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Influence of Different Cavity Designs and Restorative Protocols on Fracture Resistance and Induced Strain of Weakened Thermo-cycled Maxillary Premolar Teeth: An in-Vitro Study"

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Abstract

Aim: The aim of this in vitro study is to evaluate the influence of different cavity designs and restorative protocols on fracture resistance and induced strain of MOD cavities in maxillary premolar teeth

Methodology: 136 maxillary premolar teeth will be selected and divided into three groups (n=40), a control group and a negative group. All the groups except the control one will received MOD cavities. The MOD cavities will be classified according to the cavity design into,

Group1: MOD without cusp reduction.

Group 2: MOD with palatal cusp reduction.

Group 3: MOD with buccal and palatal cusp reduction.

Control group: No treatment.

Negative group: MOD that will left unrestored. Regarding Groups 1-3, they will be further subdivided into five subgroups (n=8) according to the restorative protocol as follows:

Subgroup A: cavities restored with highly- filled nano-hybrid composite.

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Subgroup B: cavities restored with Sonic-fill composite .

Subgroup C: cavities restored with universal Nano-ceramic composite.

Subgroup D: cavities restored with bulk-fill composite. All specimens will be subjected to thermal cycling between 5° and 55°C for 60 seconds. Surviving specimens will be loaded to fracture in a universal testing device. Induced strain will be recorded using strain gauges during the fracture resistance test.

Results: All groups were shown significantly higher fracture resistance mean value than negative control. teeth with no significant difference was recorded between the three restorative materials except for cream X one whish showed the lowest significant fracture resistance mean value. Regarding the induced strain, all groups showed no significant difference between each other except for the positive and negative control.

Conclusion: Restoring with new available restorative systems based on different new technologies had improved the fracture resistance of weakened premolar teeth and better distribute the stresses and improved induced strain within the restored tooth

Introduction

Restoration of MOD cavities in premolar teeth are always considered as a challengeable procedure, since loss of marginal ridges in premolar teeth weakened the remaining tooth structure and drastically diminishes its fracture resistance to occlusal stresses. Owing to the considerable improvement in adhesive dentistry, the concept of minimally invasive dentistry associated with the adhesive restorations have been widely introduced, not only because of its ability to preserve the maximum amount of sound tooth structure but also it can act as "internal splint" to the remaining tooth structure. [1]

Since many studies have been clearly reported that the fracture resistance of weakened maxillary premolars is highly dependent on the amount of remaining tooth structure preserved during operative procedures, therefore the primary aim in restoring weakened maxillary premolars is the preservation of the maximum amount of remaining tooth structure and maintaining both function and esthetics. This may increase the fracture resistance of the premolar teeth and hence its durability. On the other hand, cuspal coverage has been recommended to protect teeth restored with adhesive restorations, increasing its clinical survival. [(2, 3)]

The adhesive restorations can reinforce the remaining tooth structure through its higher ability to transmit the functional stresses and distribute it along the bonding interface. Many studies have been reported that the adhesive restorative materials have the ability not only to replace the lost tooth structure but also to reinforce the remaining unsupported tooth structure, thus increase the fracture resistance and promote effective marginal sealing. [4]

It is well documented that the most clinically relevant problem of resin-based composite material is the polymerization shrinkage with its associated stresses. Multiple attempts have been done to overcome this most important problem. [5]Most of these attempts are directed towards reducing the released shrinkage stresses such as incremental layering technique and more recent the production of the novel classes of bulk-fill materials, [6] while others have been directed towards producing an extra-oral indirect resin composite restorations especially with large and extensive cavities . [(7,8)]

The more closely a test simulates the clinical condition, the more likely the results are clinically relevant. Intraoral occlusal forces create dynamic repetitive loading. Therefore, it is more clinically relevant to test the specimens under occlusal loading. Adding moisture and controlled temperature to the environment is found to be important when measuring the fracture reistance of direct resin-based composites. [(9)]

Literature have well addressed that Proper cavity preparation design, the restorative material used, and the interactions between material, restored teeth, and the oral environment may have a great influence on the clinical survival of restoring a weakened premolar teeth . Unfortunately, unresolved controversy exits concerning definitive restorative protocol and performance of restorative materials for treatment of weakened maxillary premolars with variable remaining tooth structure to improve their fracture resistance under occlusal load

Therefore, the purpose of this in vitro study is to evaluate the influence of different cavity designs and restorative protocols on fracture resistance and induced strain of MOD cavities in maxillary premolar teeth after subjecting to Thermo-cycling load

Materials and methods

In this in vitro study, a total number of 140 maxillary premolar teeth were selected to have normal anatomical shape, comparable dimensions to provide meaningful comparison and were extracted for either orthodontic or periodontal treatment. After meticulous selection of teeth, teeth were randomly allocated by the researchers into three main groups according to the cavity design (n=40), a control group (n=10) and a negative group: (n=10). Groups are classified according to the cavity design (A) as follows: Group A1: MOD cavities in maxillary premolars without cusp reduction. Group A2: MOD cavities in maxillary premolars with palatal cusp reduction. Group A3: MOD cavities in maxillary premolars with buccal and palatal cusp reduction. Control group: Sound premolars that were left intact. Negative group: Unrestored premolars with MOD cavity preparation.

Regarding Groups 1-3, they were further subdivided into three subgroups (n=10 each) according to the restorative protocol (B) as follows: Subgroup B1: Cavities restored with highly-filled Nano-hybrid resin composite material (Grandio®, Voco GmbH, Cuxhaven, Germany). Subgroup B2: Cavities restored with bulk-fill resin composite posterior filling material. (X-tra fil®, Voco GmbH, Cuxhaven, Germany). Subgroup B3: Cavities restored with sonically activated bulk-fill resin composite material. (Sonic-fill™ composite, Kerr Corp., Orange, CA, USA). Subgroup B4: Cavities restored with universal nano-hybrid composite based on nano-ceramic technology. (Ceram .x® one, DENTSPLY, De Trey, Germany)

Each premolar were covered with 0.5mm light body of vinyl-polysiloxane impression material to simulate periodontal ligaments and then embedded perpendicularly in an auto polymerizing acrylic resin to simulate clinical conditions. An over impression of each tooth were made prior to the cavity preparation to facilitate restoring the original anatomic form. A standardized MOD cavity preparations were done for all selected teeth except for the control group. The palatal cusps of specimens for group (2) and both buccal and palatal cusps of specimens for group (3) were then reduced evenly by 1.5 mm from the cusp tip and parallel to occlusal plane.

After bonding procedures following the selective etching technique for all the specimens, the adhesive system of composite used in each sub-group were used in self-etch mode according to the manufacturer's instructions. Each group were then restored with the assigned direct resin-based composite according to the manufacturer's instructions.

After 24 hours, all the specimens were subjected to thermo-cycling in thermo-cycle machine between 5±2°C/55±2°C in water with a 30-second dwell time at each temperature, following a regimen of 2500 cycles, which represents three months of clinical function. All specimens were subjected to compressive axial loading until fracture in a computer-controlled universal testing machine (LRX-plus, LLOYD instruments Ltd., Fareham, UK) with crosshead speed 1mm / min. the strain induced in specimens during testing the fracture resistance was measured using the strain gauge wire that adhered on palatal cervical area of the specimen and connected to a KYOWA strain Meter (BCD 300A, KYOWA, Tokyo, Japan). The fractured specimens were evaluated for the mode of fracture using stereomicroscope.

Results:

The results of this study showed that both tested variables had statistical significance on the fracture resistance and induced strain of thermo-cycled weakened premolar teeth. Additionally the sound intact teeth used as positive control showed the highest statistically significant difference fracture resistance mean value and the lowest statistically significant difference induced strain mean value among all the groups. Contrary to the prepared but unrestored groups used as negative control that showed the lowest statistically significant difference fracture resistance mean value and the highest statistically significant difference induced strain mean value among all the groups.

Regarding the fracture resistance test of the other restored groups, MOD cavities with both buccal and palatal cusp reduction showed the highest statistically significant difference fracture resistance mean value compared to the other MOD cavities and MOD cavities with palatal reduction. On the other hand, teeth restored with Sonic-fill™ resin-based composite showed the highest statistically insignificant difference fracture resistance mean value compared to Grandio® and X-tra fil® groups . While Ceram .x® showed the lowest statistically significant difference fracture resistance mean value compared to the other restored groups.

Furthermore, regarding the induced strain test, MOD cavities with both buccal and palatal cusp reduction showed the lowest statistically significant difference induced strain mean value compared to the other MOD cavities and MOD cavities with palatal reduction. On the other hand, teeth restored with Sonic-fill™ resin-based composite showed the lowest statistically insignificant difference induced strain mean value compared to all the other group

Discussion

Sound teeth (positive control) showed the highest significant fracture resistance mean value followed by Sonic-fill resin-based composite (Sonic-fill ™), Nano-hybrid resin-based composite (Grandio®), Bulk fill Multi-hybrid resin-based composite (X-tra fil®) with an insignificant difference with each other. On the other hand, the prepared but unrestored group (negative control) showed the lowest significant fracture resistance mean value followed by Nano-ceramic resin-based composite (Ceram. X® one) with significant difference between each other and all the other groups.

The highest significant fracture resistance mean value presented by the sound teeth (positive control) could be attributed to the preservation of both sound buccal and palatal cusps with intact mesial and distal marginal ridges. It is well known that the intact marginal ridges together with the intact cusps form a continuous circle of sound tooth structure that reinforce the tooth and maintain its integrity, hence increasing its fracture resistance. [10]

It is well reported that the amount of tooth structure lost is strongly correlated to fracture resistance of the restored tooth. Additionally, regardless the restorative material used, cavity preparation reduces the fracture resistance of the tooth.[11] Regarding the MOD cavities in weakened premolar teeth, the loss of the reinforcing tooth structures, especially both the marginal ridges and cusps, reduced the tooth structural integrity and hence render them more susceptible to fracture.[12]This could explain the lowest fracture resistance mean value presented by the prepared but unrestored teeth (negative control).

Clinically, it has shown that after insertion of most of available restorative materials, it can partially restore lost mechanical properties. This could be attributed to the heterogeneity between the tooth structure and the restorative material, multiple interfaces and all faced challenges during adhesion. Moreover, clinically in-vivo challenges also occur as moisture contamination, voids or inadequate curing. This leads to further reduction in mechanical properties intra-orally.

However, in this study it is clearly found that all restored groups, regardless of the type of resin-based composite material used, displayed higher fracture resistance than the prepared but unrestored teeth (negative control). The literature have always reported that the use of adhesive materials can act as an "internal splinting" for reinforcing the weakened tooth structure. Accordingly, this results could be explained by the micro-mechanical bonding between the tooth structure, adhesive system and hybrid layer formation. This tend to bind the walls of the cusps together and reinforcing the remaining tooth structure forming a mono-block complex and hence increasing the fracture resistance. [13] moreover, many studies have reported that the mechanical properties of the available resin-based composite materials are comparable to that of intact teeth

Regarding the influence of the restorative material, Sonic-fill resin-based composite (Sonic-fill ™) showed the highest insignificant fracture resistance mean value followed by Nano-hybrid resin-based composite (Grandio®) then Bulk fill Multi-hybrid resin-based composite (X-tra fil®) with an insignificant difference with each other. While the Nano-ceramic resin-based composite (Ceram. X® one) showed the lowest significant fracture resistance mean value with significant difference among all the other groups.

Understanding structure–properties relationships is valuable in evaluating the existing materials and developing new ones. The basic formulation of resin-based composites is methacrylate monomeric mixtures and inorganic fillers coated with a silane coupling agent, and photoinitiator systems, at which upon polymerization, the material is form a highly cross-linked network with high mechanical properties.[14]bulk modulus (B

Upon searching the literature for classification of commercially- available resin-based composite, various classifications based on the filler size, morphology, distribution and loading have been recommended. It well reported that all of these factors play a major role in mechanical properties of composites such as flexural strength, modulus of elastic and fracture resistance. [15]150, 500, 350, 500, 1000 nm It should be noted that resin based- composites can be classified according to their filler morphology, filler loading is dependent on filler morphology, and both filler morphology and loading have an influence on the mechanical properties of resin-based composites.[16]

It was reported that the volume filler loading percent is more important than weight filler loading percent. Furthermore , a positive correlation between filler loading and mechanical performance was proved [17]all root canals were prepared using nickel–titanium rotary ProTaper system and obturated using gutta-percha as a core lling material with EndoSequence bioceramic sealer. All roots were randomly divided into two equal main groups (n = 15 In composites, the intrinsic properties of the different phases and their volume fractions have a great influence on its mechanical properties [18]

In the present study, regarding the filler loading, it was shown that the Sonic-fill, Grandio and X-tra fill all have similar range of filler loading by volume which is 71%, 70% and 69% respectively. This could explain the insignificant fracture resistance mean values between them. On the other hand, the filler loading volume percent of Ceram-x one is 59%. This lower value than the other used resin based composite could explain the lower significant mean fracture resistance value.

A study[19] has shown that although both Grandio and X-traFil (Multi-hybrid fill RBC bulk and nanohybrid RBC conventional counterparts) have similar flexural strength and almost a similar filler mass fraction (around 85%), both present significantly different modulus of elasticity and microhardness. this study related that to the involvement of the other parameters such as (particle size and morphology , monomer type and photoinitiators system).

In the present study, both X-traFil and

Grandio (Multi-hybrid fill RBC bulk and nanohybrid RBC conventional counterparts) acted similarly in terms of fracture resistance yet with higher insignificant mean value for the Grandio.

Grandio is a true nano-hybrid composite. An extremely high filler portion (70 % volume) of Nano-particles size of 0.5 μm, evenly imbedded in the resin matrix, yields a simultaneous reduction in the resin portion and decrease polymerization shrinkage (1.57 %). This provides Grandio with a high fracture resistance values. This material showed a bimodal distributions. It would be adventurous to definitely associate the high filler loading of grandio with specific size distributions. Since the increase in filler content requires the optimization of size distribution, a decrease in filler size and adapting the filler/resin interface, all of these highlight the influence of these characteristics on fracture resistance of the material.[18] Several studies have ranked Grandio among the best commercial available materials in terms of hardness, , flexural strength, fracture resistance and elastic modulus predominantly due to its high filler load.[19]

Regarding the X-tra Fil, the manufacturer claimed that the combination of a new multi-hybrid filler technology with an innovative initiator system formed the basis for a filler material exhibiting minimal polymerization shrinkage and excellent depth of cure. The combination of relatively small and varied size fillers permits a more dense packing, hence, increases the possible filler volume-fraction of the resin-composites.[14]bulk modulus (B

	Ceram-X One		Grandio		X-tra Fill		Sonic Fill	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
MOD	754.00[c]	59.30	981.00[c]	91.54	957.00[c]	25.24	997.67[c]	50.46
MOD+P	807.00[c]	26.85	1057.00[c]	22.65	1054.33[c]	44.74	1099.67[c]	123.20
MOD+P+B	987.33[b]	15.14	1428.67[b]	125.01	1408.00[b]	44.71	1496.33[b]	71.77
Positive	1797.00[a]	55.24	1797.00[a]	55.24	1797.00[a]	55.24	1797.00[a]	55.24
Negative	464.67[d]	72.97	464.67[d]	72.97	464.67[d]	72.97	464.67[d]	72.97
P-value	<0.001*		<0.001*		<0.001*		<0.001*	

Mean and Standard Deviation (SD) for the effect of cavity design on fracture resistance (Newtons) within each restorative protocol group

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