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The effect of ferrule height on stress distribution within a tooth restored with fibre posts and ceramic crown: A finite element analysis

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ABSTRACT

Objectives. To evaluate via finite element analysis the effect of different ferrule heights on stress distribution within each part of a maxillary first premolar (MFP) restored with adhesively luted glass fiber-reinforced resin (GFRR) posts and a ceramic crown.

Methods. The solid models consisted of MFP, periodontal ligament and the corresponding alveolar bone process. Four models were created representing different degrees of coronal tissue loss (0 mm, 1 mm, 2 mm and 3 mm of ferrule height). First set of computing runs was performed for in vivo FE-model validation purposes. In the second part, a 200-N force was applied on the buccal cusp directed at 45° to the longitudinal axis of the tooth. Principal stresses values and distribution were recorded within root, abutment, posts, crown and related adhesive interfaces.

Results. All FE-models showed similar stress distribution within roots, with highest stress present in the chamfer area. In composite abutments higher stress was observed when no ferrule was present compared to ferruled FE-models. Stress distribution within crown and GFRR posts did not differ among the models. Stress values at the adhesive interfaces decreased with increasing ferrule height.

Significance. The stress state at abutment-crown and post-root interfaces was very close to their strength, when ferrule was not present. Similarly, higher ferrule produced more favorable stress distribution at post-abutment and abutment-root interfaces. Endodontically treated teeth with higher ferrule exhibit lower stress at adhesive interfaces that may be expected to lower the probability of clinical failure.

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1. Introduction

Endodontically treated teeth are generally considered weaker and more susceptible to fracture than vital teeth [1,2]. The main change in the biomechanical behavior is attributed to the considerable loss of tooth structure [1]. Preservation of sound radicular and coronal tooth tissue and especially presence of ferrule are important factors for enhancing the performance of structurally compromised endodontically treated teeth [3,4]. Ferrule is provided by parallel walls of dentin extending coronal to the shoulder of the preparation [5], which after being encircled by a crown produces a protective effect, called ferrule effect, by reducing stresses within a tooth [4].

This topic has been studied over the past years and still represents an interesting field of research. Most of the laboratory studies agree on the beneficial effect of ferrule on the fracture resistance of compromised teeth [6–8]. In addition, the presence of ferrule could reduce the incidence of non-restorable root fractures [9,10]. Regarding the height of ferrule that is necessary to provide the protective effect, various results were reported. While 1-mm was found enough to significantly increase the number of fatigue cycles prior to failure [8], no difference in fracture resistance between teeth with 1-mm ferrule and those with no ferrule was found [10,11]. Additionally, during chewing simulation teeth with 1-mm ferrule exhibited worse performance compared with 2-mm high dentin walls [12]. The minimum heights of ferrule required to significantly improve fracture resistance were 2 mm [11] and 3 mm [10].

Existing clinical trials could not confirm that ferrule was a factor that significantly influenced the survival of endodontically treated teeth [13–15]. When all coronal walls were missing, similar failure risk was found in teeth with complete absence of ferrule and those with 2 mm ferrule [14,15]. Nevertheless, when adequate 2-mm ferrule was included in the preparation design successful treatment outcome was recorded over 2- [16] and 7 year [17] observation period, irrespective of the post type.

The impact of ferrule on stress distribution within the restored tooth under stress has been assessed by several finite element analysis (FEA) studies [12,18–20]. It was proved that cervical region of the tooth is indeed exposed to the highest stress [20] and that presence of ferrule reduced the stress level [18,20]. Analyzing von Mises stresses within the central incisor with 0-mm, 1-mm and 2-mm ferrule it was observed that stress decreased with increased ferrule height, regardless of the post material [18]. However, the differences in stress values were small [18]. Another study, investigating metal cast post-and-core restored tooth, suggested that ferrule height should be determined individually based on the bucco-lingual cervical diameter of the root [19].

Therefore, the aim of this study was to evaluate via finite element analysis the effect of different ferrule heights on stress distribution within each part of a maxillary first premolar (MFP) restored with adhesively luted glass fiber-reinforced resin (GFRR) posts and a ceramic crown. The null hypothesis was that different ferrule heights do not affect the stress distribution within the tooth.

2. Materials and methods

2.1. *Finite elements models generation*

The solid models consisted of a maxillary first premolar (MFP), the periodontal ligament (PDL) and the corresponding alveolar bone process. The average anatomical dimensions of the alveolar bone and periodontal ligament (PDL) were generated according to the literature data [21]. The external shape of the premolar was obtained by laser-based 3D digitizing (Cyberware, Inc., Monterey, California, USA) of a plaster cast (Thanaka manufacturer, Japan). The scanned profiles were assembled in a 3D wire frame structure using a 3D CAD (Autocad 12, Autodesk Inc.) and exported into a 3D parametric solid modeler (Pro-Engineering 16.0 Parametric Technologies, USA). Arrangement of dentin and enamel internal volumes and morphologies were modeled according to literature data [22]. The solid models of premolar and surrounding alveolar bone are presented in Fig. 1a.

The 3D parametric solid modeler software was used to generate four solid-models representing different degrees of coronal tissue loss. The solid-models were represented in a consistent manner, with the ferrule height as the unique geometry variable. Solid-model 0 simulated a premolar restored with a crown in absence of dentin ferrule. Solid-models 1, 2 and 3 simulated teeth with ferrule heights of 1 mm, 2 mm and 3 mm, respectively. Roots of solid-models 0, 1, 2 and 3 are presented in Fig. 1b. Buccal and palatal glass fiber-reinforced resin (GFRR) post space preparations were modeled in the root canals. GFRR posts had the following dimensions: length 12 mm, coronal diameter 1.5 mm, apical diameter 1.2 mm. Part of the post that was inserted within the root was 9 mm of length, while the remaining 3 mm were incorporated within the abutment. An abutment was modeled according to the dimensions of the MFP prepared for the full crown coverage. The ceramic crown was modeled to fit the abutment.

The four solid-models were imported to the Finite Elements Analysis (FEA) software ANSYS rel. 9.0 (Ansys Inc. Houston). The solid-models were meshed with eight nodes brick with 3 degrees of freedom per node, the crown structure was meshed with 4 nodes tetrahedral elements, finally resulting in four 3D FE models made up of 31,240 elements and 35,841 nodes (Fig. 2a). Accuracy of the model was checked by convergence tests [22]. Cement and adhesive interfaces were simulated by layers of solid brick elements: abutment-root and the abutment-post interfaces, average thickness of 10 μm [23]; root-post interface, average thickness of 50 μm [24]; abutment-crown interface, average thickness of 50 μm [24] (Fig. 2b).

Enamel and spongy bone were considered as isotropic linear elastic materials [25]. Cortical bone was considered as an orthotropic elastic material according to the mechanical characterization reported by Schwartz-Dabney and Dechow [26]. Dentin was considered as an orthotropic linear material [27]. Although the elastic moduli of the dentin are similar along its plane of symmetry, it could be safely considered as an isotropic material without a significant influence on the outcome. Management of cortical bone and dentin orthotropicity was previously described by Aversa et al. [28]. Crowns