Materials Science and Engineering C 74 (2017) 334–346

Contents lists available at ScienceDirect

Materials Science and Engineering C

journal homepage: www.elsevier.com/locate/msec

Effect of fibre posts, bone losses and fibre content on the biomechanical behaviour of endodontically treated teeth: 3D-finite element analysis

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ARTICLE INFO

Article history:
Received 27 July 2016
Received in revised form 20 October 2016
Accepted 5 December 2016
Available online 7 December 2016

Keywords:
Endodontic fibre posts
Dental restoration
Finite element analysis
Bone loss
Biomechanical behaviour
Dental materials
Composite posts

ABSTRACT

The aim of this work was to evaluate the stress distribution inside endodontically treated teeth restored with different posts (glass fibre, carbon fibre and steel posts) under different loading conditions by using a 3D-finite element analysis. The effect of masticatory and impact forces on teeth with different degrees of bone loss was analysed. The model consists of: dentine, post, cement, gutta-percha, core and crown. Four simulations were conducted with two static forces (170 N horizontal and 100 N oblique) and two sections constrained: 1 mm (alveolar bone position in a normal periodontium) and 6 mm (middle of root) below the crown. Von Mises and the principal stresses were evaluated and analysed with a 3-way ANOVA and Tukey test ($\alpha = 0.05$) and the effect of fibre percentage analysed. Significant differences were found among the stress values for all conditions ($p < 0.05$). Impact load was always responsible for the most critical situation especially when the bone loss was more evident. The system with steel posts showed the highest principal stresses at the post-cement interface with horizontal load and top constraints (compressive stress of 121 MPa and tensile stress of 115 MPa).

The use of glass posts provides a more homogeneous behaviour of the system with lower stresses. Higher fibre percentages gave higher stress in the posts. Moreover, larger bone losses are responsible for important increase in stress. Thus, this work demonstrated that periodontal disease has an important role in the success of tooth restoration after endodontic therapy, influencing the choice of post material and depth.

1. Introduction

Root canal treatment and restoration are intended to restore the elastic properties of the lost dentine by using materials with biomechanical properties (mainly the tensile modulus) as close as possible to the dentine itself [1] to obtain uniform stress distribution along the root dentine [2–5].

The proper maintenance of endodontically treated teeth depends on several factors: the quality of the restoration, the protection of residual dentine, the perfect bonding between dentine and restorative materials and the tooth structure. In clinical situations in fact, internal removal of dentine and caries may induce an excessive loss of tooth structure. In these cases the choice of the most appropriate restoration becomes very important for the success of the treatment.

The clinical technique of reconstruction of root-filled teeth comprises two actions in sequence:

1) preparation of the post-space and fixation of the post by luting cements;
2) reconstruction of the coronal core using different types of material (resin composite, amalgam, compomers, glass ionomer cements) supported by the endodontic post and choose whether to make a final reconstruction either with conservative means or prosthetic type (crown) [6–9].

The use of post is decided by the amount of remaining coronal substance [10]. Often, the quantity of residual dentine requires additional support by means of a post space and the insertion of a post, with a crown or a composite restoration. The various components of a correct reconstruction with endodontic posts (cement, build-up material and dentine) should form a structurally and mechanically homogeneous system with a uniform distribution of masticatory stresses [11].

Several solutions have been proposed in the literature over the years concerning the coronal reconstruction with posts [12,13]. The system used for many years consisted of metal posts, initially placed in the canal with the use of luting cement [14]. The main risk in the use of metal posts is that the root fracture consequently leads to the tooth extraction. Some studies showed an incidence of 4–7% for this traumatic event [15,16]. The major limitation of metal posts was evident by their high Young Modulus (200 GPa) resulting in excessive rigidity compared

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http://dx.doi.org/10.1016/j.msec.2016.12.022
0928-4931/

to dentine and the restorative material. The consequence is the localization of stresses during mastication at the post-root interface resulting in fracture of the remaining tooth structure. These issues have driven the research towards the introduction of root canal posts with physical characteristics more similar to those of the dentinal tissue. In particular, the dentine is a anisotropic material with a modulus of elasticity ranging from 18 GPa (for loads with an orientation of 30° respect to the tooth axis) to 8 MPa (for loads with an orientation of 90°) [14]. For this reason, fibre reinforced root canal posts were considered [17–23]. They are made of two components: the matrix and the fibres. Usually, a thermosetting polymer matrix is used while the fibres typically are parallel to the post axis so the higher strength and elastic modulus occur along this direction and they can be made of quartz, glass or carbon. The final mechanical properties are also strongly affected by structural integrity, dimensions, density, fibre distribution, volume fraction and the bond between fibre and matrix.

The first posts had a prosthetic cylindrical geometry with double section with the smaller diameter in the apical part [24].The posts currently used, however, have a conical geometry to facilitate their insertion into the canal root. The use of carbon posts showed through the years significant aesthetic problems, especially for the anterior teeth restored with metal free ceramics (zirconium or lithium disilicate). The carbon fibre posts and metal posts are particularly suitable in posterior teeth thanks to their dark colour [25]. They can be used also for incisors when, after the endodontic treatment, a metal-ceramic prosthetic restoration is expected in order to have an aesthetically acceptable result.

On the other hand glass or quartz fibre posts can be used without prosthetic restoration for their light colour [26,27] solving the problems of the use of carbon posts.

Even if prefabricated posts do not reinforce the root, they retain the core material especially in the cases of great destruction of the crown [28]. By quantitatively and qualitatively assessing the stress distribution in the various components of post-cement-tooth it is possible to obtain important information about the resistance of the whole restoration [1]. This can be crucial since the structural failure of one component of the restoration, very often leads to decementation of the system that represents the main cause of post-endodontic treatment failure.

The post endodontic restoration requires many different steps where the ability of the clinicians plays an important role in the duration of the reconstruction (endodontic treatment, post space preparation, post choice, post cementation, core restoration). The only method of analysis that makes it possible to eliminate the human factor and considers the materials in ideal conditions is the finite element analysis (FEM). This analysis offers major advantages over other analytical techniques such as a qualitative analysis of the stress distribution and the ability to analyse individual components. In previous years FEM analysis was widely used in dental applications both in two-dimensional and three-dimensional studies [1,29–37].

The aim of this work was to evaluate the stress distribution inside endodontically treated tooth with different posts (made of glass fibres or carbon fibres in epoxy matrix and steel post) under different loading conditions (below fracture) by using a 3D finite element analysis. In our previous study the mechanical behaviour of human teeth reconstructed with different dental fibre-reinforced posts was experimentally evaluated [20] thus recording the fracture loads of each system. These results were considered in the current work in order to choose the load conditions of the simulations.

Moreover, different constraints were considered to simulate different bone loss conditions and the aim of this work was also to evaluate the effect of different post space preparations for the success of endodontical therapy. To verify that, the following null hypotheses were that: the post material, the bone levels and the load directions do not have any effect on the stress behaviour in the post-endodontic restoration system.

2. Materials and methods

2.1. Three-dimensional finite element modelling

In this paper the physical model of endodontically treated tooth provides six components, namely: dentine, post, cement, gutta-percha, core and crown. The cement layer is used to adapt the post to the root cavity.

The construction of the FEM model included some considerations:

- the geometries of all components were modelled to be axisymmetric along the vertical axis;
- the luting cement of the endodontic posts was considered as an autonomous structure with its own properties in comparison to dentine;
- the periodontal ligament was not included in the model because of its nonlinear elastic behaviour;
- any previous stress due to endodontic treatment was not taken into account.

Fig. 1 shows the conical geometry of the post modelled with a taper of 0.02 (length and diameters along the length are reported). The model was designed using 3D CAD available in the software ANSYS® (Ansys Inc., Houston, TX, USA). The cement layer was also considered in the model with a tapered thickness up to 0.9724 mm. The cement layer could not be considered in case of custom posts while using prefabricated posts the cement layer thickness is not negligible and should be considered [29,38]. In fact, in this case, it represents an important interface between post and dentine where the failure more often occurs. The geometry of the system was obtained by measuring the cross section of a dental element treated with an endodontic post and reconstructed with a prosthetic crown. Fig. 2a shows the cross section of the model with different selected keypoints (the coordinates of the keypoints are reported in Table 1). Two sections were constrained: a top section at 1 mm below the crown and a section at the middle of the root height (6 mm).

All the volumes representing the components of the post-endodontic restoration system were then obtained and all the material properties were assigned to each volume (Young Modulus, Poisson's ratio and shear modulus) according to the axes (x, y, z). Figs. 2b–h show the single components of the post-endodontic restoration system and the whole geometry realized.

Table 2 shows the material properties attributed to the components of the system [39–42]. In particular, the Young modulus used for the gutta-percha was 7.8×10^{-2} GPa as reported in experimental tests that is of two orders of magnitude higher than the value used in many FEM studies (usually 6.9×10^{-4} GPa) [39].

The effect of different gutta-percha moduli was also evaluated in this work. The materials used for the endodontic FRC post were considered

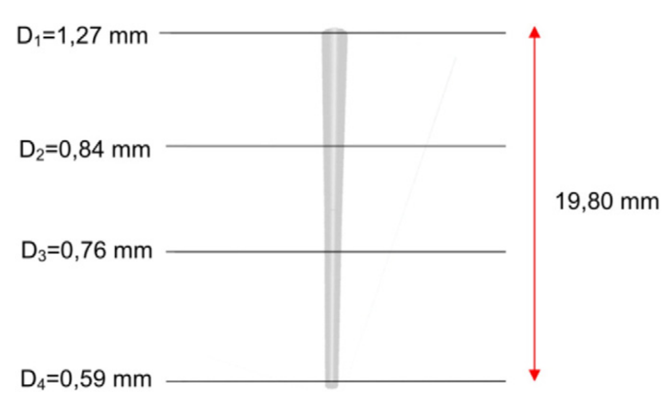

Fig. 1. Geometry of the endodontic post.