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FE analysis of conceptual hybrid composite endodontic post designs in anterior teeth

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ABSTRACT

Objectives. To assess conceptual designs of dental posts consisting of polyetherimide (PEI) reinforced with carbon (C) and glass (G) glass fibers in endodontically treated anterior teeth.
Methods. 3D tessellated CAD and geometric models of endodontically treated anterior teeth were generated from Micro-CT scan images. Model C-G/PEI composite posts with different Young's moduli were analyzed by Finite Element (FE) methods post A (57.7 GPa), post B (31.6 GPa), post C (from 57.7 to 9.0 GPa in the coronal–apical direction). 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 principal stress distribution was determined along the post and at the interface between the post and the surrounding structure.
Results. Post C, with Young's modulus decreasing from 57.7 to 9.0 GPa in the coronal–apical direction, reduced the maximum principal stress distribution in the restored tooth. Post C gave reduced stress and the most uniform stress distribution with no stress concentration, compared to the other C-G/PEI composite posts.
Significance. The FE analysis confirmed the ability of the functionally graded post to dissipate stress from the coronal to the apical end. Hence actual (physical) C-G/PEI posts could permit optimization of stress distributions in endodontically treated anterior teeth.

1. Introduction

The restoration of endodontically treated teeth represents a great challenge especially where there has been a significant loss of tooth structure [1–3]. Adhesive techniques are considered essential in such treatment [4–6] and the endodontic procedures required are often accompanied by a decrease in tooth rigidity [7,8]. Even though in many cases adhesives may be employed without a post, in larger posterior teeth the use of posts should be considered [9–12]. For anterior endodontically treated teeth with a veneer, fracture resistance should be improved by employing a cemented fiber post [13].

Post/core endodontic treatment utilizes a range of industrially constructed posts with varied *materials*, *sizes* and *shapes*

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for clinical use by endodontists. Collectively these variables may be designated *post designs*. There has been a significant trend away from traditional cast metal or ceramic posts towards the use of glass fiber composite posts that exhibit a closer match between the post stiffness, or elastic modulus, and the elastic modulus of the residual tooth structure.

Despite major differences, there are some parallels between the *design criteria* and challenges of endodontic post therapy and those involved with: (a) dental implant designs and (b) femoral prosthesis designs in total hip replacement surgery or arthroplasty. In all such cases, biomechanical stresses generated in functional service will affect the retention and stability depending upon, inter alia, the relative biomaterial/host tissue elastic moduli and the residual thicknesses of the hard tissue host.

As in many other areas of bioengineering, Finite Element (FE) analysis has proved beneficial in creating computational model scenarios that facilitate exploration of the effects of different design variables, whether in endodontics, implantology or arthroplasty. FE analyses demonstrated a non-physiological strain and stress distribution due to the presence of an endodontic post [14–17]. Moreover, many analyses showed different mechanical behavior for endodontically treated anterior teeth compared to sound teeth [18].

FE analysis has been already used to assess the influence of the shape, length, diameter and stiffness of the post as well as of the "ferrule effect" [4,19–29]. In particular, a study on the mechanical behavior of endodontically treated canine teeth provided interesting results in terms of stress distribution, evidencing the synergistic contribution of the ferrule effect and the specific material-shape combination of the post [29].

Different dental post–core systems have been proposed [30]. Metal posts were initially utilized. However, the great mismatch between the elastic modulus of metal posts and surrounding structures generally leads to stress concentration and root fracture [30]. Consequently, posts with different shape, size and materials were developed [30]. A more favorable stress distribution may be obtained using glass fiber-reinforced posts, which have an elastic modulus (45.7–53.8 GPa) [30,31] lower than those of metal posts (110 GPa for titanium and 95 GPa for gold) [30,32] and higher than that of dentin (18.6 GPa) [30,33]. It is well known that stress concentration generally occurs at the apical and cervical regions of the tooth and that flexible posts cause stress concentrations in dentin, whereas rigid posts concentrate stresses at the interfaces. To optimize stress distribution, a post should possess a functionally graded stiffness decreasing from the coronal part to the apical end [30,34]. This might be achieved with an inhomogenous post design [34].

In arthroplasty, recent studies [35,36] have investigated certain hybrid composite materials incorporating a fiber-reinforced *matrix* of polyether imide (PEI). These PEI hybrid composites have been fabricated with different shapes and functionally graded stiffness along the axial length. Although fabrication of the comparatively large femoral prostheses in a hybrid design is relatively straightforward, emerging microfabrication techniques should make it possible to construct *endodontic* posts with analogous hybrid PEI composite designs. This possibility is the motivation for the present study, where we consider a number of conceptual post designs. These are based upon the concept of a PEI matrix reinforced with either carbon (C) or glass (G) fibers, including an inhomogenous post-design with functionally graded stiffness decreasing in the coronal to apical direction.

The aim was to assess the stress distribution along the post and at the interface between the post and the surrounding structure in endodontically treated canine teeth when using three different C-G/PEI posts.

2. Materials and methods

2.1. Post material and design

Three conceptual designs of hybrid composite posts consisting of a polyetherimide (PEI) matrix reinforced with carbon (C) and glass (G) fibers were considered:

Post A (C-G/PEI with a Young's modulus of 57.7 GPa),

Post B (C-G/PEI with a Young's modulus of 31.6 GPa),

Post C (C-G/PEI with a Young's Modulus varying from 57.7 to 9.0 GPa in the coronal–apical direction).

All the composite posts with conical-tapered shape had the following geometrical features: total length — 15 mm, length on coronal part (cylindric) — 7 mm, length on conicity part — 8 mm, coronal diameters — Ø 1.05 — Ø 1.25 — Ø 1.45, apical diameters — Ø 0.55 — Ø 0.75 — Ø 0.95.

The approach towards the conceptual post design was carried out according to the experimental results obtained in a previous study on the development of composite stem for hip prosthesis with tailored properties along the head-tip direction [35,36]. This device was constructed using hand lay-up techniques, compression molding and water jet technology [35,36].

Post A and post B corresponded to Zone I and Zone II of the previous developed device [35,36], whereas post C was a C-G/PEI post with a Young's Modulus decreasing from 57.7 to 9.05 GPa in the coronal–apical direction. FE analysis, ply drop-off and stacking sequence were considered to obtain devices with the required properties [35,36].

2.2. Generation of a tooth solid model

A micro-CT scanner system (Bruker microCT, Kontich, Belgium) was used to digitize an intact canine, taking into account previously adopted methodologies from the scanning through the tessellated model [4,29,37]. A total of 951 slices were collected at a resolution of 1024 × 1024 pixels [4]. Anyway, only 252 slices were considered as already specified [4].

Briefly, image data sets were processed via ScanIP® (3.2, Simpleware Ltd., Exeter, UK). Image segmentation and filtering procedures were used [4,29,37], and the 3D tessellated model of the tooth was created [4,29]. As reported [4,29], blending operations were performed through cross sections to convert tessellated models into surfaces. These operations were carried out using SolidWorks® 2017 (Dassault Systemes, Paris, France) CAD system, where the ScanTo3D® add-in allowed to manage the tessellated geometry [4]. Lofting surfaces were created and the congruence of interfacial boundaries of tooth tissues was ensured [4,29].

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