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Mechanical behavior of endodontically restored canine teeth: Effects of ferrule, post material and shape

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ABSTRACT

Objective. To assess the effect of a ferrule design with specific post material-shape combinations on the mechanical behavior of post-restored canine teeth.
Methods. Micro-CT scan images of an intact canine were used to create a 3-D tessellated CAD model, from which the shapes of dentin, pulp and enamel were obtained and geometric models of post-endodontically restored teeth were created. Two types of 15 mm post were evaluated: a quartz fiber post with conical–tapered shape, and a carbon (C) fiber post with conical–cylindrical shape. The abutment was created around the coronal portion of the posts and 0.1 mm cement was added between prepared crown and abutment. Cement was also added between the post and root canal and a 0.25 mm periodontal ligament was modeled around the root. Four models were analysed by Finite Element (FE) Analysis: with/without a ferrule for both types of post material and shape. A load of 50 N was applied at 45° to the longitudinal axis of the tooth, acting on the palatal surface of the crown. The maximum normal stress criterion was adopted as a measure of potential damage.
Results. Models without a ferrule showed greater stresses (16.3 MPa) than those for models with a ferrule (9.2 MPa). With a ferrule, stress was uniformly distributed along the abutment and the root, with no critical stress concentration. In all models, the highest stresses were in the palatal wall of the root. Models with the C-fiber post had higher stress than models with the quartz fiber posts. The most uniform stress distribution was with the combination of ferrule and quartz fiber post.
Significance. The FE analysis confirmed a beneficial ferrule effect with the combination of ferrule and quartz fiber post, with tapered shape, affording no critical stress concentrations within the restored system.

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1. Introduction

It is widely recognized that to reduce fracture risk under physiological conditions and to preserve a seal against fluid access from the coronal end, endodontically treated teeth need to be restored with adhesive techniques [1–3]. A decrease in tooth rigidity often accompanies endodontic procedures as a consequence of the loss of one or both proximal ridges in posterior teeth and pulp chamber opening [4,5]. However, endodontically treated teeth may be successfully restored using adhesives without a post. The type of restored tooth, the shape of the residual cavity and the adhesive-material combination will influence fracture strength [6,7]. But especially in larger posterior teeth subject to compressive forces, if one or two cavity walls still remain, posts may help to reinforce weakened teeth [8,9]. For anterior endodontically treated teeth with a veneer, adhesive restoration should improve fracture resistance when a fiber post is placed and cemented in the root canal [10].

Further studies have shown that post placement may cause problems as a consequence of a mismatch between post stiffness and the residual dental structure, thus negatively affecting the mechanical resistance of teeth [11]. Compared to a sound tooth, an endodontic post may create a non-physiological stress and strain distribution as evaluated by finite element (FE) analysis [11–14].

Some authors analyzed the effects of different combinations of restorative materials in anterior endodontically treated teeth [14]. It was evidenced that the level of stress and strain along the dentin-cement-post interfaces and the position of concentration areas were strongly related to the mechanical properties of the crown and core materials [14].

Under loading conditions, many differences have been found between endodontically treated anterior teeth and sound teeth [15].

The number of interfaces in the restored system, the cement modulus and its thickness, the post shape and its modulus can influence shock absorbance and stress distribution, also promoting crack propagation and fracture of the root [16,17]. Moreover, as experimentally evaluated, a combination of metal post and a resin composite core reduces the fracture resistance, compared to a fiber post, under static and fatigue loading [18]. To avoid this effect, a cement layer alone or in combination with dental adhesives may be considered. Even with low rigidity posts, it may not be possible to reproduce a physiological stress distribution, as in a sound tooth [12]. In a finite element analysis of the mechanical behavior of a post-restored upper canine tooth, all the analyzed models exhibited a high stress gradient, because of interfaces with different material stiffnesses [1]. Nevertheless, when supragingival structures are badly damaged and subject to fracture during mastication, and when the tooth has been endodontically treated, posts and cores are widely employed [19]. The strength and longevity of a post-and-core restored tooth is influenced by several factors. These are: the post material and its length, the post attachment to tissues, the root wall length and width, and the presence of a ferrule [19,20].

Post shape slightly affects the mechanical behavior of the restored teeth as reported in the literature [1]. Specifically, whereas small variations of post diameter or conicity do not affect the stress behavior in the modeled canine, variations in crown material strongly influences the "degree of fracture" [1].

With regard to the post material, it was previously shown that a fiber-glass post with a stiffness similar to that of the employed composite crown provided suitable results [1]. For a fiber-glass post, the post shape did not affect the stress distribution, when both conical and cylindrical shapes were adopted [1].

Thus, length, diameter, shape and stiffness of the post has been widely discussed by means of FE analysis for anterior teeth, showing that stiffness influences the length of the post that can be employed and a shorter fiber-glass post may successfully replace a longer metal post [1,21].

A 3D FE analysis of the mechanical behavior of post-restored upper canine teeth evidenced a high stress gradient in multicomponent models consisting of materials with different stiffness at various interfaces and the combination of a composite crown and a conical or cylindrical fiber-glass post provided a mechanical behavior which was similar to that of a sound tooth [1].

On the other hand, a ferrule is a metal ring or cap employed for strengthening. The "ferrule effect" is the consequence of a crown encircling the remaining supragingival tooth structure, which greatly enhances fracture resistance [20–24]. A ferrule may be a part of the artificial crown or core reinforcing root-filled teeth, that resists lever forces, lateral forces related to the post insertion and the wedging effect with a tapered post under functional loading [25]. Positive strengthening influences of ferrules have been reported [26–28]. As a consequence of the ferrule effect, post/core ratios are increased, fluid erosion of the luting cement is reduced and post retention is improved. Some controversies exist about the optimum height of remaining tooth structure and the location of supragingival structures [29–33].

Currently, custom cast metal posts-and-cores or fiberglass-reinforced composite posts are recommended [34]. However, compared to metal posts, composite posts show different mechanical properties [35]. For example, fiberglass-reinforced composite posts and cast gold alloys have, respectively, four times (879 MPa) and seven times (1542 MPa) the flexural strength of dentin (213 MPa). The optimum sizes of metal posts and cores have been investigated using experimental and theoretical methods [36] and the influence of the ferrule effect and the length of cast and fiberglass-reinforced composite posts on the stresses of anterior teeth have been evaluated [19].

In particular, Dejak and Młotkowski [19] showed that the ferrule effect resulted not only in reduction of modified von Mises stresses in posts, in luting cement and in dentin, but also in a decrease of contact tensile stresses around posts: in teeth without a ferrule these were 1.7–3.0 times higher than those in teeth with a ferrule. Lower modified von Mises stresses were found in teeth with cast posts, compared to fiberglass-reinforced composite posts. Independently from the post material, in teeth restored with posts of several lengths, the modified von Mises stresses were similar [19]. It was also shown that post length had a small effect on stresses in tooth structure [19].

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