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Premolars restored with posts of different materials: fatigue analysis

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Previous works studied the effect of the material and the dimensions of the post on the biomechanical performance (fracture strength and stress distribution) of restored teeth, under static loads. The aim of this work was to study the effect of the post material (glass fibre and stainless steel) on restored teeth, which have the final crown, under dynamic conditions. The use of a biomechanical model, including a fatigue analysis from FEA, is presented as a powerful method to study the effect of the material of the intraradicular post. The inclusion of the fatigue analysis allows for a more realistic study that takes into account the dynamic nature of masticatory forces. At the same time, the results obtained are easier to interpret by both dentists and mechanical engineers. No differences were found, with the load and number of cycles considered, between glass fibre and stainless steel as material for the intraradicular post used in premolars restorations.

Keywords: Fatigue, Restored teeth, Prefabricated intraradicular posts, Influence of post material, FEA

INTRODUCTION

Endodontically treated teeth have less moisture in the calcified tissue than vital teeth, which leads to increased brittleness[1]. The ability of a post and core system to survive masticatory forces (the instantaneous loading over time) and remain firmly seated in the tooth is critical to the survival of a restoration. If either the post and/or the core material fails, the crown will ultimately fail. Therefore, the retention of a post and the stability of a core is an important factor in preventing restoration failures. Much of the literature has described techniques and methods for the construction of posts and cores including cast systems and prefabricated post systems[2,3].

Traditionally, a porcelain fused-to-metal crown has been used in tooth restoration, when an aesthetic appearance is required. However, because of concerns about allergic reactions or biocompatibility[4], patients and dentists have come to prefer metal-free restorations. It is possible to replicate the aesthetic characteristics and vitality of natural teeth by using ceramics[5]. The major problem with all-ceramic full crowns is to provide excellent aesthetics and adequate strength, *i.e.*, longevity at the same time. Ceramic materials are superior in terms of permeability to light and biocompatibility, but they can be inherently brittle and weak when placed under tensile and torsional stresses[6]. This drawback has been reduced using reinforced glass-ceramic materials. Survival rates of glass-ceramic crowns, even on posterior teeth, have far exceeded those of traditional all-porcelain crowns, despite having nearly equivalent strengths and thicknesses[7].

Although clinical trials would be the best way to assess the effects of different variables, this type of study is time consuming, expensive and ethically questionable. Other types of study are helpful, including *in vitro* studies and finite element analyses (FEA). Both methods have advantages and disadvantages. *In vitro* tests can simulate almost realistic conditions, but are time consuming and only a limited number of specimens can be tested. The transfer of results from *in vitro* tests to clinical situations is also challenging. FEA enables simulation of any situation, but the accuracy of the results depends on construction of an appropriate model. A meticulous construction process is therefore necessary. Previous works[8-10] have combined the advantages of both methods to assess the effects of the material, and the dimensions, of the prefabricated posts. Teeth restored with stainless steel posts showed significantly lower failure loads than teeth restored with glass fibre posts. The experimental results were used to validate a finite element model of a restored tooth. From that model, it was concluded that post restoration systems, in which the elastic modulus of the post is similar to that of dentine and core, offer a better biomechanical performance. In these studies, a monotonic static load was applied, which does not represent the clinical situation (where a dynamic load is characteristic).

Fatigue tests have been established as being an essential research tool for testing adhesive restorations[11-19]. They reproduce cyclical loading pattern comparable to physiological function and, therefore, can simulate the results of time-consuming clinical trials. More time could be saved if those tests were performed by means of computer simulation.

The purpose of this investigation was to compare the number of load cycles, without failure, sustained by a restored premolar (with a conventional complete crown design and two different post-and-core systems). The systems selected were: a prefabricated stainless steel

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post and composite core, and a prefabricated glass fibre post and composite core.

MATERIALS AND METHODS

A theoretical method was used to study the influence of post material on endodontically treated, and restored with a post-core-crown system, human premolars. The posts used for the study were the *ParaPost Fiber White* and the *ParaPost Stainless Steel* (Coltène/Whaledent Inc, Mahwah, NJ, USA). These posts were selected because their geometry is similar and they are manufactured in the same sizes, but have significantly different elastic moduli (20 GPa for the *ParaPost Fiber White* and 207 GPa for the *Parapost Stainless Steel*).

Finite element model

The finite element analysis (FEA) is currently used in very different fields. It has been successfully used in biomechanics and, in particular, in orthopaedics. This technique was originally developed for structural analysis in mechanical engineering, but its foundation is also applicable to biological problems. The results of a FEA are expressed as stresses distributed in the structures under investigation. These stresses may be tensile, compressive, shear, or a combination known as equivalent von Mises stress. Von Mises stresses depend on the entire stress field and are a widely used indicator of the possibility of damage occurrence[20].

The model used in this study was based on the geometry of a real tooth, obtained through a 3D scanner, and the 3D modelling software Pro/Engineer (PTC, Needham, MA, USA) was used to generate, and later assemble, the geometries for all the components. This model has been properly validated in previous works[8-10]. Figure 1 shows a longitudinal section of the geometrical model considered, including all the components that were modelled: bone (cortical and trabecular components), periodontal ligament, root, gutta-percha, post, post cement, core, crown and crown cement. The mechanical properties of the different components of the model were obtained from the literature and from the manufacturer of the posts (Coltène/Whaledent Inc, Mahwah, NJ, USA) and from the manufacturer of the glass-ceramic crown (Ivoclar Vivadent AG, Schaan, Liechtenstein). The aforementioned properties are presented in Table 1.

The Pro/Mechanica module, available within Pro/Engineer, was used to divide (mesh) the CAD geometry. Solid tetrahedral elements were created with a mesh control of 0.3 mm maximal size on all the components, except on trabecular and cortical bone, where a 1 mm maximal size control was applied. The definitive model had 216 173 elements. As boundary conditions, the displacements of all nodes on the lateral surface and base of the component representing the bone were constrained.

The analysis was carried out using the finite element analysis software MSC-PATRAN-NASTRAN (MSC.

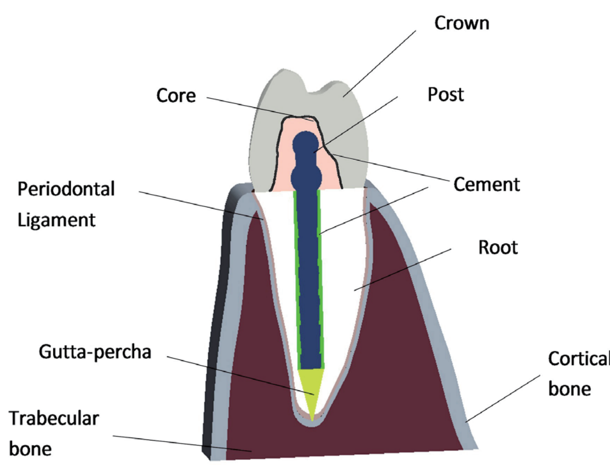

Fig. 1 Section of the geometrical model generated. Modelled components.

Table 1 Mechanical properties of the materials used in the finite element model

Component/Material	Elastic Modulus E (GPa)	Poisson Coefficient (ν)	References
Root/Dentine	18.6	0.31	20,40-44)
Gutta-percha	0.00069	0.45	20,40-44)
Periodontal ligament	0.0689	0.45	42,45)
Cortical bone	13.7	0.30	20,40-44)
Trabecular bone	1.37	0.30	20,40-44,46)
Post cement/Self cure resin cement	5	0.30	47)
Core/ParaPost ParaCore	20	0.30	Manufacturer
Crown	62	0.30	Manufacturer
Crown cement/Dual cement	10	0.30	47)
Stainless steel post	207	0.30	Manufacturer
Glass fibre post	20	0.30	Manufacturer

Software Corporation, Santa Ana, CA, USA). The study was undertaken with a model of a maxillary premolar restored using the *ParaPost Fiber White* and the *ParaPost Stainless Steel*, and with the definitive crown added. A 50 N load was applied to the palatal side of the tooth at a 30° angle to the radicular axis, in the vestibular direction, in order to simulate real biting force's direction[21-23]. An unfavourable situation of malocclusion has been considered, *i.e.*, the force was applied to the buccal incline of the palatal cusp. The value of the occlusal force was chosen to represent a relatively high biting force[24]. This value has been used in several works dealing with premolars[16,25-27]. Under this load, the stress distribution pattern of the restored tooth was studied for two different post materials. The stress distribution pattern provided information about the fracture mechanism of the restored tooth: for the same external load, higher stresses indicated a higher probability of reaching the failure load.

As biomechanical performance was not found to depend on post length[9], the widespread recommendation[28] that post length should be about three quarters of root length was used. The post diameter, considered in this work, satisfies the widely extended recommendation that post width should not be greater than one-third of the root width at its narrowest section[29,30]. Namely, the thickness ratio (post diameter/root thickness) chosen was equal to 0.2.

Fatigue Model from previous FEA

The behaviour of materials under dynamic loads is different to that under static loads. Fatigue can be defined as the progressive and localized structural damage that occurs when a material is subjected to cyclical loading[31]. The material collapses at maximum stress values that are lesser than the ultimate tensile stress limit, and may be below the yield stress limit of the material.

The von Mises stresses, obtained from the previous finite element analyses, were used through the COSMOSWorks module, available within the modelling software SolidWorks (Dassault Systèmes SolidWorks Corp., Suresnes, France). The S-N curves (Stress vs. Number of Cycles to Failure) were defined for each of the materials considered in the model. The S-N curve for dentine was obtained from the literature[32]. The S-N

Table 2 Flexural strengths for the different component materials of the model

	Flexural strength (MPa)	Source
ParaPost Fiber White	990	Manufacturer
ParaPost Stainless Steel	1,436	Manufacturer
ParaCore	90	[48]
Dual Cement	45.1	[47]
Dentine	212.9	[49]
Crown	160	Manufacturer
Parapost Cement	97	[50]

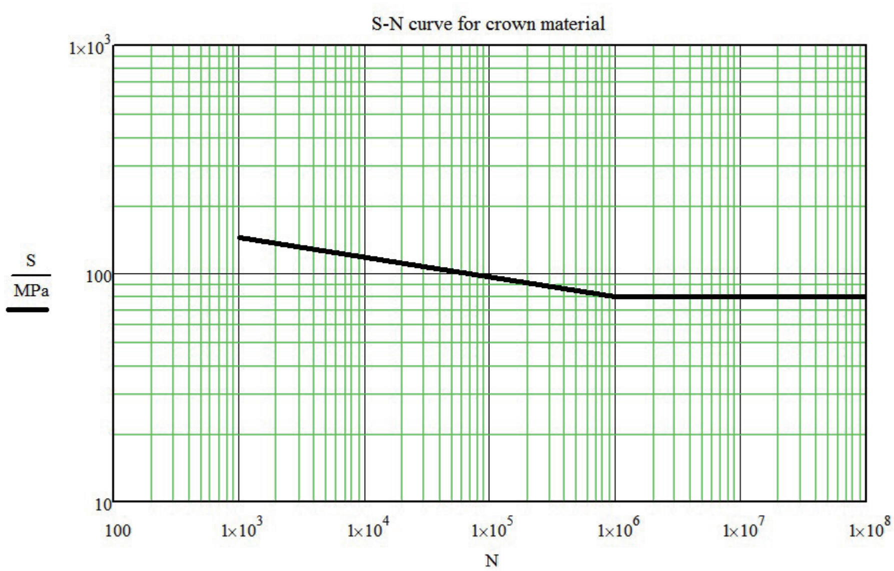

Fig. 2 S-N curve for crown material.

curves for the other materials were estimated from their static properties and S-N curves of similar materials found in the literature[33,34]. *i.e.*, the S-N curve of materials, when no experimental data are available, is approximated by the following data (strength *versus* number of cycles): ($0.9 \cdot S_f$ vs. 10^3), ($0.5 \cdot S_f$ vs. 10^6) and ($0.5 \cdot S_f$ vs. a number of cycles greater than those tested). In this paper, we have tested 1.2 millions of cycles. S_f is the flexural strength of the material considered, shown in Table 2. As an example, Figure 2 shows the S-N curve for crown material.

A cyclical load, from 0 to 50 N, was applied during 1.2 millions of cycles. These conditions are believed to simulate, approximately, 5 years of clinical service[35]. This number of cycles have been used in several fatigue studies[12-16,36,37]. Taking into account that dental materials are brittle, the Goodman[31] model was used for comparing the stresses obtained (in the previous finite element analyses) with the S-N curves.

RESULTS

Results from the static finite element analysis

In this section, the results of the study of the influence of the post material are presented. Figure 3 shows the stress distribution achieved. We prefer the more visual option of presenting the FOS (Factor of Safety) distribution. The FOS, for each component, has been calculated as the ratio between the strength of the component material and the maximal von Mises stress (obtained with the finite element model) in that component. Flexural strengths of each component material, obtained from literature, are presented in Table 2. A smaller factor of safety means that the component is more prone to failure. The smallest FOS of the components can be considered as the factor of safety of the overall system. As the saying goes, “A chain is only as strong as its weakest link”.

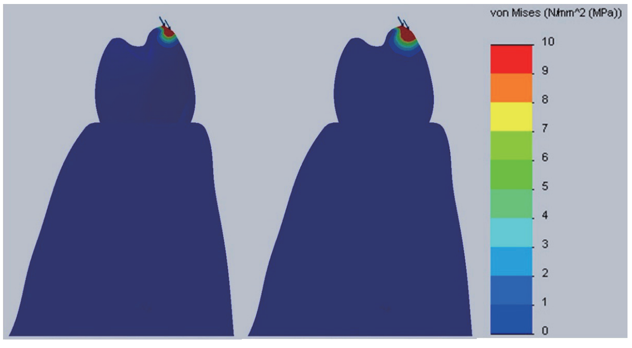

Fig. 3 von Mises stress distribution (colour scale: the warmer the colour, the higher the stress) estimated by the model for the restored tooth, on the sagittal section: using glass fibre post (left) vs. using stainless steel post (right).

For both post systems (Fig. 4), the smallest factors were located at the force application zone. Nonetheless, in the tooth restored with a stainless steel post, the extension of the zone with the smallest factors of safety is bigger. *i.e.*, the model predicts that restorations using glass fibre posts are able to bear higher statics loads.

Results from the fatigue model from previous FEA

The model predicted no fatigue failure for both post systems studied, under the cyclical load considered (Fig. 5). That means that, although restorations using glass fibre posts are able to bear higher static loads, both post systems will safely bear this cyclical load. If the cyclical load considered is good enough to represent the real case, then both systems could be used in practice with the same guarantees.

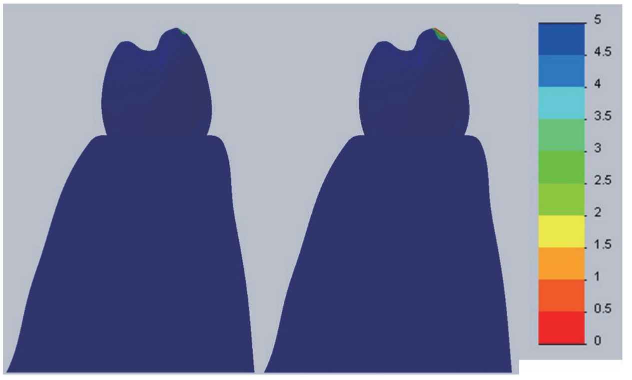

Fig. 4 Factor of safety (colour scale: the warmer the colour, the smaller the factor) estimated by the model for the restored tooth, on the sagittal section: using glass fibre post (left) and using stainless steel post (right).

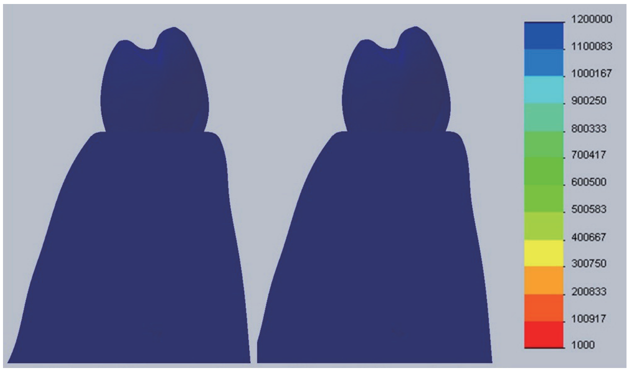

Fig. 5 Life prediction (*number of cycles*) for the cyclical load considered (colour scale: the warmer the colour, the shorter the life expected) estimated by the model for the restored tooth, on the sagittal section: using glass fibre post (left) vs. using stainless steel post (right).

DISCUSSION

In the present study, two different post systems models (glass fibre and stainless steel post) have been exposed to cyclic loading. Both post systems survived the cyclical load considered. That means that both systems would have a similar life, despite the differences found in the static analysis. It has to be pointed out that the results shown in this work have to be taken with care, because of the S-N curves that have been estimated.

The magnitude and direction of the force applied are comparable with values reported in the literature for premolars[21-23]. The analysis of the factor of safety (under a static load) revealed that the failure would occur at the crown, in the area where the load is applied. In any case, the mode of failure predicted by the model for crowned restored teeth would not affect the root.

Many studies in the literature address fatigue of a core, supported by a post, experimentally[11-16]. Nonetheless, most of them do not take into account the protective effect of the definitive crown in the restoration. In this way, their results are similar to that of the static studies, *i.e.*, post restoration systems, in which the elastic modulus of the post is similar to that of dentine and core, offer a better biomechanical performance[8-10,38]. The work of Goto *et al.*[39] obtained that fibre-reinforced resin dowels and bonded composite cores, under fatigue loading, provided significantly stronger crown retention than cast gold dowels and cores and titanium alloy dowels with composite cores under fatigue loading. But retention is not an issue addressed in this work; we have dealt with the resistance of the post system.

Besides the usual limitations of finite element studies, one limitation of this work was the exclusive use of reinforced glass-ceramic crowns, for the definitive restoration of the root-canal-treated teeth. This only gives information about the tested combinations of posts, cores, and crowns, and the results cannot be generalized for other combinations, especially for other crowns made of metal, ceramic fused to metal or composite resin.

Although the method used is more clinically relevant than study methods employing a monotonic static load, limitations exist in the interpretation of these results from a clinical perspective. The specimens in this model were not subjected to thermal cycling, and the fatigue load was always applied in a uniform manner. Also, dentine bonding was accomplished under ideal conditions that may not fully represent the clinical situation.

The method proposed in this work, for studying the biomechanics of teeth restored using intraradicular posts, is easy to perform from a previous FEA. In addition, provide results more intuitive and easier to interpret. The results are more realistic because the method takes into account the dynamic nature of masticatory loads. The main limitation of the method is that requires S-N experimental curves of dental-restorative materials, which are not usually provided by manufacturers.

CONCLUSION

Both post systems considered (glass fibre and stainless steel post) would have a similar life, despite the differences found in the static analysis.

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