

## ORIGINAL ARTICLE

**Effect of novel restorative materials and retention slots on fracture resistance of endodontically-treated teeth**BILAL YASA<sup>1</sup>, HAKAN ARSLAN<sup>2</sup>, ELIF YASA<sup>3</sup>, MERVE AKCAY<sup>4</sup> & HUSEYIN HATIRLI<sup>1</sup>

<sup>1</sup>Department of Restorative Dentistry, Faculty of Dentistry, Izmir Katip Celebi University, Izmir, Turkey, <sup>2</sup>Department of Endodontics, Faculty of Dentistry, Ataturk University, Erzurum, Turkey, <sup>3</sup>Department of Restorative Dentistry, Faculty of Dentistry, Sifa University, Izmir, Turkey, and <sup>4</sup>Department of Pedodontics, Faculty of Dentistry, Izmir Katip Celebi University, Izmir, Turkey

**Abstract**

**Objectives.** The aim of this study was to evaluate the fracture resistance of endodontically-treated teeth restored with nano-hybrid composite resin, bulk-fill flowable and short fibre-reinforced-composite in the absence/presence of retention slots. **Materials and methods.** One hundred and ten extracted non-carious human mandibular molars received endodontic treatment followed by mesio-occlusodistal (MOD) cavities with  $3 \pm 0.2$  mm thicknesses of buccal and lingual walls. Teeth were divided into two main groups according to the retention slot preparation. The dove-tail retention slots were prepared on the middle of opposite buccal and lingual walls to create mechanical interlocking. Each group was further divided into four sub-groups according to restorative material types: control (no restoration), nano-hybrid composite resin (Filtek™ Z550), bulk-fill flowable (Filtek™ Bulk Fill) and short fibre-reinforced-composite (everX Posterior™). Restored teeth were subjected to compressive load at a strain rate of 1 mm/min. The data were statistically analysed using two-way ANOVA and Tukey's test for multiple comparisons. **Results.** The fracture resistance was significantly affected by the presence of the retentive slots and restorative material ( $p < 0.05$ ). Restored teeth with retentive slots significantly increased the fracture resistance compared with restored teeth without retentive slots ( $p < 0.05$ ). Short fibre-reinforced-composite with retentive slot cavities had significantly higher fracture resistance values compared with the other test groups ( $p < 0.05$ ). **Conclusions.** The preparation of retention slots may increase the fracture resistance of endodontically-treated teeth, especially, when restored with short fibre-reinforced composite. The use of short fibre-reinforced composite with retentive slots could be an alternative technique to prevent cuspal fracture on endodontically-treated teeth with MOD cavity.

**Key Words:** Fracture resistance, MOD cavity, retentive slot, bulk-fill flowable, short fibre-reinforced composite

**Introduction**

Endodontic treatment has had a high incidence of tooth survival after 8 years [1]. However, in a prospective clinical study the presence of non-restorable cusp fractures was a significant reason for extracting endodontically-treated teeth, with an incidence of 17.8% [2]. It has been reported that the reason for the susceptibility of endodontically-treated teeth to fracture was not due to brittleness, but rather due to access cavity preparation [3], endodontic procedures [4], post space preparation [5] and weakened tooth structure by caries or operative procedures [6,7]. Therefore, preservation of tooth structure and reinforcement are important to support endodontically-treated teeth against fracture [8].

It is well established that restoration with resin composites can increase the fracture resistance of endodontically-treated teeth [9,10]. When cavity sizes increase, like in endodontic access openings, resin composites should be used with 2-mm thicknesses incrementally, which is time-consuming for the dentist and inconvenient for the patient [11]. Besides increased patient treatment time, there is an associated increased risk of forming air bubbles or causing moisture contamination between the increments [12] that may lead to fractures. To overcome these disadvantages, a new concept material, called 'bulk fill', has been recently introduced to the dental market. These materials claim to promote light transmittance to successfully enable a depth of cure in excess of 4 mm.

Correspondence: Bilal Yasa, Izmir Katip Celebi University, Faculty of Dentistry, Department of Restorative Dentistry, Izmir, 35620, Turkey.  
Tel: +90 232 325 4040 2352. Fax: +90 232 325 2535. E-mail: bilalyasa@hotmail.com

(Received 16 July 2014; accepted 27 April 2015)

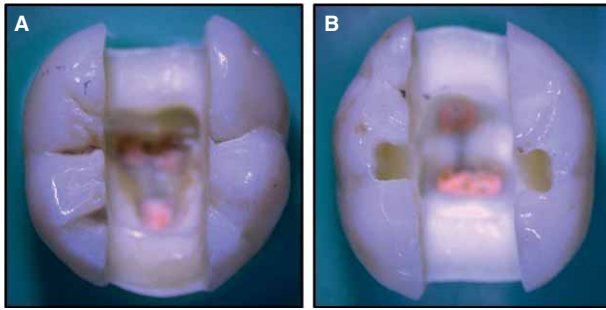


Figure 1. Preparations of MOD cavities on endodontically-treated

Although there is limited data about bulk-fill resin-based materials, reduced cuspal deflection [13] and good marginal integrity [14] have been reported. A fibre-reinforced composite (everX Posterior<sup>TM</sup>; GC Dental Products Corp., Tokyo, Japan) is one of these materials. It was improved as a base filling material in high stress bearing areas, especially in large cavities. This material contains resin matrix, randomly oriented E-glass fibres and inorganic particulate fillers [15]. This resin matrix, semi-interpenetrating polymer network, includes Bis-GMA, TEGDMA and PMMA. This matrix provides good bonding properties and improves toughness of the polymer matrix [16]. Garoushi et al. [17] demonstrated that restorations combining a base of short fibre-reinforced composite resin as sub-structure and a surface layer of hybrid composite resin displayed promising performance in high load-bearing areas.

There is limited data about the fracture resistance of endodontically-treated teeth restored with short fibre-reinforced and bulk-fill flowable composites in the absence vs presence of retention slots. Thus, the aim of the present study was to evaluate the fracture resistance of endodontically-treated teeth restored with nano-hybrid composite resin, short fibre-reinforced and bulk-fill flowable composites in the absence as well as presence of retention slots. The null hypothesis was that there was no statistically significant difference in the fracture resistance of teeth restored with various restorative materials in the absence or presence of retention slots.

## Materials and methods

The present study was approved by the Research Ethics Committee of the Izmir Katip Celebi University, under report number 2014-63. One hundred and ten non-carious human mandibular molars, with fully formed apices, extracted for reasons unrelated to this study, were selected. The inclusion criteria required teeth to be of similar crown and root sizes and absent of crack or craze lines after being evaluated with a stereomicroscope (Zeiss, Oberkochen, Germany) at 25× magnification. The exclusion criteria excluded those teeth

with root canal treatments or restorations. Soft tissues and calculus were removed mechanically from the root surfaces with a periodontal scaler. Specimens were then immersed in 0.5% Chloramine-T solution (Merck, Germany) for 48 h for disinfection and were stored in 4°C distilled water until use.

The buccal-lingual and mesio-distal dimensions were recorded for each specimen using a digital calliper (Mitutoyo, Suzano, SP, Brazil) at the most prominent point of the tooth's surface. The average buccal-lingual and the mesio-distal mean widths were  $10.30 \pm 1.30$  mm and  $10.91 \pm 1.34$  mm, respectively. Teeth were embedded in self-curing acrylic resin (Vertex Dental, Zeist, Netherlands) using a PVC cylinder (3 cm in height and 2 cm in diameter) up to 1 mm below the cemento-enamel junction (CEJ).

### MOD cavity preparation and endodontic treatment

One operator preformed all of the cavity preparations and another performed root canal treatments. The MOD cavity was prepared with a #158 cylindrical diamond bur (Acurata, Thurmansbang, Germany) at high speed under air-water spray in order to obtain a 3 mm thickness standard in cavity walls on buccal and lingual sides. The thickness was regularly measured throughout the preparation. The gingival walls were prepared at 1 mm coronal to the CEJ both mesially and distally. The depth of the cavities were measured from the gingival wall, with a mean of 5.7 mm for mesial and 5.3 mm for distal. The bur was changed after five cavities. The finished cavity preparation presented a buccal and lingual wall with a mesial to distal box and rounded internal angles defined by the diamond bur (Figure 1A).

After the removal of the pulp chamber roof, a size #10 stainless steel K-file (Dentsply Maillefer, Ballaigues, Switzerland) was moved down into the root canal until the file was just visible. The working lengths were set by deducting 1 mm from these lengths. Root canals were prepared with ProTaper rotary instruments (Dentsply Maillefer) up to size #25 (F2) in mesial root canals and up to #30 (F3) in distal root canals at the working lengths. A total of 2 mL of 2.5% NaOCl was used between instrument changes. All irrigating procedures were performed with a size-27 gauge blunt-tip needle (Ultradent, South Jordan, UT, USA). During irrigation, the needle was placed at a distance of 1 mm from the working length and then moved backwards and forwards. After instrumentation, each canal was flushed with 5 mL of 17% EDTA and 5 mL of 2.5% NaOCl and then dried with paper points. The sealer (AH Plus; Dentsply De-Trey, Konstanz, Germany) was mixed according to the manufacturer's instructions and matched single cones (F2 or F3) were lightly coated with sealer and placed into the root canals up to the working length. After filling procedures, a

Table I. Materials used in this study.

Material		Composition*	Manufacturer	Batch no
Scotchbond Etchant Gel	Etching agent	Phosphoric acid, synthetic amorphous silica, water	3M ESPE, St. Paul, MN	N414370
Clearfil SE Bond	Bonding agent	Primer: MDP, HEMA, hydrophilic dimethacrylate, photo-initiator, water Bond: MDP, HEMA, Bis-GMA, hydrophobic dimethacrylate, photo-initiators, silanated colloidal silica	Kuraray, Tokyo, Japan	C60001
Filtek™ Z550	Nano-hybrid composite	UDMA, Bis-GMA, Bis-EMA(6) silane treated ceramic, silane treated silica	3M ESPE, St. Paul, MN	N334740
Filtek™ Bulk Fill	Bulk-fill flowable composite	UDMA, Bis-GMA, Bis-EMA(6), TEGDMA, substituted dimethacrylate, ytterbium trifluoride, silane treated ceramic, benzotriazol, ethyl 4-dimethyl aminobenzoate	3M ESPE, St. Paul, MN	N435626
everX Posterior™	Fibre-reinforced composite	Bis-GMA, TEGDMA, glass fibre, barium glass, silicon dioxide, PMMA(polymethylmethacrylate), photoinitiators	GC Corp., Tokyo, Japan	1307052

Bis-GMA, bisphenol A diglycidyl methacrylate; HEMA, 2-hydroxyethyl methacrylate; MDP, 10-methacryloyloxydecyl dihydrogenphosphate; UDMA, Urethanedimethacrylate; Bis-EMA(6), bisphenol A polyethylene glycol diether dimethacrylate; TEGDMA, triethyleneglycoldimethacrylate.

\* Manufacturers' data.

heated plugger was used to remove the coronal excess gutta-percha, with no further vertical compaction.

#### Grouping of specimens

The specimens were divided into two groups ( $n = 55$ ) according to the preparation of the retention slot, as follows:

*Group 1:* No retention slots (Figure 1A).

*Group 2:* Dove-tail retention slots with 1.5 mm × 1.5 mm width and 2/3 of cavity wall height (from gingival wall) were prepared on the middle of the buccal and lingual cavity walls to create a mechanical interlocking area (Figure 1B).

The restorative materials used in the study are listed in Table I. Following selective etching of enamel surfaces for 20 s with 35% phosphoric acid gel (Scotchbond Etchant Gel, 3M Espe, St. Paul, MN), Primer (Clearfil SE Bond, Kuraray, Tokyo, Japan) was applied for 20 s and dried with a mild air flow. After that, Bond (Clearfil SE Bond) was applied and cured for 10 s. Each group was further equally divided into four sub-groups according to the type of restorative materials used as follows:

*Sub-group 1* ( $n = 10$ ): Control: No restoration.

*Sub-group 2* ( $n = 15$ ): Nano-hybrid composite resin: After the placement of the metal matrix band with a tofflemeire retainer, the nanohybrid composite resin Filtek™ Z550 (shade A2, 3M Espe) was inserted into the cavity using an incremental technique. The first 1 mm layer was placed and adapted to the mesial and distal proximal walls. Then, the restoration was completed with increments of 2 mm thick oblique composite.

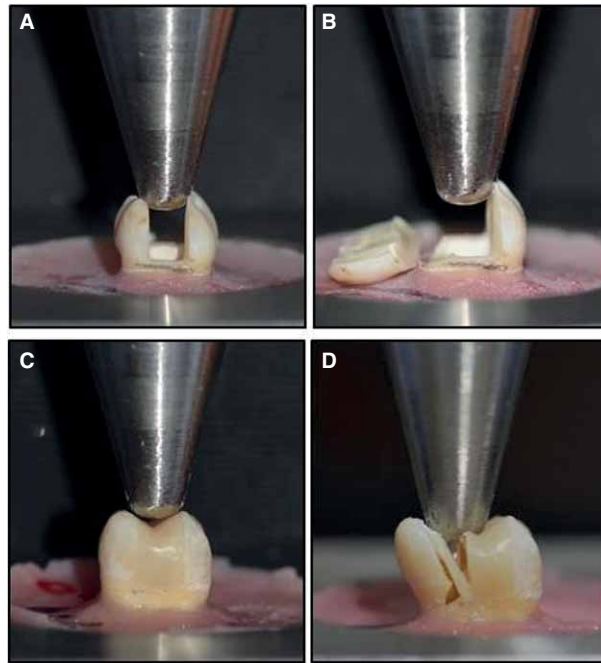
*Sub-group 3* ( $n = 15$ ): Bulk-fill flowable composite: After the placement of the metal matrix band with tofflemeire retainer, Filtek™ Bulk Fill flowable (shade universal, 3M Espe) was dispersed into the cavity at ~4 mm thickness including proximal boxes by means of the remaining 2 mm thickness occlusal cavity space. The last 2 mm of the restoration was performed using the nano-hybrid composite resin as an overlay layer.

*Sub-group 4* ( $n = 15$ ): Short fibre-reinforced composite: After the placement of the metal matrix band with tofflemeire retainer, mesial and distal walls were built with 1 mm layers of nano-hybrid composite resin (Filtek™ Z550). The fibre-reinforced composite, (everX Posterior™, GC Corp., Tokyo, Japan) with ~4 mm thickness, was inserted into the cavity. The last 2 mm of the restoration was performed using the nano-hybrid composite resin as an overlay layer.

Each increment of composite material was cured for 20 s using a LED light-curing unit (Valo Cordless, Ultradent) with an output of 1000 mW/cm<sup>2</sup>. The matrix was subsequently removed and materials were additionally proximally light cured for 20 s to ensure optimum polymerization. The specimens were then stored for 24 h in distilled water at 37°C.

#### Fracture strength test

The strength test was performed with a universal testing machine (AGS-X; Shimadzu Corporation, Tokyo, Japan). The load was delivered using a steel spherical tip with a diameter of 6 mm (1 mm/min), perpendicular to the long axis of the tooth, until a fracture occurred (Figures 2A and C). The force at



the time of the fracture was recorded in Newtons (N). Fractured specimens were observed under a stereomicroscope at  $32\times$  magnification to determine failure modes. Fracture modes were classified as (1) restorable failures when the fracture line was above the CEJ or 1 mm or less apical to the CEJ (Figure 2B); or (2) non-restorable failures, including vertical root fractures, when the fracture line was more than 1 mm apical to the CEJ (Figure 2D) [18].

#### Statistical analysis

All statistical analyses were performed using software (SigmaStat for Windows Version 3.5; Systat Software, Inc., Erkrath, Germany) at a significance level of 0.05 and confidence interval of 95%. The data were subjected to statistical analysis using a two-way ANOVA considering two factors (presence of retentive slots and restorative material type) and a Tukey *post hoc* test was used for multiple comparisons. The fracture types were analysed using a chi-square test.

#### Results

Two-way ANOVA of the fracture resistance testing data (presence of retentive slots and restorative material type) revealed that the fracture resistance was significantly affected by the presence of the retentive slots and the type of the restorative material used ( $p < 0.05$ ). However, there were no significant interactions between the presence of the retentive slots and the type of the restorative material ( $p = 0.058$ ), as presented in Table II.

The mean fracture resistance values (N) and standard deviations are presented in Table III. Retentive slots did not significantly decrease the fracture resistance of the control group. On the contrary, retentive slots significantly increased the fracture resistance of restored teeth compared with teeth without retention slot cavities ( $p < 0.05$ ). Short fibre-reinforced composite with retentive slot cavities had significantly higher fracture resistance values compared with the other test groups ( $p < 0.05$ ). There were no significant differences among the other test groups ( $p > 0.05$ ). The majority of fractures in the present study were non-restorable and the chi-square test revealed there were no significant differences in fracture pattern among the test groups ( $p > 0.05$ ).

#### Discussion

In the present study, we evaluated the fracture resistance of endodontically-treated teeth restored with nano-hybrid composite resin, short fibre-reinforced and bulk-fill composites in the absence/presence of retention slots. The null hypothesis was rejected because the fracture values of teeth restored with various restorative materials in the absence/presence of retention slots were significantly different.

Previous studies demonstrated that the majority of teeth extracted were mandibular molars [19,20]. Therefore, human mandibular first molars were used in this study.

Retention is the form of cavity that best permits the restoration to resist displacement. Slots are mechanical features that are incorporated into a cavity

Table II. Two-way ANOVA for the presence/absence of retention, the restorative material type and the interaction terms according to fracture strength data ( $p < 0.05$ ).

Source of variation	Sum of squares	df	Mean squares	F	p-value*
Presence/absence of retention	946,731.901	1	946,731.901	7.160	0.009
Restorative material type	23,911,129.825	3	7,970,376.608	60.282	< 0.001
Presence/absence of retention $\times$ restorative material type	1,024,985.747	3	341,661.916	2.584	0.058
Total	168,241,474.502	97			

\* Statistically significant difference at  $p < 0.05$ .

Table III. The mean (standard deviation) fracture resistance values (MPa) of preparations with restorative materials combinations and Tukey's analysis.

Presence of retention slots	Restorative material type			
	Control (without restoration)	Composite resin	Bulk fill	Fibre-reinforced
-	224.4 (86.4) <sup>A,a</sup>	1331.0 (443.7) <sup>A,b</sup>	1118.9 (309.7) <sup>A,b</sup>	1323.8 (460.6) <sup>A,b</sup>
+	188.7 (75.5) <sup>A,a</sup>	1389.6 (462.6) <sup>A,b</sup>	1385.5 (265.6) <sup>A,b</sup>	1825.6 (438.2) <sup>B,c</sup>

Mean values represented with same lowercase letters (row) are not significantly different according to Tukey's test ( $p > 0.05$ ).

Mean values represented with same uppercase letters (column) are not significantly different according to Tukey's test ( $p > 0.05$ ).

preparation that help retention and maintain the final restoration. The problem with using slots as the primary source of mechanical retention is loss of tooth structure [21]. In the present study, dovetail retentive slots are prepared for supporting opposite cavity walls to create mechanical interlocking. According to the results, the retention slots in cavities without restorative material did not significantly affect fracture resistance compared to those without retention slots. On the contrary, retentive slots significantly increased the fracture resistance of restored teeth compared with teeth without retention slot cavities, especially in short fibre-reinforced composite group.

A previous study used large fibre filler particles and found decreased fracture toughness [22]. Kim and Watts [23] suggested that the fracture toughness of polymer-based materials was significantly increased when they were reinforced with unidirectional E-glass fibre. Recently, this finding was confirmed in a study by Garoushi et al. [15], which compared the physical properties of various commercial posterior composites including bulk-fill and short fibre-reinforced composite. They concluded that short fibre-reinforced composite had the lowest shrinkage strain and the highest fracture toughness and flexural strength values. Results of the current study indicate that the new short fibre-reinforced composite with retentive slot cavities had significantly higher fracture resistance values compared with the other test groups. In addition, it was observed at the stage of determining of failure modes that buccal or lingual walls of teeth adhesively fractured from restoration in the groups without retention slots. On the other hand, in the groups with retention slots, dove-tail retention

part of restorations mixed fractured with buccal or lingual walls of the teeth to be affected material properties. When the fracture toughness of materials was considered according to Garoushi et al.'s [15] study, results of the current study were meaningful.

Negative clinical effects in composite resin restorations, such as marginal discrepancies, debonding, and cusp fracture are still observed in restorations with modern resin-based composites. These effects are correlated to polymerization shrinkage stress [24]. Composite resins can exhibit greater polymerization shrinkage stress that can generate more tooth-composite interfacial debonding [25]. One of the proposals to minimize this phenomenon is application of grooves or slots that would act as mechanical retention thus, reducing marginal retraction caused by polymerization shrinkage [26]. Considering the better results with retentive slots on fracture resistance in the present study, retention slots may have not only provided mechanical interlocking on the opposite cavity walls but decreased interfacial stresses between the tooth and composite restoration, as well.

The current study obtained increased fracture resistance with retentive slots, when the load was applied perpendicular to the long axis of the tooth. This finding was confirmed by a study by Lin et al. [27], which determined whether an additional reinforced slot could increase tooth/ceramic retention using finite element analysis and fracture testing. Although the aim of the preparation of retentive slots is different from that of the present study, researchers found that an additional reinforced slot at the pulpal wall with a large-cavity CEREC restoration can decrease tooth/ceramic interfacial stresses when the restored tooth is

subjected to an axial occlusal force. It was also concluded that the restored tooth, with a reinforced slot, was easy to fracture when a lateral occlusal force was applied. Because the directionality of the force was not compared in the present study, further studies should be conducted to evaluate the effect of force direction on the fracture resistance of teeth restored with composite resins.

According to the type of failures, the majority of fractures in the present study were non-restorable, defined as fracture lines extending more than 1 mm apical to the CEJ. This finding was consistent with the study by Oskoe et al. [28], which evaluated the effect of three methods of fibre insertion on the fracture resistance of endodontically-treated teeth. In contrast, reinforcement by glass fibres was found to have a positive effect on failure mode [29]. Disagreement in the results of the studies could be explained by differences in the type of teeth and the fibre inserted into the composite.

This *in vitro* study was conducted under a static load. In oral conditions, fatigue stress is an important process. Therefore, further *in vivo* studies should be performed to investigate the effect of the variables used in the present study.

In conclusion, within the limits of this *in vitro* study, it can be affirmed that retentive slots did not reduce the fracture resistance of endodontically-treated teeth with MOD cavities; on the contrary, retentive slots increased the fracture resistance of restored ones. Short fibre-reinforced composite with retentive slot cavities had the highest fracture resistance values among the groups.

## Acknowledgement

The authors thank 3M ESPE Turkiye for providing materials used in this study.

**Declaration of interest:** The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

## References

- [1] Salehrabi R, Rotstein I. Endodontic treatment outcomes in a large patient population in the USA: An epidemiological study. *J Endod* 2004;30:846–50.
- [2] Tzimpoulas NE, Alisafis MG, Tzanetakakis GN, Kontakiotis EG. A prospective study of the extraction and retention incidence of endodontically treated teeth with uncertain prognosis after endodontic referral. *J Endod* 2012;38:1326–9.
- [3] Tang W, Wu Y, Smales RJ. Identifying and reducing risks for potential fractures in endodontically treated teeth. *J Endod* 2010;36:609–17.
- [4] Topcuoglu HS, Arslan H, Keles A, Koseoglu M. Fracture resistance of roots filled with three different obturation techniques. *Med Oral Patol Oral Cir Bucal* 2012;17:e528–32.
- [5] Schiavetti R, Sannino G. In vitro evaluation of ferrule effect and depth of post insertion on fracture resistance of fiber posts. *Comput Math Methods Med* 2012;2012:816481.
- [6] Reeh ES, Messer HH, Douglas WH. Reduction in tooth stiffness as a result of endodontic and restorative procedures. *J Endod* 1989;15:512–16.
- [7] Hurmuzlu F, Kiremitci A, Serper A, Altundasar E, Siso SH. Fracture resistance of endodontically treated premolars restored with ormocer and packable composite. *J Endod* 2003;29:838–40.
- [8] Belli S, Erdemir A, Yildirim C. Reinforcement effect of polyethylene fibre in root-filled teeth: Comparison of two restoration techniques. *Int Endod J* 2006;39:136–42.
- [9] Taha NA, Palamara JE, Messer HH. Fracture strength and fracture patterns of root filled teeth restored with direct resin restorations. *J Dent* 2011;39:527–35.
- [10] Hernandez R, Bader S, Boston D, Trope M. Resistance to fracture of endodontically treated premolars restored with new generation dentine bonding systems. *Int Endod J* 1994;27:281–4.
- [11] Ilie N, Hickel R. Investigations on mechanical behaviour of dental composites. *Clin Oral Investig* 2009;13:427–38.
- [12] Flury S, Hayoz S, Peutzfeldt A, Husler J, Lussi A. Depth of cure of resin composites: Is the ISO 4049 method suitable for bulk fill materials? *Dent Mater* 2012;28:521–8.
- [13] Moorthy A, Hogg CH, Dowling AH, Grufferty BF, Benetti AR, Fleming GJ. Cuspal deflection and microleakage in premolar teeth restored with bulk-fill flowable resin-based composite base materials. *J Dent* 2012;40:500–5.
- [14] Roggendorf MJ, Kramer N, Appelt A, Naumann M, Frankenberger R. Marginal quality of flowable 4-mm base vs. conventionally layered resin composite. *J Dent* 2011;39:643–7.
- [15] Garoushi S, Sailyoja E, Vallittu PK, Lassila L. Physical properties and depth of cure of a new short fiber reinforced composite. *Dent Mater* 2013;29:835–41.
- [16] Lastumaki TM, Lassila LV, Vallittu PK. The semi-interpenetrating polymer network matrix of fiber-reinforced composite and its effect on the surface adhesive properties. *J Mater Sci Mater Med* 2003;14:803–9.
- [17] Garoushi S, Tanner J, Vallittu P, Lassila L. Preliminary clinical evaluation of short fiber-reinforced composite resin in posterior teeth: 12-months report. *Open Dent J* 2012;6:41–5.
- [18] Scotti N, Coero Borgia FA, Alovisi M, Rota R, Pasqualini D, Berutti E. Is fracture resistance of endodontically treated mandibular molars restored with indirect onlay composite restorations influenced by fibre post insertion? *J Dent* 2012;40:814–20.
- [19] Toure B, Faye B, Kane AW, Lo CM, Niang B, Boucher Y. Analysis of reasons for extraction of endodontically treated teeth: A prospective study. *J Endod* 2011;37:1512–15.
- [20] Zadik Y, Sandler V, Bechor R, Salehrabi R. Analysis of factors related to extraction of endodontically treated teeth. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2008;106:e31–5.
- [21] Vaught RL. Mechanical versus chemical retention for restoring complex restorations: What is the evidence? *J Dent Educ* 2007;71:1356–62.
- [22] Drummond JL, Lin L, Miescke KJ. Evaluation of fracture toughness of a fiber containing dental composite after flexural fatigue. *Dent Mater* 2004;20:591–9.
- [23] Kim SH, Watts DC. Effect of glass-fiber reinforcement and water storage on fracture toughness (KIC) of polymer-based provisional crown and FPD materials. *Int J Prosthodont* 2004;17:318–22.
- [24] Ilie N, Hickel R. Resin composite restorative materials. *Aust Dent J* 2011;56:59–66.
- [25] Kim RJ, Kin YJ, Choi NS, Lee IB. Polymerization shrinkage, modulus, and shrinkage stress related to tooth-restoration interfacial debonding in bulk-fill composites. *J Dent* 2015. [Epub ahead of print].

- [26] Ishikiriama SK, Mondelli RF, Kano SC, Ishikiriama A, Mondelli J. Role of additional retention on marginal adaptation and sealing of large resin composite Class II restorations. *Oper Dent* 2007;32:564–70.
- [27] Lin CL, Chang YH, Chang WJ, Cheng MH. Evaluation of a reinforced slot design for CEREC system to restore extensively compromised premolars. *J Dent* 2006;34:221–9.
- [28] Oskoe PA, Ajami AA, Navimipour EJ, Oskoe SS, Sadjadi J. The effect of three composite fiber insertion techniques on fracture resistance of root-filled teeth. *J Endod* 2009;35:413–16.
- [29] Fennis WM, Tezvergil A, Kuijs RH, Lassila LV, Kreulen CM, Creugers NH, et al. In vitro fracture resistance of fiber reinforced cusp-replacing composite restorations. *Dent Mater* 2005;21:565–72.