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Research Article

Digital Evaluation of Cuspal Deflection of Endodontically Treated Teeth Restored with Resin Composite and Different Fiber Formulations

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Abstract
Background: This study evaluated the influence of different fiber formulations incorporation in resin composite on cuspal deflection (CD) of endodontically-treated teeth with mesio-occluso-distal (MOD) cavities.
Materials and Methods: Thirty-two freshly extracted maxillary premolar teeth received MOD cavity preparation followed by endodontic treatment using single cone obturation technique, and divided into: Group I: direct composite resin only using a centripetal technique, Group II: direct composite resin with short fiber-reinforced composite (everX Flow), Group III: direct composite resin with leno wave ultra-high molecular weight polyethylene (LWUHMWPE) fibers placed on the cavity floor, and Group IV: direct composite resin with LWUHMWPE fibers placed circumferentially around the cavity walls (wallpapering technique). The CD was measured using a novel digital evaluation method, whereby each tooth was scanned by a desktop scanner (Medit T710) at three different time intervals: before and after cavity preparation, and after restoration. The intercuspal distance (ICD) was measured digitally in µm at each interval using Medit compare metrology software, followed by measurement of the CD by subtracting the ICD after cavity preparation; and after restoration from the before preparation one to obtain the “after cavity preparation CD1” and “the after restoration CD2”, respectively. The data were analyzed using one-way ANOVA and Tukey HSD tests at a significance level of 0.05.
Results: The highest CD was recorded in Group I with statistically significant differences with all other groups ($P<0.05$). No statistically significant differences were found between the other groups (Groups II, III, and IV) ($P>0.05$).
Conclusions: There was an inward deflection of the cusps in all groups following cavity preparation and restoration as elicited by the negative CD1 and CD2 values. The incorporation of fibers, regardless of their type or orientation, resulted in a significant reduction in CD of endodontically treated premolar teeth as compared with those restored with resin composite alone.

Keywords: Cuspal deflection, Digital evaluation, Fiber reinforced composite, Leno wave, Ribbond

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Introduction

Endodontically treated teeth are at a higher risk of biomechanical failure than vital teeth. The factors posing this high risk of fracture include the loss of dental tissue, preparation of an endodontic access cavity to disinfect the root canal, volume and time of contact of disinfectant within the canal space, and/or changes in the physical properties of dentin due to dehydration (1).

Composite resin has a wide popularity among restorative materials as it provides high quality esthetics and clinical performance. Nevertheless, the polymerization shrinkage or bulk contraction induced by densification of resin matrix through polymerization process is represented as a major drawback for direct composite resins (2). During polymerization if the adhesive bond strength exceeds the contraction stress, there is no detachment but the restoration maintains an internal tension that pulls the walls of the tooth together, reducing the ICD resulting in the phenomenon of 'cusp deflection' (3). The clinical importance of CD is that the greater its magnitude leads to greater tooth deformation and consequently, increased possibility of fatigue failure. This type of failure, characterized by a fracture in the presence of stress far below the maximum strength of the restored tooth, occurs in most dental fractures (4). The amount of CD has been reported to be between 4 and 45 μm depending on the measurement method, cavity size and extent of resin composite shrinkage (5). Factors influencing the development of contraction stresses can be divided into material formulation factors (filler content, monomeric chemistry, monomeric structure, filler/matrix interactions, additives, etc), material polymerization factors (polymerization rate, catalyst and inhibitor concentration), external constraint conditions, cavity geometry (C-factor), curing method and placement technique etc) (6).

Short fibers reinforced composite materials (SFRC) (everX Posterior and everX Flow, GC Europe, Leuven) have been recommended to reinforce composite restoration in high stress-bearing areas, including endodontically treated posterior teeth. They exhibited improved performance in shallow and deep MOD cavities in the context of fracture resistance and/or fracture pattern (7). On the other hand, a leno woven ultrahigh molecular weight (LWUHMW) polyethylene fiber ribbon (Ribbond THM; Ribbond Inc., Seattle, WA, USA), inserted into a bed of flowable composite, have been used in various direct restorative techniques for splinting the tooth and increasing its fracture strength. Application techniques included lining the fiber under the composite filling or over the finished composite restoration by preparing a groove (8), or applying the fibers inside the axial walls circumferentially, the so called "Wall Papering Technique" (7, 9). A recent study found that incorporating ribbond fibers within the composite restoration, whether as a wallpapering or on the floor, significantly increased the fracture resistance of endodontically treated premolars as compared with teeth restored with resin composite alone (10). Hence, this study was conducted with the aim of assessing the effect of incorporating different fiber formulations on the CD of endodontically treated maxillary premolar teeth.

The null hypothesis of this study is that there would be no significant difference in CD between teeth restored with resin composite alone or in combination with different fiber formulations.

Materials and Methods

Sample Selection: An ethical approval for this research was assigned by the Research Ethics Committee of the College of Dentistry, University of Baghdad, Iraq, in January 2022 (no. 469522). Thirty-two freshly extracted, sound human maxillary premolar teeth with two roots were used in this study, collected from the Department of Oral and Maxillofacial Surgery. Sample size was determined according to previous studies (11-13). The collected teeth were cleaned from debris and only teeth free from caries, restoration, or cracks as examined by trans-illumination and with normal occlusal anatomy and of comparable size were included (14).

Pre-operative Scan: Teeth were scanned by Medit T710 desktop scanner (Medit, Seoul, Korea). A four high-resolution camera system was used for automatic scanning of each tooth and the resulting STL file was then exported to 'Medit compare' metrology software and stored as the 'Before cavity' scan.

Cavity Preparation: Prior to cavity preparation, stamp technique was used to take an imprint for the occlusal surface of each tooth by flowable composite (Tetric N-Flow, Ivoclar Vivadent, Schaan, Liechtenstein) (15). A standardized class II MOD cavity without a proximal step (3mm buccolingual width and 6mm occlusal depth) prepared in each tooth using flat-end diamond fissure bur (no. 121415, Shofu Inc., Kyoto, Japan) (16).

Endodontic Treatment: An access cavity was prepared using a diamond round bur (No. 2128C, Microdont, Sao Paulo, Brazil) and ENDO-Z bur (Dentsply Maillefer, Ballaigues Switzerland). Working length was determined and rotary instrumentation was then performed using RACE EVO Ni-Ti rotary system (FKG Dentaire, Le Crêt-du-Locle, Switzerland) and E-connect S Endo Motor (Eighteeth, Changzhou, China) with copious irrigation of 2ml of 5.25% NaOCl between each two successive files up to RE3. Single gutta-percha cone obturation was then done using resin-based sealer (Sealapex, Kerr, Orange, CA, USA). Each tooth was then mounted in an acrylic block to facilitate the handling of the specimens during the subsequent steps.

Restorative Procedure: The prepared cavity was etched with 37% phosphoric acid gel (Super Etch, SDI, Australia) for 20s, then washed out with water for 5s and air-dried, followed by application of the G-Premio BOND universal adhesive (GC Corp., Kasugai, Japan) using a disposable microbrush, left for 10 seconds, then air dried gently for 5 seconds, after that light cured for 20 seconds using a light curing pen with light intensity of 1000 mw/cm^2 (Eighteeth, Changzhou, China). To build-up the proximal walls, SuperMat Universal Matrix Tensioning System (Kerr, Orange, CA, USA) was adapted around the tooth, tightened with its Adapt plier, then G-aenial A'CHORD composite (GC Corp., Kasugai, Japan) was applied with wall thickness of 1mm up to the marginal ridge level then light cured for the 20 seconds.

At this stage, teeth were randomly distributed (random.org) into four groups (n=8) according to the following restorative step:

Group I: The residual cavity was restored by horizontal incremental layering technique, whereby the resin composite was applied in a layer thickness for 2 mm, each layer was light-cured for 20 seconds according to the manufacturer's instructions. After the placement of the final layer of composite resin and prior to its curing, Teflon tape was wrapped on the composite surface and the prefabricated stamp was applied on the top of this layer to restore the original occlusal anatomy of each tooth, then light cured for 20 seconds.

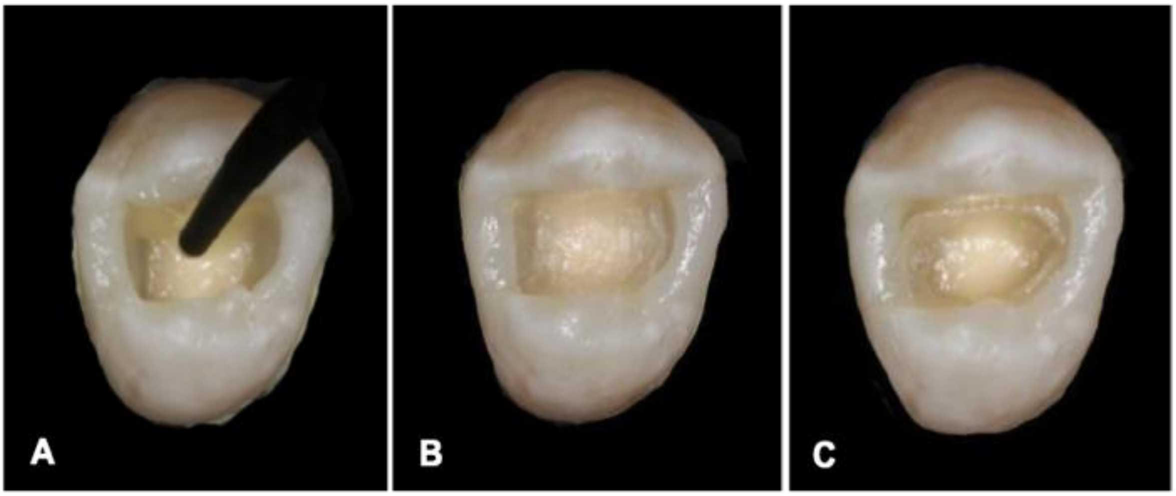

Figure 1: Application of different fibers. (A) Application of everX Flow as a core within the resin composite restoration. (B) Ribbond adapted to the cavity floor in a bucco-lingual direction. (C) Ribbond adapted to the walls of the cavity as a wallpaper.

Group II: The residual cavity was restored with SFRC (everX Flow bulk shade, GC Corp., Kasugai, Japan) up to 2mm below the occlusal cavo-surface margin, and light cured for 20 seconds (Fig. 1A). The residual cavity was then restored with one layer of universal composite (10).

Group III: A piece of ultra-thin ribbond fiber (5 mm long X 4mm wide) (Ribbond-Ultra; Ribbond Inc., Seattle, WA, USA) was adapted to the floor of the cavity prior to composite resin build-up. Formerly, the cut ribbond fiber was impregnated with a wetting resin (Ribbond wetting resin, Ribbond Inc., Seattle, WA, USA), sequeezed out the excess, then covered with a thin layer of flowable composite (Ribbond Securing composite, Ribbond Inc., Seattle, WA, USA). The ribbond fiber was then inserted in the floor of the cavity in a bucco-lingual direction, and adapted well with a plastic instrument and light cured for 20 seconds (Fig. 1B) (10).

Group IV: Ribbond fiber was applied circumferentially against the cavity walls, the so called "wall papering technique" first described by Deliperi et al.[(9)] Two pieces of ribbond fiber (4mm wide by 6mm long) were applied in a C-shaped manner, one against each other to the inside of the buccal and palatal walls circumferentially, overlapping each other in the proximal area, ending 2 mm below the cavo-surface margin and folding down onto the axio-pulpal line angle, then light cured for 20 seconds (Fig. 1C). The remaining cavity was then restored using horizontal layering as for Group I. The restored teeth of all groups were then stored in distilled water at 37°C in an incubator for 15 minutes to be scanned the 'After restoration' scan (10).

CD Measurement: In this study, a novel fully digital technique was used for the measurement of CD. Each tooth was scanned by Medit T710 at three intervals: 1) Before cavity preparation, 2) After cavity preparation, and 3) After restoration (15 minutes after restoration). The scanning procedure was done at each interval as illustrated in the pre-operative scan.

The STL file of the 'Before cavity' scan of each tooth was opened in Medit compare software, whereby two reference points were drawn, one on each cusp tip using "Brush Selection" tool of the software that enables freehand draw path on the screen. The distance between these two points was then measured linearly in µm using "Measure Distance by Two Points" tool that representing the ICD as shown in (Fig. 2A). These measuring points were then cut and aligned on the 'After cavity' and 'After restoration' scans of the respective tooth using 'Best fit alignment' option in the software as shown in (Fig. 2B, C and D) and the ICD was measured again. Accordingly, for each tooth specimen, two CD measurements were computed as follows (12):

Cuspal deflection after preparation (CD1) = ICD before preparation - ICD after preparation

Cuspal deflection after restoration (CD2) = ICD before preparation - ICD after restoration

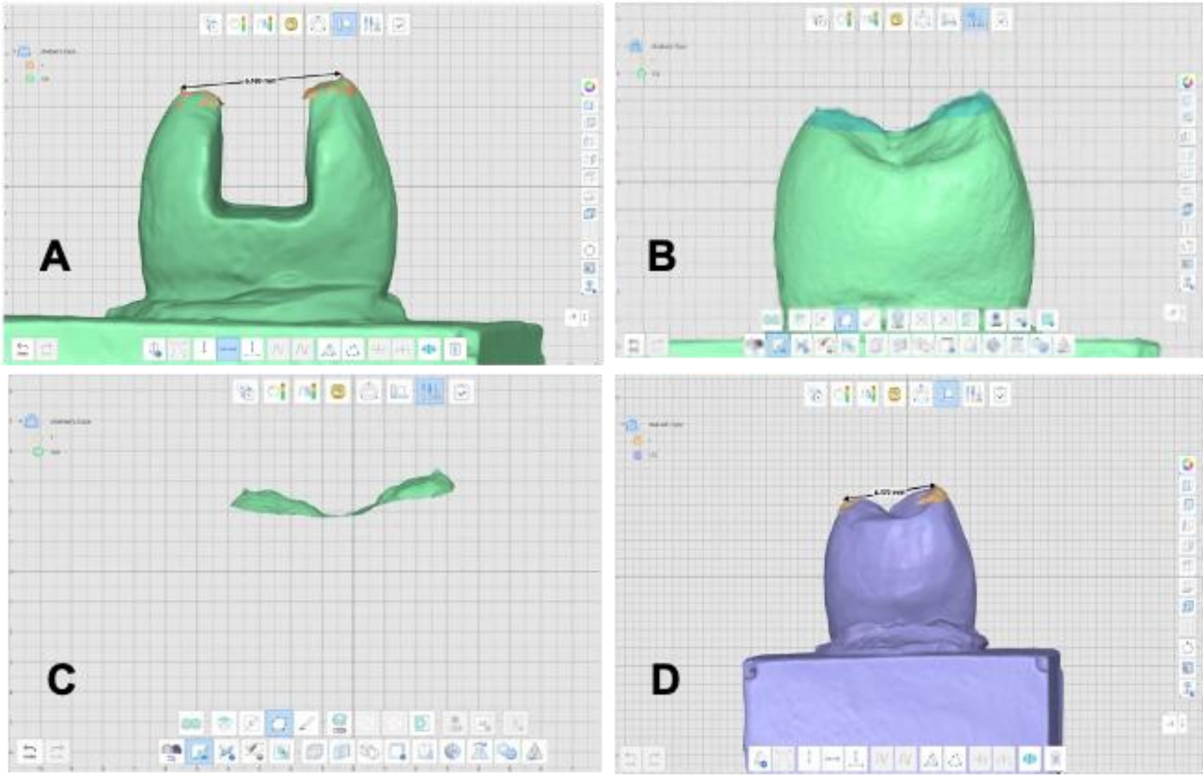

Figure 2: Digital measurement of ICD using Medit compare software. (A) Drawing of two reference points: one on each cusp tip. (B) Cutting of the reference points to be aligned on subsequent scans of the same tooth. (C) 'Best fit alignment' of the reference points on the 'After preparation' scan. (D) 'Best fit alignment' of the reference points on the 'After restoration' scan.

Statistical Analysis: Data description, analysis and presentation were performed using Statistical Package for Social Science version 22 (SPSS Inc., Chicago, IL, USA). Shapiro-Wilk test was used to test the normality of distribution of the data of CD after cavity preparation (CD1) and after restoration (CD2). One-way ANOVA test was used for comparison of significance of the CD among the four different groups after cavity preparation and after restoration. Tukey HSD test was used for multiple pairwise comparisons between each two groups. Both tests were carried out at a level of significance of 0.05.

Results

Shapiro-Wilk test revealed that the data of CD were normally distributed ($P>0.05$) as shown in (Table 1).

The results of this study showed that for all groups, the CD developed after restoration was generally higher than that developed after cavity preparation (Table 2 and Fig. 3). The highest CD was recorded in those teeth restored with composite resin alone (Group I) with statistically significant differences with all other groups ($P<0.05$). Meanwhile, no statistically significant differences were found between the other groups (Groups II, III, and IV), in which different fiber formulations were used in combination with resin composite ($P>0.05$).

Table 1: Shapiro-Wilk test for normality of distribution of the data of cuspal deflection.

Groups	CD1		CD2	
	Statistic	*p* value	Statistic	*p* value
Group I	0.926	0.479	0.878	0.179
Group II	0.848	0.090	0.955	0.765
Group III	0.856	0.111	0.953	0.746
Group IV	0.982	0.972	0.844	0.082

Table 2: Descriptive and statistical tests of cuspal deflection in µm among and in between each two groups using one-way ANOVA, Tukey HSD tests, and paired t-test.

	CD1					CD2					Paired *t*-test
	Minimum	Maximum	Mean	±SD	±SE	Minimum	Maximum	Mean	±SD	±SE	*P*-value
Group I	3.100	5.800	4.713 ^{Aa*}	0.952	0.337	9.100	13.200	10.562 ^{Ab}	1.461	0.517	<0.001
Group II	1.300	5.100	3.825 ^{Aa}	1.184	0.419	5.700	7.900	6.738 ^{Bb}	0.739	0.261	0.001
Group III	2.900	4.800	3.725 ^{Aa}	0.814	0.288	5.200	7.500	6.400 ^{Bb}	0.775	0.274	<0.001
Group IV	2.400	5.200	3.963 ^{Aa}	0.913	0.323	4.700	8.600	6.681 ^{Bb}	1.054	0.372	<0.001
One-way ANOVA	F value 1.689		*P*-value 0.192			F value 29.629		*P*-value <0.001			

* Different letters indicate statistically significant differences. The uppercase letters comparison among groups, while lowercase letters for comparison between CD1 and CD2.

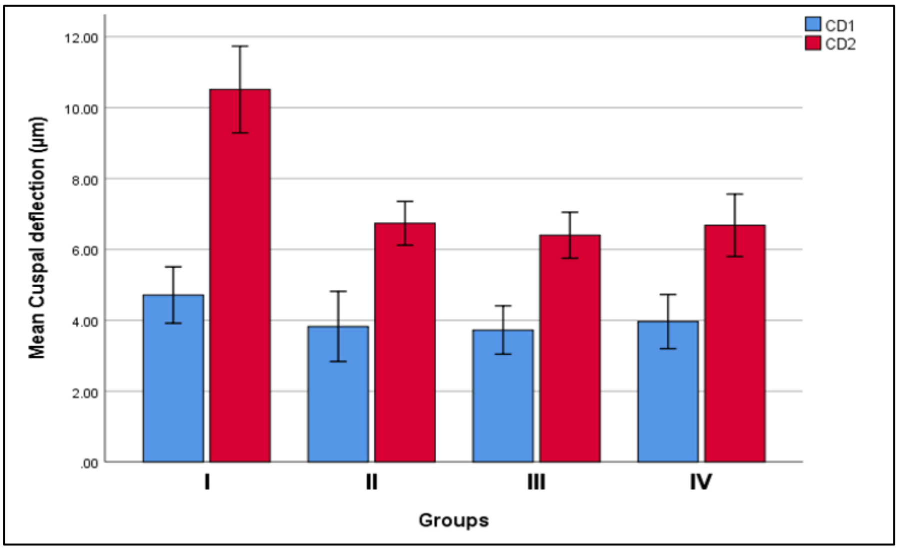

Figure 3: Bar chart graph showing the mean values of cuspal deflection after cavity preparation (CD1) and after restoration (CD2) of all groups in µm.

Discussion

Cuspal displacement may eventually result in microcrack propagation, enamel cracks, crazing, and a decrease in fracture resistance. About 10–45µm of CD has been reported during composite restoration, varying according to the measurement method, tooth type, and cavity size (17). The initial period of negative CD after tooth restoration is critical because normal occlusal contacts are adapted through this period. This could cause a greater tendency to tooth fracture till relaxation reached (18). In recent years, new dental materials containing glass or other types of fibers have become available. Glass fibers have proven that they are capable of withstanding tensile stress and preventing crack propagation in composite materials (3, 19).

The polymerization shrinkage developed during composite curing is the main force inducing CD. The cuspal deformation depends on the amount of polymerization shrinkage, the total amount of composite in a cavity, and the elastic modulus of the cured composite. The polymerization shrinkage force is also affected by the flow of composite and the C-factor (12). It is very difficult to establish a formula estimating the cusp deflection from so many variables; therefore, it is practical to measure the deflection experimentally.

In this issue, a standardized cavity was prepared in teeth of all groups and the same type of universal adhesive and resin composite were used in this study to exclude the effect of these confounding variables and to provide standardized conditions for the estimation of CD.

In this study, a novel method for measuring CD was invented and used that relies on full digital workflow. This method offers many advantages over existing methods traditionally used to measure CD: it is a non-invasive, repeatable, reproducible, fast and accurate method, thanks to the high accuracy and high scanning speed of Medit T710 desktop scanner. It relies on four high-resolution camera system that can effortlessly complete a full-arch scan in just 8 seconds with a reported accuracy of 4 µm according to ISO 12836 (Medit, Seoul, Korea). The other milestone of this technique is the metrology program 'Medit compare' which presents a set of convenient options and tools that enable repeatable superimposition of the scan data. It also offers either a linear two-dimensional or three-dimensional measurement of the deviation between two scan data expressed in numerical values and color map. By doing so, there is no need to sacrifice the specimens.

In this study, Medit compare complemented two objectives: First is the drawing of a reference point on each cusp tip, thus eliminating the need for fixation of steel balls used in the traditional method for measurement of CD. The second objective is the superimposition of the reference points on the successive scans of the same tooth using the 'Best fit alignment' option in the software. This method also allows easy storage and recall of the data. Another advantage offered by this method is the measurement of the linear deflection without any contact with the tooth, so it doesn't interfere with the free movement of the cusps (20). In the same context, owing to its high accuracy, Falih and Majeed[21] used Medit T710 desktop scanner as a reference scanner when comparing the precision and trueness of eight different intra-oral scanners.

Interestingly, the recorded CD values in this study were far below the values reported in the literature (10–45 µm) (17). This might indicate that this method is more precise in measuring CD than the conventional method owing to its reliance on full digital workflow.

After cavity preparation, a negative or an inward CD ensued in teeth of all groups. This could be due to the preexisting residual stresses in the sound teeth. The cause for these stresses is not clear. They could be resulted from the extraction and water storage before using or are normal in teeth. Another possible cause may be related to that the preparation of a large MOD cavity that weakened the remaining tooth structure by removing the marginal ridges in addition to the loss of enamel continuity, rendering the viscoelastic nature of dentine more pronounced. This is in agreement with Al-Obaidi and AL-Rawi (12), and Güler and Karaman (22).

Obviously, no statistically significant differences were recorded among teeth of all groups at this stage as teeth of comparable size were used and a standardized cavity was prepared in teeth of all groups.

After restoration, the inward deflection of the cusps persisted in teeth of all groups, but with a varying extent. The shrinkage stresses developed as a result of the polymerization process of resin composite result in an inward CD (5, 18, 23). The polymerization shrinkage of resin composite in a cavity generates stress that can be transmitted via the adhesive interface to the adjacent dental tissues, resulting in dental deformation. This is in agreement with González- López et al. (18), and Taha et al. (5). During the polymerization process, the elastic modulus of the material plays an important role in the generation of polymerization stress. The viscosity of resin-based materials increases during the polymerization reaction with the formation of bonded cross-linked network accompanied by a rapid increase in material's rigidity. While the volumetric change of the material occurs, it is restricted by the perimeter of the surrounding tooth structure, which leads to increase the stress in the internal structure of the material (24).

CD was measured 15 minutes after completing the restorative procedure with totally hydrated specimens since it has been found that the maximum amount of inward CD occurs during this period (12). This might be attributed to that the remaining free radicals and double bonds in the resin-based restoration continue to react; therefore, CD is much longer and slower than the polymerization shrinkage and continues for several minutes after completing the curing procedure.[25] In this study, the inward CD of the specimens of all groups post light irradiation pointed out that the adhesion at the tooth/restoration interface was well-established to exhibit such kinetics and to cause tooth deformation by the contractile resin composite.

Excitingly, the incorporation of fibers, regardless of their type or orientation (Groups II, III, and IV), had decreased the CD of the restored teeth significantly as compared with those teeth restored with resin composite alone (Group I). Accordingly, the null hypothesis was rejected.

Up to our knowledge, there is no available research dealing with the effect of incorporating these types of fibers on the CD of the restored teeth. However, the reduction in CD achieved by the incorporation of these fibers could be attributed primarily to that the placement of these fibers, irrespective of their type, reduced the volume of composite resin in the cavity which in turn reduced the degree of polymerization shrinkage and thus reducing the CD.

On the other hand, the decrease in CD when using everX Flow (Group II) could be attributed to that SFRC is dentin-like in two aspects: structurally, the short fibers resembling the collagen network in dentin, and mechanically having a modulus of elasticity close to dentin (9.5GPa) (26). EverX Flow contains short millimeter-scale randomly orientated E-glass fibers with a unique semi-interpenetrating polymer network structure that act as a crack stopper providing a toughening effect and stress bearing capabilities that allows the relief of shrinkage stresses generated during composite resin polymerization (7). This function is eased by the flowable nature of everX Flow which assured optimum adaptation to the cavity walls and floor, making the material to act in stress harmony with the bonded substrate (10).

Likewise, the insertion of ribbond fibers, whether against the cavity floor (Group III) or against the cavity walls as a wall paper (Group IV), reduced the CD significantly as compared to those teeth restored with resin composite alone (Group I). This could be attributed to the locked stitch interwoven framework structure of LWUHMWPE ribbon with nodal intersections that allow intrinsic stress and energy-absorbing mechanism (27), that would aid in relieving the shrinkage stresses of the polymerizing resin composite, which in turn would decrease the deflection of the cusps. The structure of the ultrathin polyethylene fibers allows good adaptation to the contours of the tooth, thanks to the flowable composite resin bed that brings the ribbond fibers to be in intimate contact with dentin. On the other hand, the

cold plasma treatment of ribbond during its manufacture increases its adhesion to the flowable resin (27).
When the ribbond was applied to the floor of the cavity (Group III), the integrity of the restoration was maintained by the density of the fixed nodal intersections of ribbond fibers, which also transfers the stresses effectively through the restoration along well-defined paths (28). This is in agreement with Eskitaşçıoğlu et al. (29), who suggested the combination of polyethylene fibers with a flowable composite resin to act as a stress absorber due to its lower modulus of elasticity. By embedding polyethylene fibers into a bed of flowable composite, the elastic modulus of the tooth is decreased, which helps to reduce residual stress and prevent the tooth from fracturing (30).

On the other hand, when the ribbond fibers placed as a wall paper against the cavity walls (Group IV), they would act similarly to the dentino-enamel complex, allowing tooth structure and composite materials to function in strain harmony (6). The ribbond fibers would thus connect the opposite walls together and the fibers are not stretched under any tension (22). In addition, by embedding the polyethylene fibers into a bed of flowable composite, the elastic modulus of the tooth is decreased (30), hence the placement of ribbond as a wall paper would serve as a splint against the occlusal forces and pull the cusps together, resisting the inward deflection of the cusps.

Despite that standardization measures were followed in all steps, still this study has the limitations of *in vitro* studies. Although *in vitro* studies provide standardized conditions, they may still not correlate to in vivo conditions. In addition, the CD was measured using a novel fully digital workflow that offers several advantages over the conventional method, still a comparison between both methods is still needed to test their sensitivity in detecting the CD. Within the limitations of this study, there was an inward deflection of the cusps in all groups following cavity preparation and restoration. However, the incorporation of fibers, regardless of their type or orientation, had significantly decreased the CD of the restored teeth as compared with teeth restored with resin composite alone.

Declaration of competing interest
We have no conflicts of interest to disclose regarding this article. The opinions expressed are solely those of the authors and have not been influenced by any financial or personal relationships.

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