DENTAL MATERIALS 33 (2017) e39–e47

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.intl.elsevierhealth.com/journals/dema

The effects of cavity-margin-angles and bolus stiffness on the mechanical behavior of indirect resin composite class II restorations

Pietro Ausiello[a], Stefano Ciaramella[b], Franklin Garcia-Godoy[c], Antonio Gloria[d], Antonio Lanzotti[b], Saverio Maietta[b], Massimo Martorelli[b,*]

[a] School of Dentistry—University of Naples Federico II, Italy
[b] Department of Industrial Engineering, Fraunhofer JL IDEAS—University of Naples Federico II, Italy
[c] Bioscience Research Center, College of Dentistry—University of Tennessee Health Science Center, USA
[d] Institute of Polymers, Composites and Biomaterials—National Research Council of Italy, Italy

ARTICLE INFO

Article history:
Received 8 July 2016
Received in revised form
28 October 2016
Accepted 1 November 2016

Keywords:
CAD
Finite element analysis
Endodontics
Micro-computed tomography
Stress analysis

ABSTRACT

Objective. To study the influence of the different class II mesio-occlusal-distal (MOD) cavity shape on the stress and strain distributions in adhesive indirect restorations, using numerical finite element analysis (FEA). To investigate the relationship between restored teeth failure and stiffness of food, three values of Young's modulus were used for the food.

Methods. A 3D model of a sound lower molar and three class II MOD cavities with different shape were created. Slide-type contact elements were used between tooth surface and food. An adhesive resin-based cement, modeled with fixed-type contact elements, and a single restorative filling materials were considered. To simulate polymerization shrinkage effect, which is basically restricted to the thin composite cement layer, shell elements were employed and the thermal expansion approach was used. A vertical occlusal load of 600 N was applied, while assigning fixed zero-displacements on the cutting surfaces below the crevices. All the materials were assumed to be isotropic and elastic. A static linear analysis was carried out.

Results. In the lingual cusp, the displacements increased as the values of the stiffness food increased. In the restored teeth, the stress near the restoration-tooth interface was strongly dependent on the MOD cavity shape. The stress peaks were mainly located along the enamel–dentin interface at the lingual side; wedge-shaped MOD cavity with a low angle, in combination with the lowest food stiffness provided the best results.

Significance. A more complex load application on the occlusal surfaces was introduced. Food stiffness slightly affected the stress distribution of the restored and sound teeth. Teeth with adhesive class II MOD indirect resin composite restorations were potentially more susceptible to damage if the class II MOD cavity-margin-angle was higher than 95°. Restored teeth with a higher cavity-margin-angle led to considerable stress concentration in the lingual

* *Corresponding author*. Fax: +39 0817682470.
E-mail address: massimo.martorelli@unina.it (M. Martorelli).
http://dx.doi.org/10.1016/j.dental.2016.11.002

cusp along the enamel–dentin interface. These models were more susceptible to fracture in the lingual cusps when compared to the buccal ones.

1. Introduction

Resin-based composite materials are widely used in indirect adhesive restorations particularly in class II MOD cavities [1]. A promising advantage is the well known possibility to bond an inlay using modern adhesive materials [2,3]. In addition, indirect restorations rather than direct restorations could help in reducing the polymerization shrinkage, which is basically restricted to the thin composite cement layer [4,5]. The polymerization shrinkage of the resin-based composites represents one of the main causes of leakage in dental restorations. This is also influenced by different parameters, such as the material properties, cavity configuration factor (C-factor) [6,7], cavity size, presence or absence of enamel at the cavity margins, and the dentin quality, morphology, and location [8,9]. Residual shrinkage stress distributions in molars after composite restoration have been investigated by means of 3D finite element analysis (FEA) and compared to shrinkage strains measured by the strain gauge experiments [10]. In indirect restoration method, the polymerization of the resin composite occurs only in a laboratory oven, outside the oral cavity. Thus, the composite resin inlay restoration has improved mechanical properties [8]. However, with regard to restorative materials, considerable disadvantages are also reported. First, there is a great mismatch between the mechanical properties of the employed filling materials and dental tissues. Furthermore, the occlusal loading of adhesively restored class II MOD restorations did not lead to equal fracture strength and comparable fracture or stress pattern [11], depending on the intensity of the masticatory loading, on the contact-points or on the contact-area of the applied load, on the used test [9,12]. Also, repeated functional loading will determine fatiguing of the restored tooth [13]. Crack growth and propagation inside the restored teeth under occlusal fatigue loading have been investigated in simulated conditions by means of 3D FEA, reproducing a standard load application [14]. However, cohesive or adhesive cracks and fracture patterns are not always similar. Thus, it is still difficult to understand and to investigate their propagation and where and when was the origin. The influence of the cavity size and design of class II MOD indirect restorations have been frequently considered in terms of mechanical resistance. Cavity materials angles (CMA) can be differently squared to achieve a better stress distribution during mastication, also avoiding the stress concentration along the occlusal margins, as well as to reduce or to eliminate microcrack developments [15]. It is well reported that dental research may be expensive and ethically questionable if carried out on live subjects. On the other hand, the use of virtual models and simulation, can contribute to perform interesting investigations reducing the costs of in vitro and in vivo experiments and improving the benefits [16–18]. Accordingly, in the adhesive and restorative dentistry a great interest has been focused on CAD-FEM modeling [19,20] and several studies focused on the stresses at the tooth-restoration interface, as well as on the transfer of occlusal forces through molars and on the tooth deformation [21]. In this context, the study investigated the stresses induced in a mandibular molar during clenching and chewing of morsels with different values of Young's modulus. As reported in the literature, teeth experience a force whose magnitude is dependent on the food bolus stiffness [22]. The mastication force is distributed over the bolus surface, which is in contact with the mandibular and maxillary teeth when the bolus is compressed [23]. During mastication the gliding phase does not always occur. Anyway, it starts when the total compression of the food bolus occurs (i.e., tooth-to-tooth contact), continuing until the start of the preparatory phase (i.e., the jaw begins to open). At contact, the mastication force is concentrated in the occlusal contact area [24,25]. Accordingly, in the current research a 3D model of an untreated lower molar was developed and analyzed. Over the last decade, great efforts have been made in the development of process and analysis techniques as well as in the design of polymer networks for dentistry and tissue engineering applications [26]. So, the FEM model was soon generated. Finally, three different class II MOD indirect cavities were modeled and restored with a resin-based composite material. The variability of the masticatory function, depending on the contact between tooth surface and food bolus, was considered. The influence of both different MOD cavity shape and stiffness on the stress and strain distributions was assessed.

2. Materials and methods

2.1. *Generation of tooth solid model*

A 3D model of the sound tooth, described in a previous work [14], was used in the current study. It was digitized with a high resolution micro-CT scanner system (1072, SkyScan, Belgium). A total of 471 slices was 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 was mainly focused on the macro-structure of the tooth, there was no need for all slices. Just 91 slices were properly required. Isosurfaces were detected by using the "K-Means" clustering algorithm that operates by grouping image pixels, defined with their gray scale, into K groups/clusters. A constant pixel value (the centroid of the cluster) is associated with each cluster. By using this classification, for the ith slice, logical matrices (pixel mask) of pixels are introduced: the value of the tth pixel is equal to "1" if it belongs to the kth cluster, otherwise it is assumed equal to "0". In the present application, the number of clusters was two: enamel and dentin regions. Once clustering classification was performed for all image slices, 3D