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Fracture resistance of molar teeth with mesial-occlusal-distal (MOD) restorations

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ABSTRACT

Objective. Filled MOD restorations show near-complete recovery of tooth strength relative to the newly prepared, unfilled state. The present study examines the underlying mechanics of this recovery by more closely quantifying the mode of splitting fracture from the cavity base. By understanding the role of specific cavity dimensions on fracture resistance, useful clinical guidelines concerning MOD morphologies are formulated.
Methods. A systematic in vitro study is made of the load-bearing capacity of filled and unfilled MOD cavities by axially loading extracted molar teeth with a hard metal ball. Filled and unfilled cavities are considered as bounding cases. Focus is placed on drillings with rectangular or rounded tips, covering a range of cavity widths and depths. The failure process is monitored during loading by a video camera, enabling the entire damage evolution from first contact to ultimate failure to be recorded.
Significance. While respecting the widely accepted clinical practice of drilling cavities with internal widths less than one third that of the entire tooth, a stronger correlation is obtained between critical splitting load P_C and ratio of cavity wall thickness h (distance between cavity wall and outer tooth surface) to cavity depth D. Imposing a conservative upper limit on P_C for tooth survival, the study recommends that MOD cavities be prepared such that the ratio remains in the region $h > D$, regardless of the tooth size.

1. Introduction

Molar teeth with significant damage or carious infection are routinely subjected to mesial-occlusal-distal (MOD) cavity filling [1,2]. Such cavities are generally drilled with a diamond or carbide bur, most often with a rectangular or base-rounded profile, sometimes with undercuts. Current procedure involves sequentially filling the drilled cavities with layers of dental composite, with intermittent curing. Modern-day adhesive treatments have led to improved bonding between composite and tooth structure, and are thus less likely to open up fissures at the filler margins. While producing successful immediate outcomes, MOD cavity filling involves a substantial amount of tooth removal and constitutes a potential weakness over the long term in the event of any degradation of the composite-tooth interface.

Several empirical studies have been reported on the load-bearing capacity of extracted molar or premolar teeth with MOD fillings [3–12]. In all such studies tests are usually done by pressing a large hard ball or cylinder onto the occlusal fossae so that cuspal contact wedges open the MOD cavity walls. Failure is marked by a precipitous drop in applied load. Critical failure loads in extracted molars and premolars have been measured for different cavity designs, with and without fill-

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ings [6,8–9,13–14]. The data indicate a considerable loss in structural integrity for cavities without fillings as compared to intact (undrilled) specimens, but strong recovery after filling. However, while the mode of failure is broadly reported as fracture from the base region of the cavity, little attempt has been made to observe the evolution of such fractures during loading. More importantly, nor has there been any systematic quantitative study of the role of characteristic cavity dimensions in determining failure resistance. While some stress analyses of MOD cavities have been reported [9,15], none has hitherto addressed the critical issue of crack evolution. Accordingly, there appears to be little scientific basis for optimizing MOD morphologies for optimum fracture resistance.

To answer these questions, this paper examines the fracture behavior of simple MOD-drilled cavities geometries such as rectangular or rounded bases. Filled and unfilled cavities are considered, with cavity depth and width systematically varied. The evolution of damage is observed in real time during the loading, and a basic strength of materials approach used to analyze failure load data.

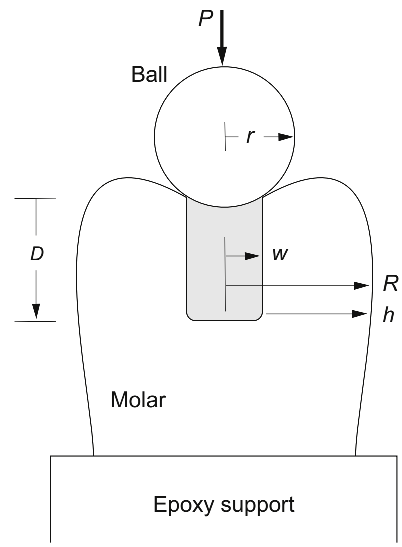

Fig. 1 – Schematic of MOD cavity in molar tooth mounted into epoxy support and axially loaded at force *P* with a tungsten carbide ball of radius *r*, for cavity of half-width *w* and depth *D*, wall-thickness *h* = *R* − *w*, where *R* is the tooth half-width in the near-base region of the cavity.

2. Materials and methods

A quantitative study of MOD cavity-drilled extracted molar teeth in axial loading with a hard ball is made. Filled and unfilled cavities are considered as bounding cases, the former representative of a near-intact occlusal surface and the latter of a compromised filling completely detached from the tooth walls. Extracted mandibular molar teeth for drilling MOD cavities were obtained from the American Dental Association laboratories at the US National Institute of Standards and Technology, with patient consent and IRB approval. Any teeth with visible pre-existing cracks or carious damage were eliminated from the supply. The remaining teeth ($n = 28$) were embedded with their roots in self-curing polymethlmethacrylate resin 1–2 mm below the cemento-enamel junction for support during ensuing preparation and testing. These selected teeth were kept in distilled water until just prior to preparation and testing. Rotary drills of various sizes with either a flat-end or round-end diamond-coated burs (A&M Instruments, Inc., Alpharetta, GA) were used to produce cavities of depth D and width $2w$ as indicated in Fig. 1. The drills were mounted on a high-speed dental drill attached to an x, y, z stage. Specified cavity dimensions were obtained by repeat passes of the drill. The resulting wall thickness $h = R - w$ was measured close to the cavity base. To help understand general trends the cavity dimensions covered broad ranges, $w = 0.7$–2.3 mm and $D = 2.1$–6.8 mm. The depth D was such that the cavity always penetrated some way into the dentin but not as far as the pulp.

Drilled specimens were cleaned and examined by optical microscopy to ensure freedom from preparation defects. Three teeth groups were studied: filled rectangular base cavities ($n = 9$); as-drilled unfilled rectangular base cavities ($n = 12$); as-drilled unfilled rounded base cavities ($n = 7$). The teeth in the first group were restored with a dental composite according to manufacturer's specifications. This latter entailed first etching the cavity walls with 37% acid gel (Phosphoric Acid Etching Gel, Pentron Clinical Technologies, Orange, CA), followed by application of a primer (Clearfil SE, Kurary America, New York, NY). After drying, a bonding agent (Clearfil SE Bond, Kurary America, New York, NY) was applied to the primed walls and light-cured for 20 s (Max 100, Dentsply Caulk, Milford, DE). Resin composite (Clearfil Majesty Posterior, Kurary America, New York, NY) was then filled into the cavity layer by layer [16,17], with intermittent light curing for 20 s at each step (Max 100, Dentsply Caulk, Milford, DE). The fillings were ground with a carbide bur and polished to fit the natural occlusal contour. All such filled specimens were left to age in water for 24 h at room temperature before failure testing.

The failure testing was conducted by mounting the epoxy-supported tooth specimens onto the platen of a screw-driven testing machine (Instron 4501, Instron Corp, Canton, MA) and by placing a tungsten carbide ball of radius $r = 3.17$ mm laid freely in the central fossa. This ball size was chosen to ensure contact with the inner surfaces of the enamel cusps ($r > w$, Fig. 1). A vertical force was applied monotonically to the ball at a fixed displacement rate 0.1 mm/min up to failure at a critical load P_C, as marked by a precipitous drop in the load-displacement record. A video camera was placed side-on to observe the damage evolution during the testing. In this way the entire fracture sequence could be monitored, both at the side walls and in the occlusal regions immediately adjacent to the contact. Dimensions R, h, w and D were determined from video images with the help of a calibrated digital ruler using a Photoshop package. The tooth radius of the selected specimens showed relatively small variation, $R = 5.3 \pm 0.4$ mm (mean and standard deviation).

The statistical significance of the ensuing data sets was analyzed by one-way ANOVA. The significance level was set at $p \leq 0.05$ for all analyses.