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Comparative Analysis of Fracture Resistance of Maxillary Premolars with Class II MOD Cavities Restored with Novel Nanocomposites Including Fibre Reinforced Composite Restorative System: A Step Ahead in Composite Dentistry

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ABSTRACT

Aim: To determine the influence of nanocomposites such as nanofilled, nanoceramic and fibre reinforced composite restorative systems on the fracture resistance of maxillary premolars with Class II mesio-occlusodistal (MOD) cavities.

Materials and Method: Eighty sound maxillary human premolars were divided into four groups of 20 teeth each. Teeth in the first group were left intact (unprepared) and tested as positive controls. Teeth in the remaining three groups were prepared with MOD cavities and were restored with a nanofilled composite (Ice), a nanoceramic composite (CeramX mono) and a fibre reinforced composite (Tetric N Flow & CeramX mono). All groups were stored in water at 37°C for 24 hours and thermocycled and then tested in universal testing machine. Statistical analysis was done by Kruskal-Wallis and Mann-Whitney *U* tests. The level of significance was set at 0.05.

Results: Results between each group were statistically significant ($P > 0.05$) except between nanoceramic and fibre reinforced composite system.

Conclusion: Under compressive load testing, all restored teeth had lower cuspal fracture resistance than unprepared control teeth. Nanoceramic showed the highest mean cuspal fracture resistance while nanofilled showed the least and fibre reinforced composite proved to be a true tooth reinforcing agent.

Keywords: Cavity preparation, Premolars, Nanocomposites.

INTRODUCTION

Dental caries is a common disease occurring in the oral cavity and it can be restored with various restorative materials. In the last decade, the urge to undergo esthetic restorations has tremendously increased in general population so the need has arised to use tooth coloured adhesive resins. A lot of studies have already proved that overall strength of a tooth is directly proportional to the amount of its remaining structure[1].

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A significant reduction in tooth strength is caused by mesioocclusodistal cavity preparation due to the microfractures caused by applied occlusal forces as well as the loss of marginal ridges[2,3]. In wide class II cavities there is a risk for the cusps to move apart when continuous occlusal force is applied leading to their breakage[4].

One of the most important characteristic features of any dental material is its fracture resistance which means the resistance of the material to prevent crack propagation[5]. With the introduction of tooth coloured composites, dentinal adhesives and the novel advances blossoming in esthetic restorative materials, the fracture resistance of the teeth has increased significantly[6]. Composites have well known drawbacks like discoloration, polymerization shrinkage and thus the resulting sensitivity issues. Reinforcing the restoration with short fibres either glass or polyethylene has shown positive results in controlling the polymerization shrinkage and microleakage[7].

Fiber reinforced materials have highly favorable mechanical properties, and their strength-to-weight ratios are superior to those of most alloys. When compared to metals they offer many other advantages like non-corrosiveness, translucency, good bonding properties and ease of repair[8].

Nanofilled composites use nanotechnology thereby offering higher translucency, similar polish like microfilled composites but have slightly inferior physical or mechanical properties[9].

Nanoceramic composites have conventional filler (1µm), nano fillers (10nm) and most importantly organically modified ceramic nano particles (2-3nm). This nanoceramic technology has the added advantages of excellent biocompatibility and high fracture toughness[10].

Currently there is no study in literature that compares fracture resistance of nanoceramic, nanofilled and fibre reinforced composites. Also the materials used in this study are in demand now because of their esthetic advantages and toughness.

Thus, the goal of this in vitro study was to check and compare the fracture resistance of maxillary premolars with Class II mesio-occlusodistal (MOD) cavities restored with nanofilled, nanoceramic and fibre reinforced nanoceramic composite restorative systems.

MATERIALS AND METHOD

In this study, 80 sound maxillary premolar teeth extracted for orthodontic reasons from healthy humans were collected. After proper cleansing they were placed in 10% formalin and used within a span of seven days. They were mounted on cylindrical acrylic blocks of thickness 7mm or less in mesio-distal direction, specifically kept for fitting into universal testing machine. Teeth were then randomly divided into five groups namely:

Positive control group – unprepared teeth
Negative control group – prepared but unrestored teeth
Group I – restored with nanoceramic composite
Group II – restored with nanofilled composite
Group III – restored with fibre reinforced composite

They were used in accordance with the manufacturers' instructions and one operator performed all the restorative procedures. The shade was uniformed to A2 body shade in all the specimens and a light emitting diode (LED) curing unit (Ledition, Ivoclar Vivadent) was used for light polymerization. The wavelength of the unit was between 430 and 480 nm with light intensity kept 500mW/cm^2 throughout the experiment under constant observation.

Cavity preparation

The teeth were randomly divided into five groups of which first two groups had 10 teeth each and remaining groups had 20 each. Out of these, MOD cavities were prepared in the four groups except positive control group. For cavity preparation, diamond straight fissure burs were used in a high-speed handpiece under copious air-water cooling. Burs were replaced after five preparations to ensure high cutting efficiency.

The occlusal preparation was made 2-mm deep with a width of almost one-third the intercuspal distance. The facial and lingual walls were prepared parallel to each other with a 90-degree cavosurface angle. The proximal box that was prepared was one-third the buccolingual distance and 1.5 mm deep axially. The cervical wall was 1.5 mm coronal to the CEJ. Cavity dimensions were measured with a digital caliper.

Restoration procedures

Teeth of negative control group were not restored. For the other three groups, routine procedures for composite restoration starting from cleansing of the preparation with pumice slurry, rinsing with water for 15 seconds, drying, etching with 35% to 37% orthophosphoric acid for 15 seconds, rinsing with water for 15 seconds, slow gentle drying so as not to dessicate the cavity and then particular bonding agents were applied and light polymerized. The adhesive and composite were light cured keeping the light source obliquely from both proximal sides so that each side was cured for 20 seconds.

Table 1: Materials used in the study.

Restorative material	Manufacturing unit	Batch No.	Composition	Filler type and percentage
Prime & Bond NT (two-step etch-and-rinse)	Dentsply DeTrey, Konstanz, Germany	1107001780	Etchant: 36% phosphoric acid Adhesive: Di- and trimethacrylate resins, functionalized amorphous silica, PENTA, stabilizers, cetylamine hydrofluoride, acetone	
CeramX Mono	Dentsply DeTrey, Konstanz, Germany	1108001670	Methacrylate-modified polysiloxane, dimethacrylate	Ba-Al-fluorosilicate glass, methacylate functionalized silicon dioxide (nanofiller) 10 nm, 76 wt%
Ice	SDI, Melbourne, Victoria, Australia	8480002	22.5% wt (39% vol.) multifunctional methacrylic ester.	77.5% wt (61% vol.) inorganic filler (40nm - 1.5 micron).
Tetric N Flow	Ivoclar Vivadent AG, FL, Schaan	1135203	bis-GMA, UDMA, TEGDMA	Ba glass, Ba-Al fluorosilicate glass, Al_2O_3, YbF_3, pyrogenic SO_2. Mean particle size 0.7 µm, 79 wt%
Fibre-splint	Polydentia SA, Mezzovico, Strada Cantonale Switzerland	02020909	Sized E glass > 98%, silane - sticking agents lubricants < 2%	

The details of the restorative materials used in this study are listed in Table 1.

For Group I, teeth were restored with nanoceramic composite (CeramX mono/Prime & Bond NT, Dentsply DeTrey, Konstanz, Germany).

For Group II, teeth were restored with nanofilled resin composite (Ice, SDI, Melbourne, Victoria, Australia).

For Group III: Test specimens were restored in the following manner: A layer of Prime and Bond NT (Dentsply DeTrey, Konstanz, Germany) was applied after the routine cleansing, etching, rinsing and drying procedures. Then light polymerization was done. A thin layer (approximately 0.5 mm) of Tetric N Flow composite (Ivoclar Vivadent AG, FL, Schaan) was placed over the primed surface. After placement of Tetric N Flow, a strip of glass fibre (Polydentia SA, Mezzovico, Strada Cantonale, Switzerland) of appropriate measurements (measured according to the cavity dimensions) was cut to fit inside the diameter of the composite column and light cured (Figure 1). Subsequent layers of nanoceramic composite were applied by incremental technique over fibre-flowable

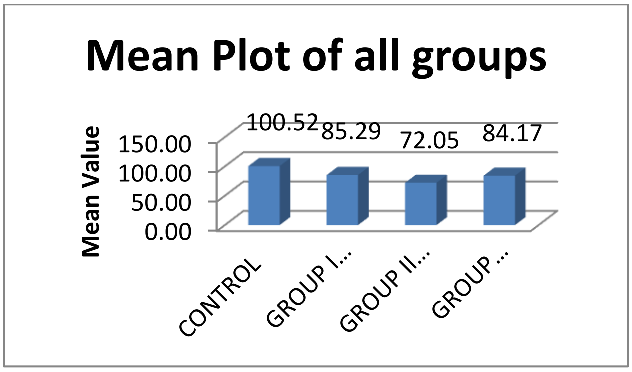
Table 2: Mean and standard deviations (SDs) of fracture resistance for different groups.

Group N=80	Mean (kg/f)	Std. Deviation	Std. Error	Interval for mean Lower bound Upper bound		Statistical Mann-Whitney comparison
Positive Control (N=10)	100.52	6.90	2.30	97.29	103.75	A
Negative Control N=10	22.12	5.66	1.79	18.07	26.17	B
Group I - nanoceramic N=20	85.28	14.97	3.35	78.27	92.29	CE
Group II – nanofilled N=20	72.04	15.47	3.46	64.80	79.28	D
Group III – fibre reinforced N=20	84.16	14.67	3.28	77.30	91.03	E
Total	75.75	25.72	2.88	70.03	81.488	

Table 3: Fracture patterns of test specimen groups.

Restored groups	CFT	AFI	CFR	CFS
Group I	2	2	4	12
Group II	5	5	2	8
Group III	4	0	10	6

CFT - Cohesive Fracture of the Tooth
AFI - Adhesive Fracture at the Interface
CFR - Cohesive Failure or fracture of the Restorative material
CFS - Complete Fracture of the Specimens that includes both the cusps as well as the restorative material.



Graph 1: Showing mean fracture resistance value of all groups.

composite matrix. One investigator prepared all specimens. Recent studies have shown that combination of Prime and Bond NT and Tetric N Flow are synergisitic[11].

Fig 1: U shaped glass fibre placed and gently tucked onto the flowable composite lining already placed at the base of cavity.

Testing

The specimens were stored in distilled water at 37°C for 24 hours. They were subjected to thermocycling treatment that comprised 2000 cycles between 5°C and 55°C, with a dwell time of

20 seconds and transfer time of 5 seconds. Axial compression was performed by a universal testing machine (Tinius Olsen) using a customized iron carved pencil shaped cylinder in contact with the dental structure with a crosshead speed of 10 mm/min.

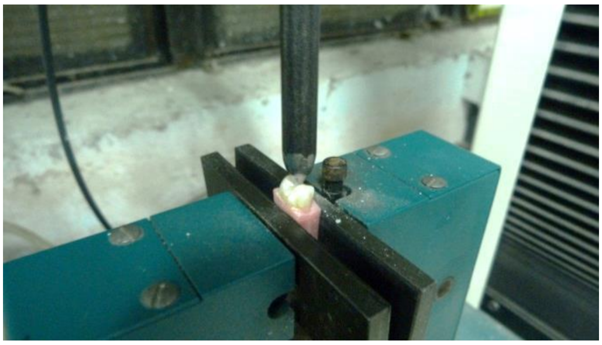


Fig 2: Customized iron cylinder aiming at centre of the tooth enclosed within the prongs of Univeral testing machine (Tinius Olsen).

Fracture resistance was recorded in kilograms (kg/f). The fractured specimens were examined under microscope to evaluate the failure patterns which were considered according to a previous study[11] as follows: cohesive fracture of the teeth (CFT), adhesive fracture at the interface (AFI), cohesive failure of the restorative material (CFR), and complete fracture of the specimens that includes both the cusps as well as the restorative material (CFS).

Statistical Analysis

Analysis was performed using nonparametric tests (Kruskal-Wallis and Mann-Whitney *U* tests) in which the Kruskal-Wallis test was used to test significance of difference between group variability. The level of significance was set at $p < 0.05$. The Mann Whitney *U* test was used to test significance of differences between each group. According to the Bonferroni adjustment for multiple comparisons, Mann-Whitney *U* test p value was considered significant if less than 0.0033 (equivalent to 0.05 for single comparison). All analyses were performed using SPSS for Windows 17 (IBM).

RESULTS

The mean force that caused fracture of the teeth in each group and the standard deviation are presented in Table 2. Statistical analysis was first made by Kruskal Wallis Test which showed significant difference of fracture resistance between the groups as a whole (p value <0.0001). Next done was Mann Whitney U Test. It showed significant statistical differences between both control groups and other three groups. On comparison between the three groups itself, there was significant difference between Group I - Group II and between Group II – Group III while no significant difference was obtained between Group I and Group III (Table 2 last row). The mean and median values of all the groups individually are mentioned in Table 2.

As mentioned in Table 3, majority of the fracture patterns observed were cohesive in nature. Nanoceramics had majority of CFS, few CFR and equal numbers of CFT and AFI. Nanofilled had more number of CFS in its specimens followed by AFI and CFT and lastly by CFR (least). But the thing to note is that the nanofilled composites had the highest number of adhesive fractures which shows inferior quality of adhesion. Lastly, fibre reinforced composites had majority of CFR, followed by CFS and then CFT. None of the fracture patterns observed in fibre reinforced composites were of adhesive in nature.

DISCUSSION

Since the groups restored with nanoceramic, nanofilled and fibre reinforced composites exhibited significant differences in fracture resistance, the null hypothesis was rejected. It was proved by studies of Burke et al that the best method for evaluating fracture resistance of premolar teeth is the use of a cylinder of defined diameter[12]. Universal testing machine is the best and renowned mechanical test to check the fracture toughness of teeth when pressurized through a concentrated and increasing load[13-15]. Thus in this test an iron cylinder carved on lathe machine into a pencil like shape with slightly blunt rounded tip was used and checked for the intimate contact with the restoration before conducting the testing (Figure 2).

Based on the results of this study, improved fracture resistance was noted with the nanoceramic and fibre reinforced group in comparison to nanofilled group but all the groups showed significant differences when compared to the mean values of control group. The results of this study confirm the results of previous studies that showed an increase in the fracture resistance of teeth restored with bonded composite resins[11,16].

Studies by Kahler et al proved composites to have comparable mechanical properties to that of intact sound teeth[17]. Still, the main drawback of composite that is polymerization shrinkage remains unsolved. Due to it, various deleterious effects are caused including deformation of cusps as a result of residual stresses, micro cracks at the interface and ultimately microleakage especially at the dentinal or cemental margins[18,19]. Composite resins with a high Young Modulus exhibit lower cusp movements under occlusal loading[20] and better tooth protection from fatigue associated with occlusal or thermal loading. Previous studies[21,22] showed that the nanoceramic composite restorative material showed reduced shrinkage and the best modulus and hardness values compared to other materials, which could explain the comparable results in the group of teeth restored with nanoceramic material.

Pertaining to the addition of fibres within the composite system, it has been theorized that a stress-free shock absorbing complex is created at the fibre-resin interface. This could thus create an environment in which either crack initiation or crack propagation beyond the fibre layer would be nearly impossible[23] as the mesh of fibre itself is such that if one of the fibre part gets torn away, the resultant stresses are deviated to the adjacent intact fibre mesh and thus the crack either seizes or significantly slows down at that moment. Also, fibres replace some part of the composite, resulting in a slight but significant overall reduction in volumetric contraction of the composite and thereby decreasing the shrinkage stress[24,25]. It has also been reported that shear bond strength of resin composite to fibre reinforced substrates depends on proportionality of the load direction and fibre direction, and it is higher when both the latter aspects are same[26]. Thus the buccolingual fibre orientation being proportional with the direction of the applied load is the reason behind significant rise in fracture resistance. Such a splinting effect on the proximal walls prevents separation of cusps thus permitting maximum loading under more than optimal occlusal stresses according to the anisotropic characteristic behaviour of the fibres[11] and hence fibre part was placed bucco-lingually in this study.

But the explainable reason for insignificant increase in fracture toughness for fibre group is the formation of voids between the fibres and the matrix which lowers the fracture resistance of the system which is theorized to happen because of creation of huge surface of oxygen inhibition layer at the interface of matrix and fibres. Thus the presence of voids and structural defect in fibre-composite complex can be considered a probable reason of decreased fracture resistance of fibre group than nanoceramic alone.

The potential clinical significance of these findings that have to be considered in vivo is the fracture patterns of the specimens and not the fracture toughness values alone. Technically reviewing the fracture pattern results closely, it is obvious that any restorative material that fractures first (CFR) rather than the tooth portion or both fracturing simultaneously when such heavy (10mm/min) force is applied, is considered to be better. Fracture of the restorative material first means that it had reinforced the remaining tooth portion quite well and resisted the fracture of the tooth including cusps and rather got fractured first. This also clearly signifies that such cases are reparable with least danger for entire fracture of tooth as well as restoration. Complete fracture of entire specimen (CFS) is also considered to be the result of high fracture toughness of the restoration as well as the tooth as a monoblock but it is irreparable. So it can be hypothetically proved that fibre group is clinically better in reinforcing the remaining tooth portion and long term prognosis of the restored tooth is improved with easily reparable quality.

CONCLUSION

Within the limitations of this study, it can be concluded that

- The preparation of MOD cavities resulted in the decreased fracture resistance of maxillary premolars.
- Under compressive loads, nanofilled composites showed the least fracture resistance while nanoceramic and fibre reinforced composites showed higher and comparable fracture resistance.

- Reinforcing quality was proved to be better for fibre reinforced composite group according to the fracture patterns result.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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