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Asymptotic stress field for the interface between teeth and different restorative materials

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ABSTRACT

Brittle fracture of restored teeth with direct or indirect restorations materials are often observed in dental clinics. These fractures have different causes such as complex clinical procedures, material choice, cavity design and many more. In order to evaluate this phenomenon this study was focused on stress distribution due to only materials choice and cavity design for direct and indirect restorations.

Reverse engineering was used to convert a real molar tooth into a virtual numerical model. A 3D finite element analysis was performed in order to determine the stress field in a Class II restored tooth.

The asymptotic stress fields for the interface between teeth and different dental restorative materials for Class II preparations were obtained analytically using complex functions. The influence of cavity line angles and restorative material properties was also investigated. The resulting fields are shown to be singular.

Analytical and numerical predictions were validated by testing human teeth samples prepared with direct restorative materials (amalgams, composite resins and ionomers), and different internal cavity line angles.

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1. Introduction

Carious lesions affect the occlusal and one proximal surface of a posterior tooth, a cavity must be obtained after removal the sclerotic dental tissue. The first step is the development of the ideal cavity preparation. By doing an ideal cavity preparation, the extent of the carious lesion on the pulpal, lateral, and axial walls is seen. If there is any remaining carious lesion, it is removed. Any remaining carious lesion is removed only after establishment of the ideal internal and external outline forms. Then the cavity is filled with adhesive and composite resin in order to obtain the restoration of the tooth, Fig. 1. After the filling procedure is completed numerous problems could affect the integrity of the Class II composite resin filling that could lead to micro-leakage or even fracture of the fillings or of the hard dental tooth walls, Fig. 2. The problems that can produce such effects includes the correct angulations of the cavities walls, the quality of the adhesive layer, the strength of the filling materials and the materials defects from inside the filling structures.

Lindberg et al. [1] evaluated the durability of a polyacid-modified resin composite versus resin composite open sandwich restoration in a 9 years follow-up. The failure rate during the 9 year period was 1.1%. The reasons of failure were: secondary caries, fracture of the tooth, fracture of the restorations and endodontic treatment. Reis et. al. [2] tested the hypothesis that the effects of filling technique, cavity configuration and use of a low viscosity composite liner influence resin bond strength to the dentin of Class II cavities gingival floor. They analyzed the failures modes of the fractured specimens, also. Standardized Class II cavities were prepared in the proximal surfaces of freshly extracted third molars, which were randomly assigned to 10 experimental groups. All prepared surfaces were acid-etched, bonded with single bond adhesive system and restored with TPH composite, according to each technique: G1 and G2-horizontal layering, G3 and G4-faciolingual layering, G5 and G6-oblique layering, G7 and G8-bulk filling, G9 and G10-control (flat dentin surfaces). Groups were tested, with or without a low-viscosity composite liner (Tetric Flow Chroma). After storage in water for 24 h, teeth were vertically serially sectioned to yield a series of 0.8 mm thick slabs. Each slab was trimmed into an hourglass shape of approximately 0.8 mm^2 area at the gingival resin–dentin interface. Specimens were tested in tension at 0.5 mm/min until failure. Fractured specimens were analyzed using SEM to determine the failure modes. No significant difference was found between groups restored with and without a low-viscosity composite liner (p, 0.05). Among filling techniques, the bulk filling groups presented the lowest bond strength values (p, 0.05), while incremental filling groups did not differ from control (flat dentin surfaces). Failure modes varied significantly among groups restored with and without the low-viscosity composite liner. Bond strengths

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Fig. 1. RX image of a Class II restored tooth.

were not improved when a low-viscosity composite liner was applied, but it remarkably influenced the failure modes. Incremental techniques improved bond strength.

Ausiello et al. [3] investigated the effect of differences in the resin–cement elastic modulus on stress-transmission to ceramic or resin-based composite inlay-restored Class II Mesial–Occlusal–Distal (MOD) cavities during vertical occlusal loading. Three finite-element (FE) models of Class II MOD cavity restorations in an upper premolar were analyzed. Model A represented a glass–ceramic inlay in combination with an adhesive and a high Young's modulus resin–cement. Model B represented the same glass–ceramic inlay in combination with the same adhesive and a low Young's modulus resin–cement. Model C represented a heat-cured resin composite inlay in combination with the same adhesive and the same low Young's modulus resin cement. Occlusal vertical loading of 400 N was simulated on the FE models of the restored teeth. Ansys FE software was used to compute the local Von Mises stresses for each of the models and to compare the observed maximum intensities and distributions. Experimental validation of the FE models was conducted. The results pointed out the fact that complex biomechanical behavior of the restored teeth became apparent, arising from the effects of the axial and lateral components of the constant occlusal vertical loading. In the ceramic-inlay models, the greatest Von Mises stress was observed on the lateral walls, vestibular and lingual, of the cavity. Indirect resin–composite inlays performed better in terms of stress dissipation. Glass–ceramic inlays transferred stresses to the dental walls and, depending on its rigidity, to the resin–cement and the adhesive layers. For high cement layer modulus values, the ceramic restorations were not able to redistribute the stresses properly into the cavity. However, stress-redistribution did occur with the resin composite inlays [3].

Ausiello et al. [4] carried on a 3D FE analysis to investigate the cusp movements in a human upper premolar restored with adhesive resin composites (RC). They concluded that Young's modulus values of the restorative materials play an essential role in the success of the restoration. The effect of elastic modulus of restorative materials (Tetric Flow, Glass Ionomer Composite, Z100, amalgam and gold alloy) on the stress of non-carious cervical lesions was also investigated numerical by Kwon et al. [5]. Using a 3D finite element analysis they obtained the stress distribution of lesion in tooth, and found that restorative materials with lower stiffness than the dentin provide lower stress in occlusal and cervical regions.

The Taguchi method combined with finite element analysis were used to evaluate the sensitivity of restored tooth to various parameters like cavity depth, cavity width, cavity interaxial thickness, restorative material properties, resin cement modulus, resin cement thickness and loading conditions, Lin et al. [6]. The study starts from the complex 3D geometry of a restored tooth, considering various parameters influencing the biomechanical response of a premolar Class II MOD restoration. The simulated results show that the cavity depth was the most critical for the stress distribution. It was also pointed out that lower Young modulus of the luting material provide a better force-transmission mechanism for the restored tooth.

All experimental and numerical studies on Class II MOD cavity restorations highlight the presence of stress concentration and fracture initiation. However, up to now only Kahler et al. [7] investigated the asymptotic stress field in the vicinity of dentin-restorative material joints. The asymptotic analysis proposed by Bogy and Wang [8] was implemented. They evaluated the strength of the singularity at interface corner between restorative material and dentin. The results are reported in terms of ratio between Young's modulus of restorative material and dentin, Poisson's ratio of the restorative material and cavity angle. Four categories of singularity were identified from weakest to strongest singularity, depending on material combinations and cavity angles.

Similar analytical approaches were used to find the stress singularity for different types of joints, geometries, material combinations and were reported in the literature [9–21]. Such analytical approach was used in present study to determine the singularity orders of different types of dental joints.

2. Experimental investigations

2.1. Materials and methods

For all samples a Class II cavity was produced. For this, the cylindrical bur (ISO 835) was penetrated 90° to the plane of occlusal surface with the bur tilted slightly lateral for ease of penetration. The initial outline form included only the defective occlusal pits and fissures. The occlusal segment of the tooth preparation was started by entering the deepest or most carious pit orienting

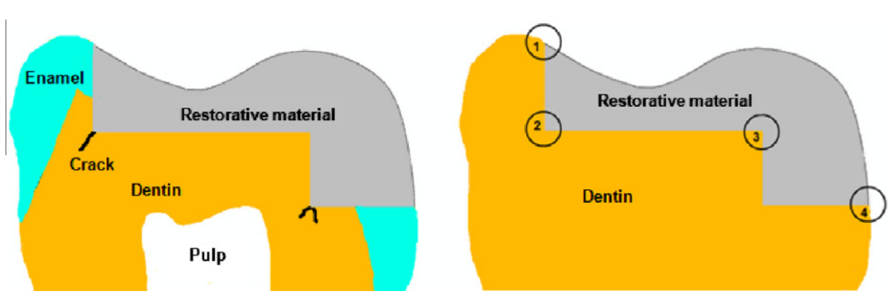

Fig. 2. Schematization of a Class II restored teeth (a: initiation of failure in Class II restored teeth, b: identification of different types of joints).

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