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Mechanical behavior of bulk direct composite versus block composite and lithium disilicate indirect Class II restorations by CAD-FEM modeling

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ABSTRACT

Objectives. To study the influence of resin based and lithium disilicate materials on the stress and strain distributions in adhesive class II mesio-occlusal-distal (MOD) restorations using numerical finite element analysis (FEA). To investigate the materials combinations in the restored teeth during mastication and their ability to relieve stresses.

Methods. One 3D model of a sound lower molar and three 3D class II MOD cavity models with 95° cavity-margin-angle shapes were modelled. Different material combinations were simulated: model A, with a 10 μm thick resin bonding layer and a resin composite bulk filling material; model B, with a 70 μm resin cement with an indirect CAD-CAM resin composite inlay; model C, with a 70 μm thick resin cement with an indirect lithium disilicate machinable inlay. To simulate polymerization shrinkage effects in the adhesive layers and bulk fill composite, the thermal expansion approach was used. Shell elements were employed for representing the adhesive layers. 3D solid CTETRA elements with four grid points were employed for modelling the food bolus and tooth. Slide-type contact elements were used between the tooth surface and food. A vertical occlusal load of 600 N was applied, and nodal displacements on the bottom cutting surfaces were constrained in all directions. All the materials were assumed to be isotropic and elastic and a static linear analysis was performed.

Results. Displacements were different in models A, B and C. Polymerization shrinkage hardly affected model A and mastication only partially affected mechanical behavior. Shrinkage stress peaks were mainly located marginally along the enamel-restoration interface at occlusal and mesio-distal sites. However, at the internal dentinal walls, stress distributions were critical with the highest maximum stresses concentrated in the proximal boxes. In models B and C, shrinkage stress was only produced by the 70 μm thick resin layer, but the magnitudes depended on the Young's modulus (E) of the inlay materials. Model B mastication behavior (with E = 20 GPa) was similar to the sound tooth stress relief pattern. Model B

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internally showed differences from the sound tooth model but reduced maximum stresses than model A and partially than model C. Model C (with E = 70 GPa) behaved similarly to model B with well redistributed stresses at the occlusal margins and the lateral sides with higher stress concentrations in the proximal boxes. Models B and C showed a more favorable performance than model A with elastic biomechanics similar to the sound tooth model.

Significance. Bulk filling resin composite with 1% linear polymerization shrinkage negatively affected the mechanical behavior of class II MOD restored teeth. Class II MOD direct resin composite showed greater potential for damage because of higher internal and marginal stress evolution during resin polymerization shrinkage. With a large class II MOD cavity an indirect composite or a lithium disilicate inlay restoration may provide a mechanical response close to that of a sound tooth.

1. Introduction

Today materials employed in adhesive dentistry to restore decayed teeth are principally resin composite [1] and ceramic systems, such as lithium disilicate [2]. The former incorporate an organic matrix, formed from monomers such as Bis-GMA and TEGDMA and a reinforcing phase of inorganic glass particles that are micro or nano-structured. A silane coupling agent chemically links the two phases. They perform adequately in both anterior and posterior situations [3]. Lithium disilicate is a pressed glass ceramic material with good physical properties and clinical performance [4]. Resin composites are used in Class I and in II MOD adhesive restorations but there is some evidence contra-indicating their use via adhesive direct techniques in large size cavities [5]. This is mainly due to shrinkage stress effects on the adhesive interfaces [6–9].

Bulk-fill composite materials showed comparable results to traditional composited regarding their shrinkage properties [10]. Clinically, there may be a preference for indirect resin composite inlays created by milling industrially cured blocks in combination with adhesive luting materials [11]. Glass ceramic lithium disilicate restorations can also reduce polymerization shrinkage effects. In both cases this is restricted to the thin composite cement layer [7] rather than to the bulk filling material. Also bulk filling materials for direct use in class I and class II cavities are now established [12–15]. Nevertheless, fatigue through mechanical loading, can marginally damage composite restorations and lead to debonding and bacterial penetration along marginal gaps [16]. Functional modeling by 3D-finite element analysis has suggested acceptable performance of Class II inlay adhesive composite restorations [17]. Furthermore, stress propagation and potential crack growth inside adhesively restored teeth under occlusal loading have been simulated. Results indicated that principal stress behavior of Class II MOD restored teeth can be influenced by several factors such as Class II cavity-margin-angle and different bolus stiffness [18]. However, the effect of restorative material selection requires investigation. This could clinically influence whether or not restoration behavior as close as possible to the sound tooth could be obtained.

The aim of the present study was to determine, by means of 3D-FEA under shrinking and loading conditions, the displacements and the stress distribution in a Class II MOD cavity for the following three representative restoration scenarios, using: (a) an adhesively bonded bulk fill direct resin composite material; (b) a 70 μm resin cement layer beneath a milled composite inlay and (c) a 70 μm resin cement layer beneath a lithium disilicate inlay machinable restoration.

2. Materials and methods

A 3D model of a human lower molar, used in previous investigations [17,18], was considered in this study. The adopted procedure may be summarized as follows. First, the 3D CAD model of the sound tooth was built-up starting from micro-CT scan images [17]. Then, the restored tooth modeled properly [18]. Finally, numerical FEA simulations were performed to understand the influence of different resin based and lithium disilicate materials in terms of stress and strain distributions.

2.1. *Generation of tooth solid model*

A 3D model of the sound tooth was digitized with a high resolution micro-CT scanner system (1072, SkyScan, Belgium). A total of 471 slices were collected using an image resolution 1024 × 1024 pixels, a voltage at 110 kV and a voxel dimension of 19.47 μm. As the aim of this study concerned the macro-structure of the tooth, there was no need for all slices. Just 91 slices were sufficient. Iso-surfaces were detected by using the “K-Means” clustering algorithm implemented in [17] that operates by grouping image pixels, defined with their gray scale, into K groups/clusters. A constant pixel value (the centroid of the cluster) was associated with each cluster. By using this classification, for the ith slice, logical matrices (pixel mask) of pixels were introduced: the value of the tth pixel was equal to “1” if it belongs to the kth cluster, otherwise it was assumed equal to “0”. In the present application, the cluster number was two: for enamel and dentin regions. Once clustering classification had been performed for all image slices, 3D tessellated surfaces were created using the marching-cube algorithm. This numerical procedure allows connection between pixels having the same value on different slices. The “isosurface” function available in Matlab® was used for the surface tessellation. Then 3D volumes were created by using SolidWorks® CAD software.