industries, Iran) with an intensity of 680-720 mW/cm2. Before restoring each cavity, the intensity of the apparatus was checked by the built-in radiometer. Each layer was polymerized according to the manufacturer's instruction, and after placing the last layer, the aforementioned templates were placed on the teeth to control the thickness of material covering the cusps. Then the restorations were finished and polished with diamond burs and discs (Soflex, 3M/ESPE Co., St. Paul, MN, USA), and then stored in water at room temperature for 24 hours.

Indirect Restoration Procedures

Impressions of the prepared teeth were taken with a condensational silicon rubber based material (Speedex, Asia Shimi Teb, Tehran/Iran) and working dies were casted (Fuji Rock, GC Corp, Tokyo, Japan). Gradia separator (serial No: 0104231, Tokyo, Japan) was applied on dies and indirect composite (Gradia, GC Corp, Aichi, Japan) was placed using the layering technique. Each layer was polymerized with pre-curing light (GC steplight SL-L, serial No: 03894, Tokyo, Japan) for 10 seconds; finally, they were placed in GC steplight SL-L (serial No: 03894, Tokyo, Japan) for 5 minutes in order to post-cure the composite. Each restoration was checked for marginal fitness on both die and tooth. Restorations with an unacceptable fit, namely; those with a visible marginal opening and/or detectable with a probe (probe No.8, Dentsply LTD, UK) were excluded and new restorations were made. In the luting step, teeth were rinsed and dried, and then GC Fuji plus conditioner (GC Co., Tokyo, Japan) was applied on each tooth for 20 seconds. Teeth were rinsed completely and dried gently with air spray, but did not dessicate. The cement (GC Fuji Plus) was mixed and placed on restorations as recommended by the manufacturer and subjected to a load of 2N that was inserted vertical to the occlusal surface of the tooth using a 2 kg weight for 5 minutes to standardize the cement thickness. The excess cement was removed in the gel phase. Samples were stored at room temperature for 24 hours. In each group, the samples were prepared in one day and were stored in distilled water at room temperature for 24 hours.

Testing

The teeth were mounted up to cervical, 1 mm below the cemento-enamel junction, in self-curing acrylic resin cylinders with 20mm height and 15mm diameter. The teeth were mounted in the universal testing machine (Model: 55144, Zwick/Roell, Germany) and were loaded to fail with a cross-head speed of 1mm/min using a 4mm diameter stainless steel rod that was placed in the midline of the tooth fissure. The results were analyzed using one-way analysis of variance (ANOVA) and Tukey post-hoc test.

The mode of failure of the samples based on visual analysis was also studied using the following criteria described by Burke et al. [20]:

Mode I- Minimal destruction of teeth;

Mode II- Fracture of one cusp, intact restoration;

Mode III- Fracture of at least one cusp, involving up to one-half of the restoration;

Mode IV- Fracture of at least one cusp, involving more than one-half of the restoration;

Mode V- Severe fracture, involving tooth structure completely and/or longitudinal fracture.

RESULTS

The descriptive data are presented in Table 2. One-way ANOVA revealed significant differences between groups ($P = 0.001$); therefore, Tukey test was used to analyze the data (Table 3).

Table 2. Mean and Standard Deviation of Fracture Strength

Group	Description	Number	*Mean ± SD (N)
1	Filtek Z-250 with cusp coverage	13	[a]1148.46 ± 262.67
2	Filtek Z-250 without cusp coverage	13	791.54 ± 235.86
3	Gradia, direct with cusp coverage	13	880.00 ± 123.90
4	Gradia, indirect onlay	13	800.00 ± 187.44
5	Control	13	[a]1051.54 ± 345.47

Table 3. Tukey's Post Hoc Test Results

Group I	Group J	P Value
1	2	0.004
	3	0.049
	4	0.005
	5	0.846
2	3	0.884
	4	1.00
	5	0.061
3	4	0.917
	5	0.382
4	5	0.075

Table 4. Mode of Failure in Test Groups

	Group 1	Group 2	Group 3	Group4
Mode I	0	0	0	0
Mode II	0	0	0	0
Mode III	2	10	3	1
Mode IV	4	2	3	3
Mode V	7	1	7	9

Fracture resistance in the teeth restored with Filtek Z-250 with cusp coverage were higher than the other three groups (1148.46N±262.67), but similar to sound teeth (1051.54±345.47); however, sound teeth were similar to the four other groups (P= 0.001).
The specimen mode of failure is shown in Table 4.
A large number of the samples in groups 1, 3 and 4 showed modes IV and V (severe) fracture pattern. The fracture pattern of teeth in group 2 that were restored with direct restoration without cusp coverage showed less severity (mode III).

DISCUSSION

In the present study, the fracture resistance of human maxillary premolar teeth was evaluated, as these teeth have shown a high incidence of fracture in clinic [21,22]. Vital teeth with conservative restorations are less susceptible to fracture than those with large restorations or with root canal treatment, regardless of the restorative material used [23]. Unlike some studies and for simulation of the clinical condition, large MOD cavities were prepared, so that the width of the isthmus was larger than one third of the intercuspal width [12,24]. According to some studies and based on the one-third rule, in the present study onlay design was selected [25-28].
As an alternative to "external splinting", a number of studies investigated the suitability of the adhesive technique in order to obtain an "internal splinting" for strengthening of the weakened teeth. It was suggested that these adhesive restorations preserve tooth structure, and at the same time, provide esthetic and function [29].
Based on this idea, inlay design was selected for one group to compare with adhesive onlays to define how much resistance can be reconstructed in such cavity design; moreover, the effect of the direct and indirect method on fracture resistance was compared using Gradia direct and indirect.
The results revealed that fracture resistance of the teeth restored with Filtek Z-250 with cusp coverage (1148.46 ± 262.67 N) was significantly higher than the teeth filled with Filtek Z-250 without cusp coverage (791.54 ± 235.86 N). Along this finding, some studies reported that regardless of the type of material used, routine coverage of weak cusps can increase the fracture resistance of the restored tooth to an equal value of the non-restored tooth [30]. In addition, a study based on finite element analysis reported that large onlay restorations were characterized by pure compression stress at the transition line angle between the occlusal coverage and the vertical wall of the cavity that seems to be favorable. They declared that the compressive-type interfacial stress is able to prevent deboning [31]. This behavior contrasts with that of inlays that showed a majority of tensile interfacial stress challenging the adhesive bond. It is claimed that the amount of interfacial tensile stress was highly related to the elastic modulus of the material. It seems that Filtek Z-250 with a higher elastic modulus caused lower interfacial stress and consequently, it showed a higher fracture resistance; however, there is a significant difference between the fracture resistance of the teeth restored with or without cusp coverage, emphasizing its importance [31]. The results showed that fracture resistance of teeth restored with Filtek Z-250 with cusp coverage was significantly higher than the teeth restored with direct Gradia with cusp coverage. According to the manufacturer's data, the difference between these two groups may be the result of difference in the mechanical properties of the two materials that affect the fracture nature, such as fracture toughness, elastic modulus, flexural and tensile strength. In addition, the aforementioned mechanical properties can also be influenced by the composition of the material i.e. type of resin matrix, type and amount of filler. Although Gradia has a ceramic and pre-polymerized filler, a higher level and larger particles of filler, the

mechanical properties of this material is adversely affected by UDMA monomer. A higher ratio of flexible urethane in addition to TEGDMA results in an extensive deformation before fracture. In UDMA, the long aliphatic segment in repeated units results in more flexibility and coiling of the chain. Despite the ability of “O-CO-NH” groups in UDMA in forming hydrogen bonds, easy breakage of these bonds with water may be an explanation for the low elastic modulus and the increased flexibility of chains as a result of a moderate change in temperature or stress [32]. On the other hand, Filtek Z-250 is formed from zirconia filler, BisGMA, BisEMA and flexible UDMA monomers. BisGMA has two aromatic rings that cause a lower cyclization (it has no effect on the improvement of mechanical properties) of pendant groups and a higher cross linking in polymer [33]. BisEMA molecule does not contain any hydroxyl groups, so unlike BisGMA, hydrogen bonds among the molecules of this monomer do not exist. This leads to an increased movement of the molecules resulting in a higher degree of conversion [34]. Therefore, it is predictable that Filtek Z-250 shows more suitable mechanical properties and higher fracture resistance compared to Gradia. Teeth restored with Filtek Z-250 composite with cusp coverage have a significantly higher fracture resistance from those restored with Gradia composite onlays. The difference in fracture resistance between these two materials can be explained by that of Z-250 and direct Gradia, due to a nearly equal composition of direct and indirect Gradia (manufacturer’s information). The only difference between direct and indirect Gradia is the probable increase of DC after post curing in indirect Gradia composite, and even if this fact is approved, it is more likely that the increase in DC is not that significant to improve the fracture resistance.

Although in this study a significant difference was not observed between groups 3 and 4, teeth restored with direct Gradia with cusp coverage, showed a higher fracture resistance compared to those restored with Gradia onlay. This could be due to the nearly equal composition of direct and indirect Gradia according to the manufacturer’s information. There are two points that should be considered; first, the post-curing effect of indirect Gradia on the probable increase of fracture resistance; and second, the bonding of direct and indirect Gradia composites to the tooth. Contradictory results concerning the effect of DC on mechanical properties of material have been reported [35-38]. In this study, it is more likely that DC did not increase, or despite DC improvement, mechanical properties and fracture resistance did not change.

Another fact that is considered to have influence on the fracture resistance of onlay is the type of cement used. Resin-modified glass ionomers have been suggested as a cementing agent for inlay/onlay restorations due to the ability to release fluoride, as well as the bonding ability to the tooth structure; hence, Fuji Plus (GC international, Tokyo/Japan) was used. In clinic, the final prognosis for the maintenance of a fractured tooth is closely related to the position of the fracture line.

The location of the fracture depends on the ability of the tooth to distribute the energy imparted by trauma evenly over the whole tooth body; therefore, minimizing the tension created. Whenever tooth strength weakens due to any pre-existing damage, the energy loaded by mastication forces or trauma can be easily transferred and localized in the root region. In this situation, if a fracture occurs due to load concentration in a specific part of the tooth, presumably, the line of fracture will be transported to the root region.

Therefore, it seems that with a higher fracture resistance the mode of failure has changed from the favorable mode III (group 2) to the severe mode (V) (groups 1, 3, 4), which is unrepairable in clinic.

CONCLUSION

Reinforcement of the teeth might be achieved through the restorative procedure; however, the quality of this reinforcement is related to the material and type of restoration (*i.e.* onlay and inlay).

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