Finite element method applied for the evaluation of teeth restored with custom made post-and-core systems

LILIANA POROJAN, FLORIN TOPALĂ, SORIN POROJAN
School of Dentistry
“V. Babeş” University of Medicine and Pharmacy
9 Revolutiei 1989 Blv., 300041 Timişoara
ROMANIA
lilianasandu@gmail.com

Abstract: Root canal treated teeth often require post-and-core restorations for retention purposes because of the extensive structural defects resulting after preparation. In these cases preserving tooth structure is one of the most important factors in avoiding complications after intraradicular retention. An important design element for tooth preparation when using a post-and-core is the incorporation of a ferrule. The objective of this study was to evaluate and compare, using finite element analysis, stresses induced in teeth restored with and without ferrule and different types of custom made post-and-cores, and overlaid with a ceramic crown. The study was performed on a central upper incisor, using a finite element analysis. The tooth preparations and the restorations were designed. The ferrule height was increased from 0 to 2.5 mm. Stress analysis was performed on the restored incisor. As restoration materials for the dowel-and-core restoration base metal alloy, and zirconia were chosen, and for the overlying crown pressed ceramics was selected. Maximal equivalent stresses were recorded in the tooth structures and in the restorations. High stresses are distributed cervical in the crowns, in the prepared teeth under the finishing line and in the post cervical. No significant differences were found between the maximal stress values for the studied preparation designs. Zirconia custom made registered higher stresses than cast base metal alloys post-and cores.

Key-Words: finite element method, teeth, post-and-core, base metal alloys, zirconia, ferrule, stresses.

1 Introduction
The use of dowel-and-core is a recognized treatment modality to retain final restoration in an endodontically-treated tooth when a large amount of coronal structure has been lost [1]. Root canal treated teeth often require post-and-core restorations for retention purposes because of the extensive structural defects resulting after preparation [2]. Although the insertion of a post does not strengthen or reinforce endodontically treated teeth, it is used to provide retention of the core material, which is used to retain a fixed restoration [3,4,5]. Some studies showed that endodontically treated teeth restored with custom cast post and core were as strong as the untreated teeth [6] The predominant function of an endodontic post is to retain the core [7]. Preserving tooth structure is one of the most important factors in avoiding complications after intraradicular retention [2]. Several possibilities to restore endodontically treated teeth have been associated with criteria for success and dependent on variations in length, diameter, shape and surface configuration, amount of dentinal structure, materials and techniques used in construction [8,9,10]. The selection of a particular type of endodontic post is based on its mechanical properties, ease of fabrication, biocompatibility, availability in the market, and the cost factor. The ability of post-core system to sustain masticatory forces and remain firmly seated in the tooth is essential for the survival of a restoration [7]. Many years cast post-and-cores were widely used. Unfortunately, several disadvantages are associated with conventional cast post-and-cores, such as loss of post retention, root fractures, and risk of corrosion. During the preparation of teeth a large amount of root dentin is removed, increasing the risk of tooth fracture [2]. Metal posts and cores are commonly used because of their superior physical properties. Nevertheless, the increased use of all-ceramic crown provides a rationale for tooth-colored core. Composite post-core, prefabricated post with composite resin core, prefabricated all-ceramic post such as zirconium oxide post, and mask of the metal core with opaque ceramic or photo-curing opaque resin are the...
alternatives of tooth-colored core or custom-fabricated ceramic post-and-cores. The increased use of all-ceramic crown addresses new requirements for core materials. Dark gray shadow reflected from metal core may affect aesthetic outcomes [11]. Resistance to fracture is directly related to the amount of remaining tooth structure [1]. An important design element for tooth preparation when using a post and core is the incorporation of a ferrule [7,8]. Dental ferrule is an encircling band around the coronal surface of the teeth. The use of ferrule as part of the artificial crown was proposed in reinforcing the endodontically treated teeth [6]. When a crown that extended at least 2.0 mm apical to the junction of the core and the remaining tooth structure, the encirclement of the root with this ferrule effect would protect the pulpless tooth against fracture by counteracting spreading stresses generated by the post [11]. A properly built ferrule significantly reduces the incidence of fracture in the nonvital tooth by reinforcing the tooth at its external surface. It resists the lateral forces from the tapered dowels and the leverage from the crown in function. It also increases the retention and resistance of the restoration [7]. The effectiveness of the ferrule has been evaluated by a variety of methods, including fracture testing, impact testing, fatigue testing, photoelastic analysis, finite element analysis [8,12]. The only method of analysis that eliminates operator factors and uses materials under ideal conditions is the finite element model (FEM). In the FEM, digitally modeled tooth structures are divided into simple geometric models, called elements, whose tips aggregate to generate nodes. Each modeled element layer has specific elastic constants, such as Young’s elastic modulus ($E$) and Poisson’s ratio ($\nu$). Thus, the FEM has become a reliable method for dental applications that enables the calculation of load distributions and the influence of model parameter variations once an accurate three-dimensional model is created [13,14,15]. Stress analysis in dentistry has been a topic of interest for the past few decades. Finite element method is a numerical tool, which is popularly used to analyze very complex and irregular structures. Since its beginning in 1956, the versatility and efficiency of this method has been recognized in various engineering fields like civil, mechanical, and aeronautical engineering. Besides this, it has a wide application in biomechanical sciences like dentistry and orthopedics [7].

2 Purpose
The objective of this study was to evaluate and compare, using finite element analysis, stresses induced in an incisor restored with and without ferrule and different types of custom made post-and-cores, and overlaid with a ceramic crown.

3 Materials and Method
Detailed three-dimensional models are required for the analysis of the mechanical behavior of teeth structures and prosthetic dental restorations. The first step of the study was to achieve 3D models in order to analyze teeth, dowel and core restorations and overlying crowns. The study was performed on a central upper incisor, using a finite element analysis. Surfaces were modeled according with anatomical dimensions. The nonparametric modeling software (Blender 2.57b) was used to obtain the shape of the teeth structures. The collected data were used to construct three dimensional models using Rhinoceros (McNeel North America) NURBS (Nonuniform Rational B-Splines) modeling program. The tooth preparation and the restorations were designed. The use of ferrule was proposed in reinforcing and therefore six levels of amount of remaining tooth structure height were designed in order to be investigated. Round canal shapes were modeled for the dowel, to allow the design of the dowel-and- core 3D models. The base diameter and insertion depth of about 2/3 of the root length were maintained constant. The ferrule height was increased from 0 to 2.5 mm, with 0.5 mm for each case (Fig. 1).

![Fig. 1. Design of the tooth preparation with different ferrule heights.](image)

All the restorations were simulated to be covered by all-ceramic crowns (Fig. 2). Models were exported in Ansys finite element analysis software for structural simulations. An occlusal load of 50 N was conducted, according to the contact point with the antagonists.
The forces were applied perpendicular to the tooth surface (Fig. 3).

Fig. 2. Design of the restored tooth.

Fig. 3. Loading on the restored incisor.

Stress analysis was performed on the restored incisor. As restoration materials for the dowel-and-core restoration base metal alloy, and zirconia were chosen, and for the overlying crown pressed ceramics was selected. The mesh structure of the solid 3D model was created using the computational simulation of Ansys finite element analysis software (Fig. 4).

Fig. 4. Mesh structure of the restored incisor.

Von Mises equivalent stresses were calculated and their distribution was plotted graphically.

### 3 Results and Discussions

Maximal equivalent stresses were recorded in the tooth structures and in the restorations for all the ferrule heights. The values were higher in the crowns in all cases, followed by the stresses in the dentin and the lowest were recorded in the post and core system (Table 1, 2, Fig. 5, 6).

Table 1. Maximal Von Mises equivalent stress values in the pressed ceramics crown, cast post and core system, and prepared tooth for all the ferrule heights.

<table>
<thead>
<tr>
<th>Ferrule height [mm]</th>
<th>Maximal Von Mises equivalent stress [Pa]</th>
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<tbody>
<tr>
<td></td>
<td>crown</td>
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<tr>
<td>0</td>
<td>9.64E+07</td>
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<tr>
<td>0.5</td>
<td>9.85E+07</td>
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<tr>
<td>1</td>
<td>1.04E+08</td>
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<td>1.5</td>
<td>9.24E+07</td>
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<tr>
<td>2</td>
<td>1.01E+08</td>
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<td>2.5</td>
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Table 2. Maximal Von Mises equivalent stress values in the pressed ceramics crown, zirconia post and core system, and prepared tooth for all the ferrule heights.

<table>
<thead>
<tr>
<th>Ferrule height [mm]</th>
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Fig. 5. Distribution of the maximal Von Mises equivalent stress values in the prepared incisor and restorations (pressed ceramics crown, cast post-and-core system).
No significant differences were found between the maximal stress values for the studied preparation designs (a ferrule height between 0 and 2.5 mm).

Regarding stress distribution in the crown, high stresses are present cervical, in the oral and buccal surfaces (Fig. 7, 10). In the prepared root stresses are under the finishing line, especially buccal and in the post cervical (Fig. 8, 9, 11, 12).

Regarding the restoration material used for the post-and-core, differences were registered only for the stress values in the post-and-cores, which were higher in the zirconia ones.

In the post stresses increase with the increase of the ferrule height and move in apical direction, more fare from the junction between the core and the tooth structure.
The functional and para-functional forces that occur within the mouth result in extremely complex structural response by the oral tissues [1]. Metal posts were associated with more unfavorable complications, namely root fracture. It was suggested that a post should have a modulus of elasticity similar to that of dentin for a more uniform distribution of stress along the post length [16,17].

Post geometry has very important effect on stress distribution at the post-dentin interface [13]. Less stress is concentrated into the root for parallel-sided posts because the wedging effect is lower. Also this type of post results in fewer root fractures than tapered posts, but the failure rate is higher than that of a tapered post system [2,18]. Studies showed similar fracture strength for custom ceramics post-and-cores restored teeth with 2.0 mm dentine ferrule and cast metal post-cores restored teeth with 2.0 mm dentine ferrule. There was a statistically significant difference between the fracture resistance of these post-core restored teeth with and without 2.0 mm dentine ferrule [11].

There is a mixed opinion regarding the efficacy of ferrule in increasing the threshold of failure load in an endodontically treated tooth. Some mechanical studies favor the placement of ferrule as it confers increased fracture resistance to the endodontically treated teeth. Other found that the ferrule height has no important influence on the stress values in corono-radicular restored teeth for the studied designs [19,20]. Increasing the ferrule length did not improve the fracture resistance of endodontically treated teeth restored with glass ceramic crowns [3]. Different studies reported that the preliminary failure occurred with lower number of cyclic load in endodontically treated central incisors with ferrule length of 0.5 and 1.0 mm as compared to 1.5 and 2.0 mm. The FEM study revealed that the ferrule increased the mechanical resistance of a post/core/crown restoration in central incisor. But, it also created a larger area of palatal dentin under tensile stress, a condition favorable for a crack development on the palatal aspect of the root eventually leading to an oblique root fracture. In comparison, a restoration without ferrule was prone to fail primarily by debonding and subsequently by root fracture through the lever action of the loose post [21].

Several authors [8,22] have suggested that the tooth should have a minimum amount of 2 mm of coronal structure above the cement-enamel junction to ensure proper strength and increasing ferrule length significantly increased the fracture strength of endodontically treated teeth. This coronal structure will provide a ferrule effect with the artificial crown to prevent root fracture and post fracture or dislodgement. Other showed no significant correlation between amount remaining coronal structure and fracture strength [23].

Ni-Cr cast post-core produced maximum stresses within the post-core system and the least amount of stresses transmitted to the surrounding dentin. Although FRC posts recorded minimal stress level within the posts, the stresses transmitted to the surrounding dentin were more as compared to Ni-Cr cast post-core. Ferrule did not reduce the stress values either in the tapered or parallel posts of Ti and Ni-Cr. Incorporation of ferrule offered some degree of stress reduction in nonmetal post, and it increased the stresses within cervical dentin [7].

No post and core system provides an ideal solution for all clinical cases. The ideal post and core system would be the one that ideally meets all the mechanical requirements of a prosthesis and absorbs as much of the loads as possible without transmitting them to the root dentin. Maximal conservation of dentin remains a key factor in the choice of restoration procedure for endodontically treated teeth. The cervical ferrule prevents the wedge effect and improves load distribution. The physical resistance of a tooth is improved significantly when it is restored with materials that have a low modulus of elasticity rather than with materials having high modulus of elasticity [24].

4 Conclusion
Within the limitations of this study, the following conclusions were drawn:
1. Finite element analysis provides a biomechanical explanation for the ferrule effect on stresses in roots restored with and without ferrule and different types of custom made post-and-cores, and overlaid with ceramic crowns.
2. High stresses are distributed cervical in the crowns, in the prepared teeth under the finishing line and in the post cervical. In the post, with the increase of the ferrule height, the stresses move in apical direction, more fare from the junction between the core and the tooth structure.

3. No significant differences were found between the maximal stress values for the studied preparation designs (ferrule height between 0 and 2.5 mm).

4. Zirconia custom made registered higher stresses than base metal alloys cast post-and cores.

References:


