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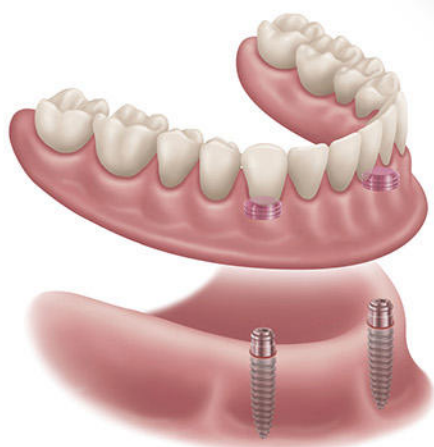
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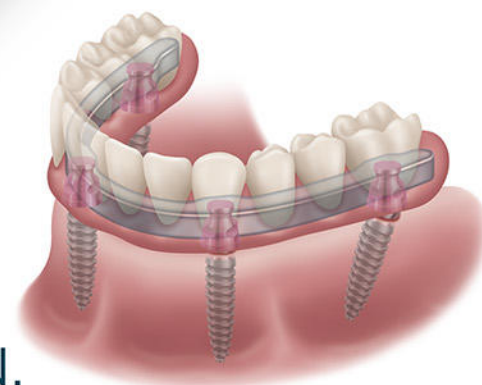Clinician Removable

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In Vitro Fracture Resistance of Adhesively Restored Molar Teeth with Different MOD Cavity Dimensions

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Abstract

Purpose: Molar MOD (mesial-occlusal-distal) cavity preparation weakens relative cuspal stiffness by up to 63%, often resulting in cuspal fracture. This investigation inspects fracture resistance of MOD cavities restored using direct composite restoration.

Materials and Methods: 120 extracted, intact mandibular molars were selected. MOD cavities with different depth/wall thickness were prepared in 9 groups (n = 12): A: 3 mm/3.5 mm, B: 3 mm/2.5 mm, C: 3 mm/1.5 mm, D: 5 mm/3.5 mm, E: 5 mm/2.5 mm, F: 5 mm/1.5 mm, G: 7 mm/3.5 mm, H: 7 mm/2.5 mm, I: 7 mm/1.5 mm. Specimens with 7 mm deep cavities received root canal treatment. The teeth were restored with dental composite. Maximal fracture strength test was conducted. Intact natural teeth were used as control. For statistical analysis Kruskal-Wallis ANOVA with post-hoc pairwise comparisons was used ($\alpha = 0.05$).

Results: Significant difference was indicated between the control and groups D, E, F, G, H, and I. No significant differences were found between the A, B, C groups and the control. Comparing the 5 and 7 mm cavity depth groups, there was no statistical difference between any of them.

Conclusions: Within the limitations of this investigation, the following conclusions can be drawn regarding molar teeth with a MOD cavity: 3 mm or shallower cavities can be restored to the physiological fracture strength with direct composite restorations; 5 mm or deeper cavities cannot be restored to the physiological fracture strength with direct composite restorations. Cusp thickness does not significantly influence fracture strength in molar MOD cavities with a direct composite restoration.

Loss of tooth structure as a result of caries, trauma, or restorative and endodontic procedures has a negative influence on the fracture resistance of teeth and increases the risk of cusp fracture.[1] Studies have pointed out that the primary reason for tooth fragility in the posterior region is the presence of extensive cavity preparations[2] and endodontic therapy.[3] Endodontically treated posterior teeth present specific restorative challenges due to their more brittle behavior compared to vital teeth.[4] According to Dietschi et al[5] this difference cannot be explained by their altered moisture content or dentine toughness, but rather the structural defect generated during tooth preparation; however, according to several studies a conservative endodontic access cavity preparation in posterior teeth reduced the relative cuspal stiffness only by 5% to 20%.[6,7] Meanwhile a standardized MOD cavity preparation in maxillary premolar teeth was shown to result in an average loss of 63% in relative cuspal stiffness,[8] which is related principally to the loss of marginal ridge integrity.[9] This causes a reduction in fracture strength of approximately 54%.[10,11] Complete cusp fracture of posterior teeth, especially with class II amalgam restorations, is a common phenomenon,[12] highlighting the importance of the marginal ridges regarding the stability of the remaining opposing walls. It seems that posterior cavities with intact marginal ridges are less susceptible to serious cusp deflection and resulting cuspal fracture than those with discontinued marginal ridges.

Depth and design of the cavity preparation have been shown to be the most critical factors for generating stress in enamel.[13,14] Cuspal deflection increases with increasing cavity dimensions,[15] meaning the larger the restoration's volume, the higher the stress generated in the remaining dental structure. Hood[16] reported that the remaining cusp after cavity preparation acts as a cantilever beam under occlusal load. The floor of the cavity serves as a fulcrum for cusp bending, and the

cantilever length increases with the depth of the cavity. Granath and Svensson[17] found that cusp displacement was directly related to the extent of cavity width and depth. The width of the cavity correlates with the width of remaining cavity walls. The residual cavity wall thickness represents the quantity of remaining enamel and dentin and is directly correlated with the residual sound tissue,[1] thus, measuring this parameter could be a simple but effective way to aid the selection of the appropriate type of future restoration.

Another important question in MOD (mesial-occlusal-distal) cavities both in vital and nonvital cases is the necessity of cuspal coverage. In endodontically treated teeth the provision of cuspal coverage is considered a key element in long-term success,[18] since lowering of the remaining sound cusp to create cuspal coverage for protection of the intact cusp increased the fracture resistance.[19] There is evidence to suggest that large preparations require cuspal coverage to prevent possible fracture.[20,21] Since the point at which onlays should be preferred over bonded inlays is a matter of debate,[22] this study aims to provide clinically useful and easily measurable information regarding cavity configuration and its prognosis on restorative decision making.

The question arises: What cavity depth and remaining wall thickness is restorable without cuspal coverage? The aim of this study is to assess the effect of different cavity configurations on the maximal fracture load strength of restored molar teeth, without cuspal coverage.

Materials and methods

All procedures of the study were approved by the local Ethics Committee, and the study was designed in accordance with the Declaration of Helsinki. One hundred and twenty mandibular third molars extracted for periodontal or orthodontic reasons were selected for this investigation. The freshly extracted teeth were immediately placed in 5.25% NaOCl for 5 minutes and then stored in 0.9% saline solution at room temperature until use, all within 2 months of extraction. During specimen preparation, the soft tissue covering the root surface was removed with hand scalers. The inclusion criteria were visual absence of caries or root cracks, absence of previous endodontic treatment, posts or crown, or resorptions. Teeth with severe polymorphism of the coronal structures were excluded from the investigation.

Approximately 80% of the specimens ranged 10.0 to 10.9 mm in size, measured at the widest bucco-lingual dimension, and the rest were between 11.0 and 12.0 mm. The mesio-distal dimension of the specimens was also measured, and this parameter allowed a maximum deviation of 10% from the determined mean. The height was between 8.0 and 9.0 mm measured from the cementoenamel-junction (CEJ). The 120 teeth were randomly distributed between 10 study groups (n = 12)[3,18,22] including 9 restored groups (Table 1) and a control group of intact natural teeth.

Cavity preparation

MOD cavities with different wall thicknesses and with different depths (Fig 1) were prepared by the same trained operator in 9 of the groups. The MOD cavities were prepared into each of the teeth according to the parameters listed in Table 1.

Table 1 Cavity parameters per tested group

Depth/wall thickness	3.5 mm	2.5 mm	1.5 mm
3 mm	A	B	C
5 mm	D	E	F
7 mm (Endo)	G	H	I
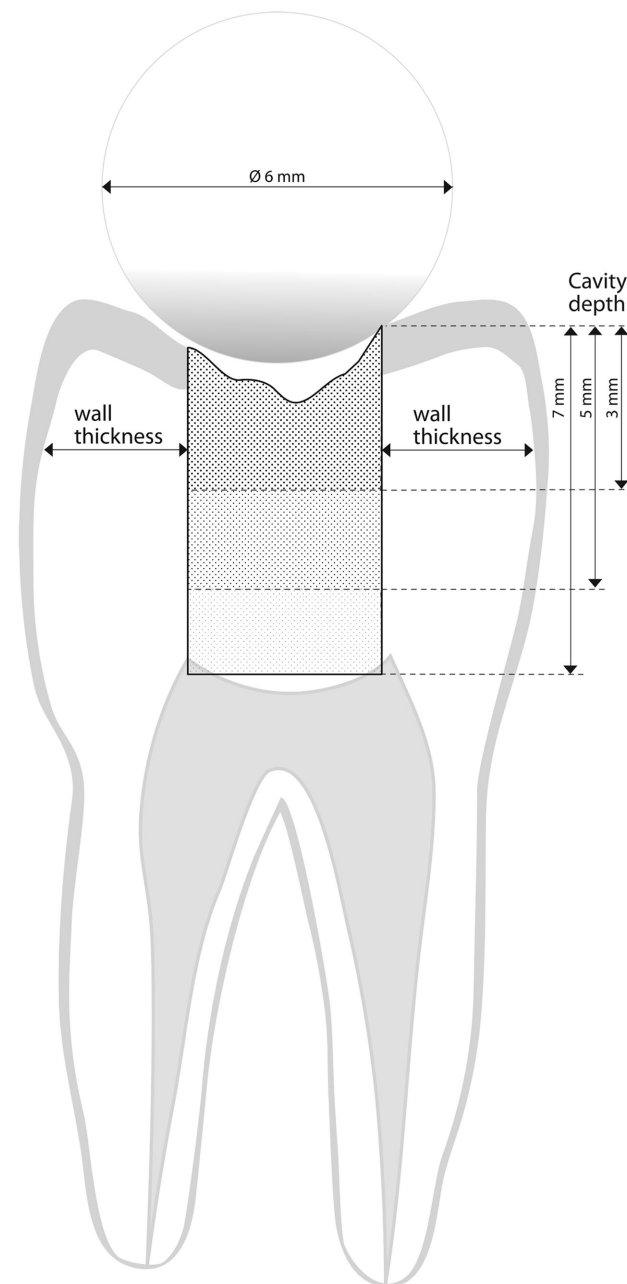
Figure 1 Schematic orovestibular cross section of cavity proportions prepared in mandibular third molars subject to adhesive restoration and maximal fracture strength testing. Depth/wall thickness per group: A: 3 mm/3.5 mm, B: 3 mm/2.5 mm, C: 3 mm/1.5 mm, D: 5 mm/3.5 mm, E: 5 mm/2.5 mm, F: 5 mm/1.5 mm, G: 7 mm/3.5 mm, H: 7 mm/2.5 mm, I: 7 mm/1.5 mm.

The preparation was performed with a round-end parallel diamond bur (881.31.014 FG; Brasseler USA Dental, Savannah, GA) initially positioned at the midline of the occlusal surface of the teeth (determined by dividing the distance between the buccal and lingual cusp tips by two). The thickness of the opposing walls at the cavity base was continuously checked during the preparation with a digital caliper (Mitutoyo Corp., Kawasaki, Japan). The cavity walls were prepared parallel to the axis of the tooth. The depth of the cavity was evaluated with a 15 UNC periodontal probe (Hu-Friedy Mfg. Co., Chicago, IL) measured from the corresponding cusp tip by touching the cavity wall with the full length of the instrument. The cavity was one continuous cavity with the proximal box having exactly the same width and depth as the occlusal one.

In the specimens in which the depth was meant to be 7 mm, an endodontic access was prepared, and endodontic treatment was carried out. After shaping with step-back technique (maximum file size 35-40), the root canals were filled with a thermoplasticized gutta percha delivery system (ObturaII; Obtura/Spartan, Fenton, MO). Following root canal obturation a base was applied to the pulp chamber in the form of a 2.0- to 3.0-mm-thick resin modified glass-ionomer (Fuji II LC; GC Europe, Leuven, Belgium). barrier.[23] This was cut back with a coarse diamond bur (801.36.6801 FG/Surg; Brasseler USA Dental) to establish the 7 mm final depth of the cavity. The cavosurface margins were prepared perpendicular to the tooth surface. The cavity was rinsed with water and air-dried with an air/water syringe. After application of a Tofflemire (1101C 0.038; Kerr, Bioggio, Switzerland) matrix, the enamel was acid-etched selectively with 37% phosphoric acid for 15 seconds, rinsed with water, and air-dried. The cavity was adhesively treated with G-aenial Bond (GC Europe) according to the manufacturer's instructions. The adhesive was light-cured for 40 seconds with an Optilux 501 halogen light (Kerr, Orange, CA) operating in standard mode at a light intensity of 740 ± 36 mWcm^2. In all groups, an approximately 0.5 mm-thin flow composite layer (G-aenial Flo A2; GC Europe) was applied on all walls of the cavity.[24-26]

This layer was light-cured for 40 seconds. After the flowable layer was applied, composite resin (Gradia Direct Anterior A2; GC Europe) was placed in several consecutive 2 mm-thick oblique increments. Each increment was light cured from the occlusal surface for 40 seconds each, and after removal of the Tofflemire matrix band the mesial and distal sides were light cured for 20 seconds each (total 80 seconds). Light-curing times chosen were double that recommended by the manufacturer for each material used, in order to securely obtain maximal conversion at each layer.

The restorations were finished with a fine granular diamond bur (FG 7406-018, Jet Diamonds, Kerr, and FG 249-F012; Horico, Berlin, Germany) and aluminum oxide polishers (One-Gloss PS Midi; Shofu Dental GmbH, Ratingen, Germany) and were stored in physiological saline solution (Isotonic Saline Solution 0.9%; B. Braun, Melsungen, Germany) in an incubator (mco-18aic; Sanyo, Moriguchi, Japan) at 37°C. Specimens were subjected to a thermocycling process consisting of 500 cycles between hot- and cold-water baths of 5° and 55°C for 20 seconds each with an intermediate pause of 3 seconds' transfer time in between.[27]

To simulate the periodontal ligament, the root surface of each tooth was coated with a layer of liquid latex separating material (Rubber-Sep; Kerr) prior to embedding. Specimens were embedded in methacrylate resin (Technovit 4004; Heraeus-Kulzer, Hanau, Germany) at 2 mm from the CEJ to simulate the bone level.

All specimens were tested for fracture strength within 24 hours of restoration, using a universal loading device (5848 MicroTester1; Instron, Norwood, MA), according to the method described by Wu et al.[28] Each test was performed at a 2 mm/min crosshead speed, and load was applied using a 6 mm diameter stainless-steel ball-shaped stylus positioned at the center of the occlusal surface of the tooth between the buccal and oral cusps in the central pit. A force vs. extension curve was dynamically plotted for each tooth. Fracture threshold—defined as the load at which the tooth-restoration complex exhibited the first fracture, resulting in a peak formation on the extension curve—was recorded in Newtons (N).

Statistical analysis was conducted in SPSS 21.0 (SPSS Inc., Chicago, IL). For the comparisons between the groups, Kruskal-Wallis ANOVA with post-hoc pairwise comparisons was used. The significance limit was set at $\alpha = 0.05$. The null hypothesis was that restored teeth are not weakened compared to the intact control specimens.

Results

Median fracture strength values are presented in Figure 2. As the Kruskal-Wallis ANOVA indicated significant variance, post-hoc pairwise tests were performed. The pairwise tests indicated significant difference between the control group and all 5 and 7 mm groups (D, E, F, G, H, I). The 3 mm groups (A, B, C) did not show significant difference as compared to the control. Significant difference was found between group A and all 5 and 7 mm groups (D, E, F, G, H, I). No significant differences were found between 3 mm cavity depth groups (A, B, C). Comparing the 5 and 7 mm cavity depth groups, there was no statistical difference between any of them. The pairwise statistical analysis is detailed in Table 2. The null hypothesis was rejected, as the fracture strength of groups D, E, F, G, H, and I were significantly lower than that of the control group.

Discussion

A number of studies, with or without root canal preparation, have demonstrated that if the cavity involves the marginal ridge(s), the fracture resistance of the tooth is significantly reduced.[28-30] In this study the fracture resistance of MOD cavities varying from small through medium to large sizes was tested. These latter ones are considered to be typical of an amalgam replacement with the indication of an indirect or large direct restoration, which is becoming more common.[30] The reason for the placement of large direct restorations is not only financial, but it is also a goal to preserve the tooth structure as much as possible, according to the principles of minimal intervention dentistry.[32-35] As found in previous studies, the depth of the preparation is one of the most critical factors in terms of future fracture.[14,36] In addition, the choice of the restorative method is commonly based on the cavity configuration and
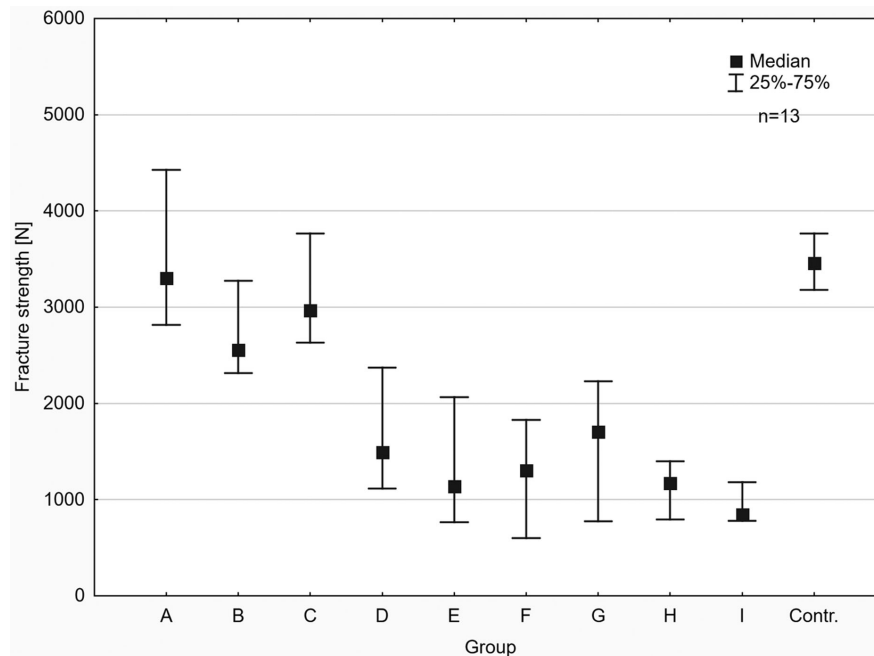
Figure 2 Mean fracture strength and standard deviation of the tested groups.

Table 2 Kruskal-Wallis ANOVA pairwise statistical analysis ($p < 0.00001$). Significance indicated with ✳ symbol

Group	A	B	C	D	E	F	G	H	I	Contr.
A		1.000000	1.000000	0.029247✳	0.000970✳	0.002154✳	0.021271✳	0.000389✳	0.000170✳	1.000000
B	1.000000		1.000000	0.923576	0.072278	0.132891	0.732700	0.035687✳	0.018728✳	1.000000
C	1.000000	1.000000		0.300701	0.017307✳	0.034044✳	0.231264	0.007930✳	0.003899✳	1.000000
D	0.029247✳	0.923576	0.300701		1.000000	1.000000	1.000000	1.000000	1.000000	0.008013✳
E	0.000970✳	0.072278	0.017307✳	1.000000		1.000000	1.000000	1.000000	1.000000	0.000203✳
F	0.002154✳	0.132891	0.034044✳	1.000000	1.000000		1.000000	1.000000	1.000000	0.000478✳
G	0.021271✳	0.732700	0.231264	1.000000	1.000000	1.000000		1.000000	1.000000	0.005670✳
H	0.000389✳	0.035687✳	0.007930✳	1.000000	1.000000	1.000000	1.000000		1.000000	0.000076✳
I	0.000170✳	0.018728✳	0.003899✳	1.000000	1.000000	1.000000	1.000000	1.000000		0.000032✳
Contr.	1.000000	1.000000	1.000000	0.008013✳	0.000203✳	0.000478✳	0.005670✳	0.000076✳	0.000032✳	

dimensions and the number of residual cavity walls.[37-39] In this study the thickness of the cavity walls was measured with a dental caliper, and the depth was measured with a millimeter-scale periodontal probe.

Group A, having the most amount of dentine, showed the highest median fracture strength among the restored groups, whereas group I, having the largest cavity, thus the least amount of dentine, showed the lowest fracture resistance. This is in accordance with previous research by Goel et al[40] and Torbjömer et al[41] showing that preserving the anatomical structures and dentinal tissues is directly correlated with increased mechanical properties and less weakening of the tooth. The groups of 3 mm cavity depth (group A, B, C) presented the highest fracture resistance of all the restored specimens, and we found no significant difference in this respect between these three groups. The 3 mm groups were also not significantly weaker compared to the control teeth. The relatively small cantilever beam from the occlusal margin to the cavity floor, is a possible explanation for this finding. According to Hood's hypothesis, cusps of teeth with MOD cavity preparations function as a cantilever beam, with the extent of deflection under load influenced by both beam thickness and length.[16] It seems from the results that when the cavity is shallow (3 mm deep), and thus the cantilever arm is small, the thickness of the walls is not a crucial factor in fracture strength.

When the cavity depth increased to 5 mm, but access cavity preparation was still not needed, the fracture strength dropped to approximately half of the value measured in group A. This could be caused by the increased depth leading to a greater cantilever effect in these groups. With deeper cavity preparations the length of the freely deflectable cusp increases, and the cuspal deflection increases.[28,29] Jantarat et al[42] found that cusps do not deform as simple cantilever beams, which seemingly contradicts the present findings.

In this study, cavity depth corresponding to an endodontic treatment (groups G, H, I) did not cause significant

weakening, in comparison to the groups with 5 mm depth (groups D, E, F). This is in accordance with previous studies conducted by Reeh et al, showing that when endodontic access is prepared after the preparation of a deep MOD cavity, the decrease measured in relative cuspal stiffness values is not significant compared to the values of MOD cavities without endodontic access.[9,43]

Based on the results of this investigation, 3 mm can be considered a safe cavity depth for adhesive direct restorations. This is in accordance with Frater et al, who found that when restoring shallow MOD cavities with direct techniques using oblique layering, there was no significant difference between the restored groups and the intact control group.[45] These findings do not support the findings of Batalha-Silva et al,[46] who concluded that 5 mm deep cavities could safely be restored with direct techniques. These results rather suggest that a cavity of 5 mm depth is already in the "danger zone" when talking about direct composite restorations without cusp coverage.

To aid clinical decision making, exact cavity dimensions or remaining tissue dimensions under which cuspal coverage must be provided would need to be established. As Seow et al found, maxillary premolars lost on average 53% of their stiffness when prepared with a MOD cavity with an isthmus width of one-third of the intercuspal distance, and if the isthmus width was half of the intercuspal distance, the prepared premolar teeth lost approximately 67% of their stiffness.[18] When a MOD cavity is loaded, force and stress is concentrated at the bottom corners of the prepared cavity.[47] Therefore, the thickness of the residual cusp wall at the base could be a key element in decision making when it comes to preserving or eliminating cusps.[48] According to Scotti et al[37] and Deliperi et al,[48] cavity walls with thickness greater than 2 mm should not be reduced, and cuspal coverage should be avoided, whereas "sufficient" thickness was defined as 2.5 mm in a later study by Scotti et al.[49] In this study reducing only the wall thickness, without changing the depth of the cavity, did not cause a significant reduction in fracture strength. From the results it seems that cavity wall thickness is only secondary to cavity depth in molar MOD cavities in terms of fracture strength, as the change in cavity wall thickness did not lead to a significant difference between the groups in the "safety zone" or between the "danger zone" groups. Within the limitations of this study, this leads us to the conclusion that when the fracture safety of a cavity for a direct restoration without cusp coverage is to be determined, cavity depth is the primary determining factor. This is in accordance with the results of Morin et al[50] and Manhart et al,[51] who found that the depth of the preparation is the most critical factor in terms of future fractures. Since groups with cuspal coverage restorations were not included in this study, the results do not offer direct guidance on cuspal coverage. Also, since the cavities were only restored with a conventional adhesive direct composite restoration, the results cannot be extrapolated to situations when fiber-reinforced materials are used; however, if the cavity depth of molar teeth with a MOD cavity reaches or exceeds 5 mm, cusp coverage with a direct or indirect adhesive restoration could be considered as a safety measure. Future investigations with similar methodology—involving cusp coverage with direct and indirect methods—need to be conducted to further our understanding on the effect of MOD cavity di-

mensions on the restorability of molar teeth and limitations of adhesive restorations.

According to Taha et al, "In experimental studies, fracture resistance to static loading has been used as a measure of the effect of cavity preparation and/or restoration on tooth strength. Although the fracture load is typically much higher than functional occlusal loads, it is still a valid method for comparing restorative materials and different cavity designs."[52] The use of a 6 mm steel sphere for resistance to fracture testing by Dietschi et al[53] and Soares et al[54] was shown to be ideal for molars, because it contacts the functional and nonfunctional cusps in positions close to those found clinically. Also, in the current study, the teeth were subjected to vertical compressive loading with a stainless steel sphere 6 mm in diameter.

Conclusions

Within the limitations of this investigation, the following conclusions can be drawn:

1. Molar teeth with 3 mm or shallower depth MOD cavities can be restored to the same fracture resistance as intact teeth with a direct composite restoration, regardless of cavity wall thickness.
2. Molar teeth with 5 mm or higher depth MOD cavities cannot be restored to the physiological fracture resistance with a direct composite restoration, regardless of cavity wall thickness.
3. Cusp thickness does not significantly influence fracture strength in MOD cavities with a direct composite restoration.

Acknowledgments

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