The Effect of Select Pulp Cavity Conditions on Stress Field Development in Distal Abutments in Two Types of Fixed Dental Prostheses

Mirianthi Manda, DDS, MSc[a]/Christos Galanis, PhD[b]/Dimitrios Venetsanos, MSc[c]/
Christofer Provatidis, MSc, PhD[d]/Petros Koidis, DDS, MSc, PhD[e]

Purpose: Insufficient coronal tooth structure may require restoration of endodontically treated (ET) teeth with cast posts and cores (CPCs). The prognosis for these teeth is a matter of scientific debate, especially if they serve as distal abutments in cantilever fixed dental prostheses (FDPs). The purpose of this study was to study stress field development in distal abutments in two types of FDPs with different pulp cavity conditions. ***Materials and Methods:*** The methodology involved the development of four digital models in which the right mandibular premolars were splinted via an FDP with: *(1)* no cantilever and a vital distal abutment, *(2)* no cantilever and an ET CPC distal abutment, *(3)* a single-unit cantilever and a vital distal abutment, and *(4)* a single-unit cantilever with an ET CPC distal abutment. The models were analyzed using a three-dimensional finite element program, and von Mises stress values and patterns were evaluated. ***Results:*** The results revealed that although the stress distribution patterns in dentin were dissimilar, the von Mises stress values registered for the vital and ET CPC distal abutment were not considerably different. However, higher stress values were detected in the dentin area surrounding the post–gutta-percha interface after CPC placement. The addition of the cantilever resulted in a considerable increase in stress on the dental tissue structures. ***Conclusions:*** CPCs appear to create a risk of potential fracture that is initiated in the dentin at the apex of the post. The type of restoration appears to have a much more serious impact on the stress pattern developed in the distal abutment, and the addition of a cantilever appears to biomechanically compromise both biologic and restorative structures. *Int J Prosthodont 2011;24:118–126.*

[a]*Graduate Student, Department of Fixed Prosthesis and Implant Prosthodontics, School of Dentistry, Aristotle University of Thessaloniki, Thessaloniki, Greece.*

[b]*Associate Researcher, Mechanical Design and Control Systems Division, School of Mechanical Engineering, National Technical University of Athens, Athens, Greece.*

[c]*Graduate Student, Mechanical Design and Control Systems Division, School of Mechanical Engineering, National Technical University of Athens, Athens, Greece.*

[d]*Professor, Mechanical Design and Control Systems Division, School of Mechanical Engineering, National Technical University of Athens, Athens, Greece.*

[e]*Professor and Chairman, Department of Fixed Prosthesis and Implant Prosthodontics, School of Dentistry, Aristotle University of Thessaloniki, Thessaloniki, Greece.*

Correspondence to: *Dr Petros Koidis, Department of Fixed Prosthesis and Implant Prosthodontics, School of Dentistry, Aristotle University of Thessaloniki, University Campus, Dentistry Building, GR 54124, Thessaloniki, Greece. Fax: +2310-999676 Email: pkoidis@dent.auth.gr*

Prosthodontic restoration of teeth with pronounced coronal structures may require endodontic treatment followed by custom-fabricated cast posts and cores (CPCs).[1] Although cast cores enhance the retention and resistance of the superstructure, the reinforcement effect of cast posts extending into the root is still disputed.[2,3] This is attributed to differences in managing the in vitro and in vivo test parameters, producing results that are difficult to compare and often contradictory.[4,5] The latter renders the expected longevity of these teeth questionable if they serve as distal abutments in cantilever fixed dental prostheses (FDPs), ie, in cases where the preferred treatment of posterior edentulism is through use of the extended shortened dental arch concept, providing improved esthetics, masticatory function, occlusal stability, and properly directed occlusal forces.[6,7] Thus, the controversy beyond emphasizes the importance of proper in

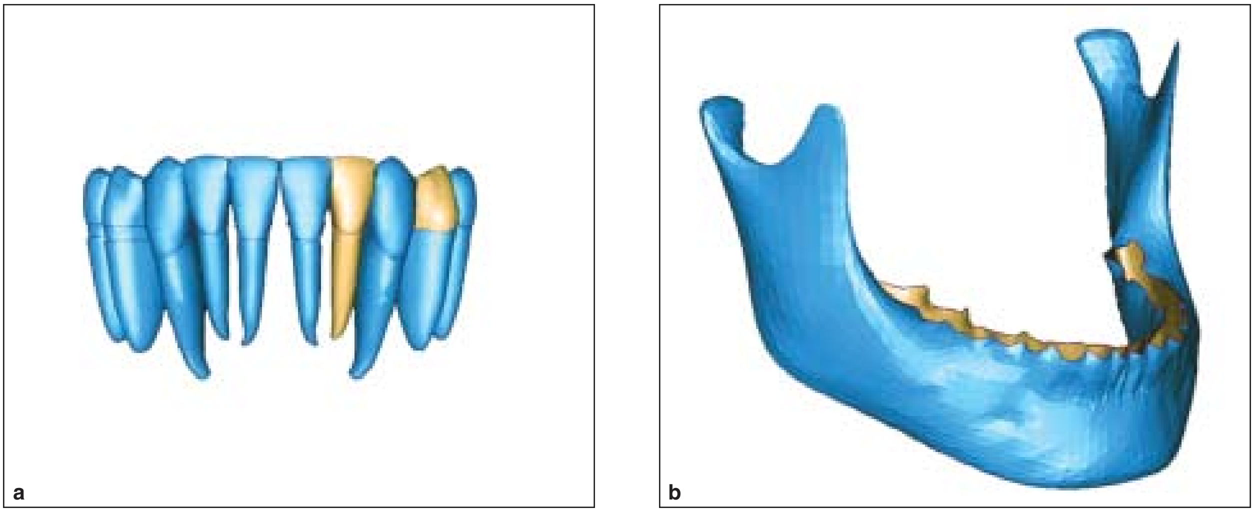

Fig 1 Digital model of **(a)** the teeth and **(b)** the mandible.

silico studies as additional means by which to evaluate simulation and add to the strength of in vitro and in vivo studies.

The most sophisticated theoretical method for simulating clinical reality is finite element analysis (FEA)[8]—an in silico numeric tool predicting biomechanical response.[9] This has the advantage of reducing the number of uncontrolled variables influencing the final outcome.[8]

FEA has been adopted widely in dental research, resulting in several FEA studies.[10–14] However, none of these have tried to evaluate the most distal position of the cast post–tooth complex in conjunction with different types of FDPs. Accordingly, the purpose of the present study was to comparatively evaluate the stress field developed in the distal abutment of two types of FDPs with reference to pulp cavity conditions.

Materials and Methods

Four three-dimensional (3D) models were designed, the structures of which were either obtained from computed tomography (CT) scan images (MIMICS: Materialise Interactive Medical Image Control System, Materialise) or developed in a 3D computer-aided design (CAD) environment (SolidWorks 2006, SolidWorks; Geomagic Studio, Geomagic; and Algor, Algor). The models were analyzed using 3D FEA software (Algor). The stress patterns and values were evaluated using von Mises criteria. Permission for the use of CT scan images was granted by the ethics committee of the School of Dentistry, Aristotle University of Thessaloniki, Thessaloniki, Greece.

Each model simulated a human mandible dentate to the second premolars (Fig 1). Right premolars were splinted via an FDP without a cantilever or a single-unit cantilever FDP. The distal abutment of the FDPs was vital or endodontically treated (ET) and restored with CPCs. The resulting models are shown in Fig 2.

The mandible and teeth were modeled using the image control system (MIMICS) (Fig 2); periodontal ligament models were designed using the reverse engineering software (Geomagic Studio).[15] The prepared teeth, pulp, CPC, root filling material (gutta-percha), and metal-ceramic FDP geometries were designed using CAD software (SolidWorks 2006). Tooth preparations were completed with a slightly chamfered finish line (1.2 mm), while ET abutments had a 2-mm ferrule.[16,17] The gutta-percha was extended 5 mm from the apex, and the post space inside the root was designed with a diameter equal to one third of the root diameter.[13,18] The FDP geometry was designed based on the construction principles of gold-ceramic restorations.[19,20]

All four 3D models were subsequently imported into the FEA software (Algor) and meshed with brick elements. The nodes on the outer surface of the ramus and angle area were assumed to be fixed in all directions, while at the cross-sectional area of the symphysis, only the nodal displacement along the x-axis and the nodal rotations about the y- and z-axes were restrained.[21] The restored teeth, including the cantilever, were subjected to forces with vectors parallel to the longitudinal tooth axis. The magnitude of force applied was determined from the literature (Fig 3).[10,22] All materials were homogenous and isotropic (Table 1).[21,23,24]

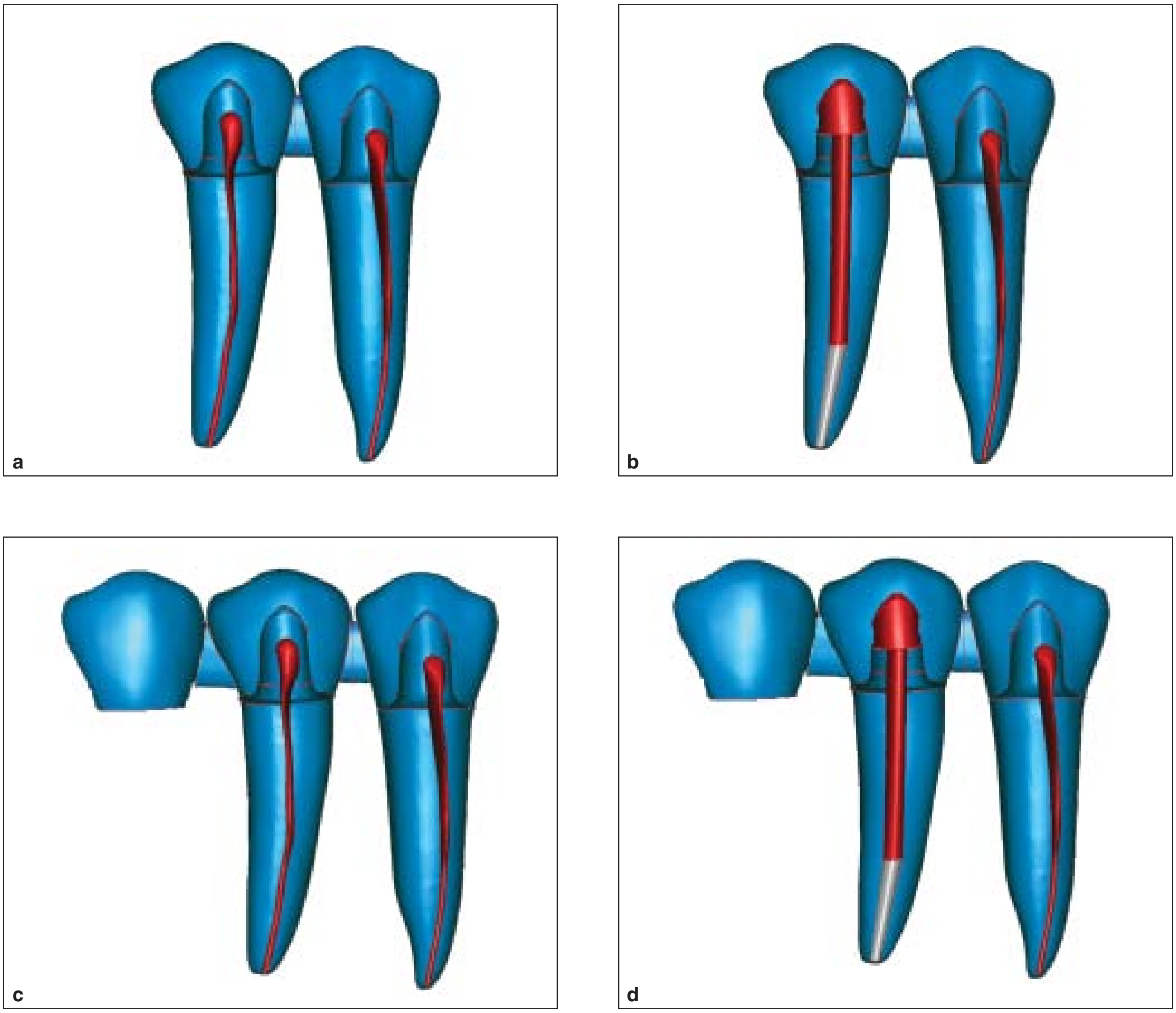

Fig 2 Design of the models: **(a)** no cantilever FDP/vital end abutment, **(b)** no cantilever FDP/post-restored end abutment, **(c)** cantilever FDP/vital end abutment, and **(d)** cantilever FDP/post-restored end abutment.

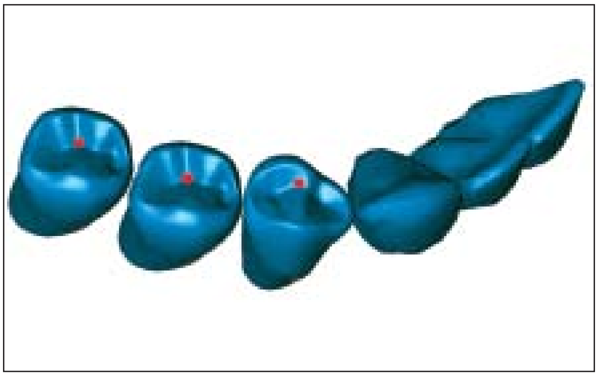

Fig 3 Force distribution along the splinted tooth and cantilever segment. Red dots represent regions in which an occlusal force was applied (200 N).

Table 1 Mechanical Properties of Biologic and Restorative Structures

Material	Young modulus (MPa)	Poisson ratio
Teeth[21]	22,700	0.30
Pulp[23]	2	0.45
Periodontal ligament[21]	50	0.49
Alveolar bone[21]	13,700	0.30
Casting gold III[21]	100,000	0.30
Ceramic[21]	68,900	0.30
Gutta-percha[24]	0.69	0.45

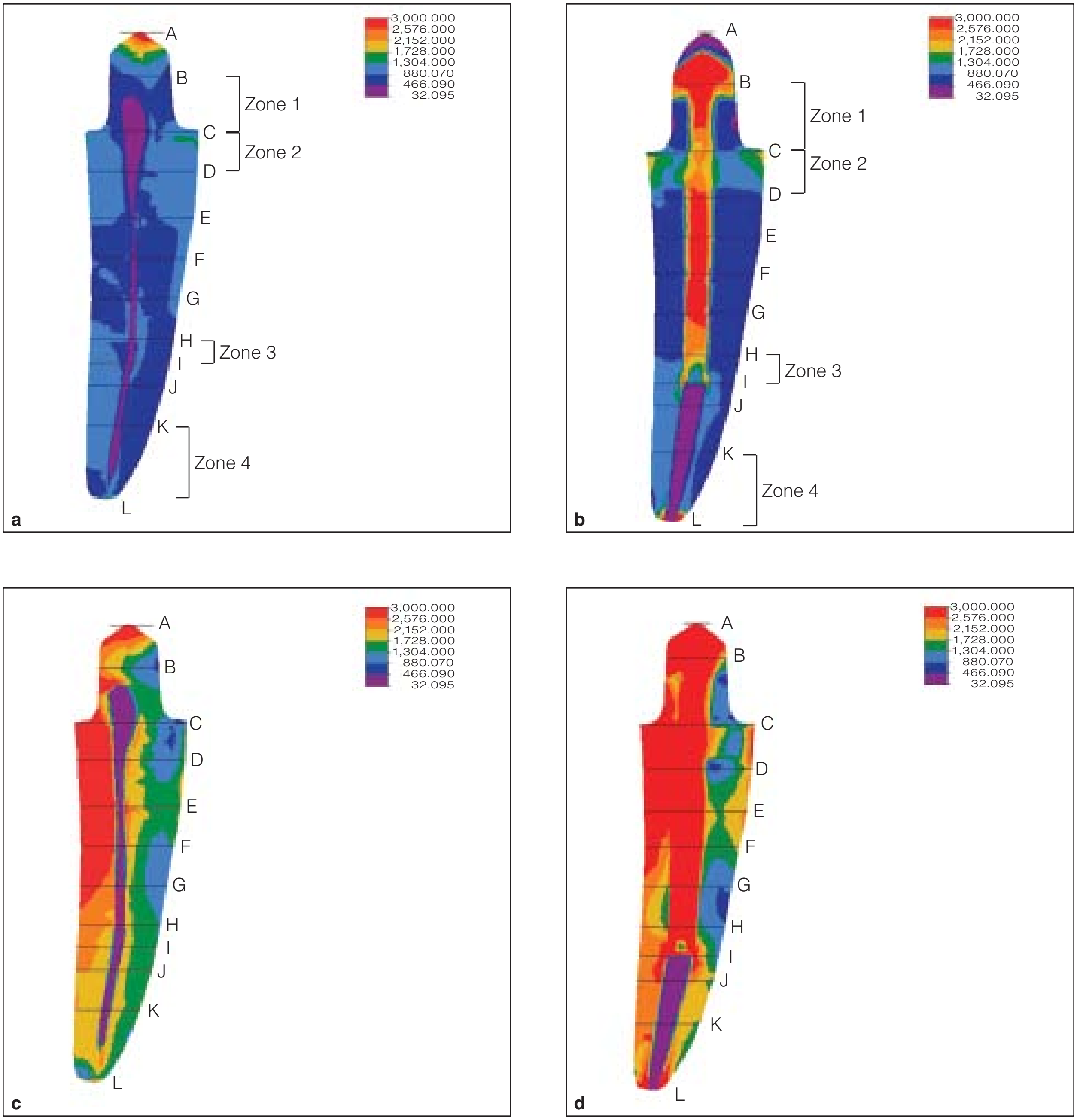

Fig 4 Stress distribution of the end abutment in frontal and horizontal cross-sections for: **(a)** no cantilever FDP/vital end abutment, **(b)** no cantilever FDP/post-restored end abutment, **(c)** cantilever FDP/vital end abutment, and **(d)** cantilever FDP/post-restored end abutment.

Results

Figure 4 shows the von Mises stress distribution of the distal abutment in a medial frontal cross-section, which is divided into multiple horizontal cross-sections (A through L). Figure 5 shows the von Mises stress distribution of the distal abutment in the surface aspect.

The von Mises stress values of the horizontal cross-sections are presented in Tables 2 through 4 for the dentin, the post–gutta-percha, and pulp, respectively, while Fig 6 presents the relevant comparative graphs. Numeric data are illustrated as color contours, providing a color representation of the stress distributions.

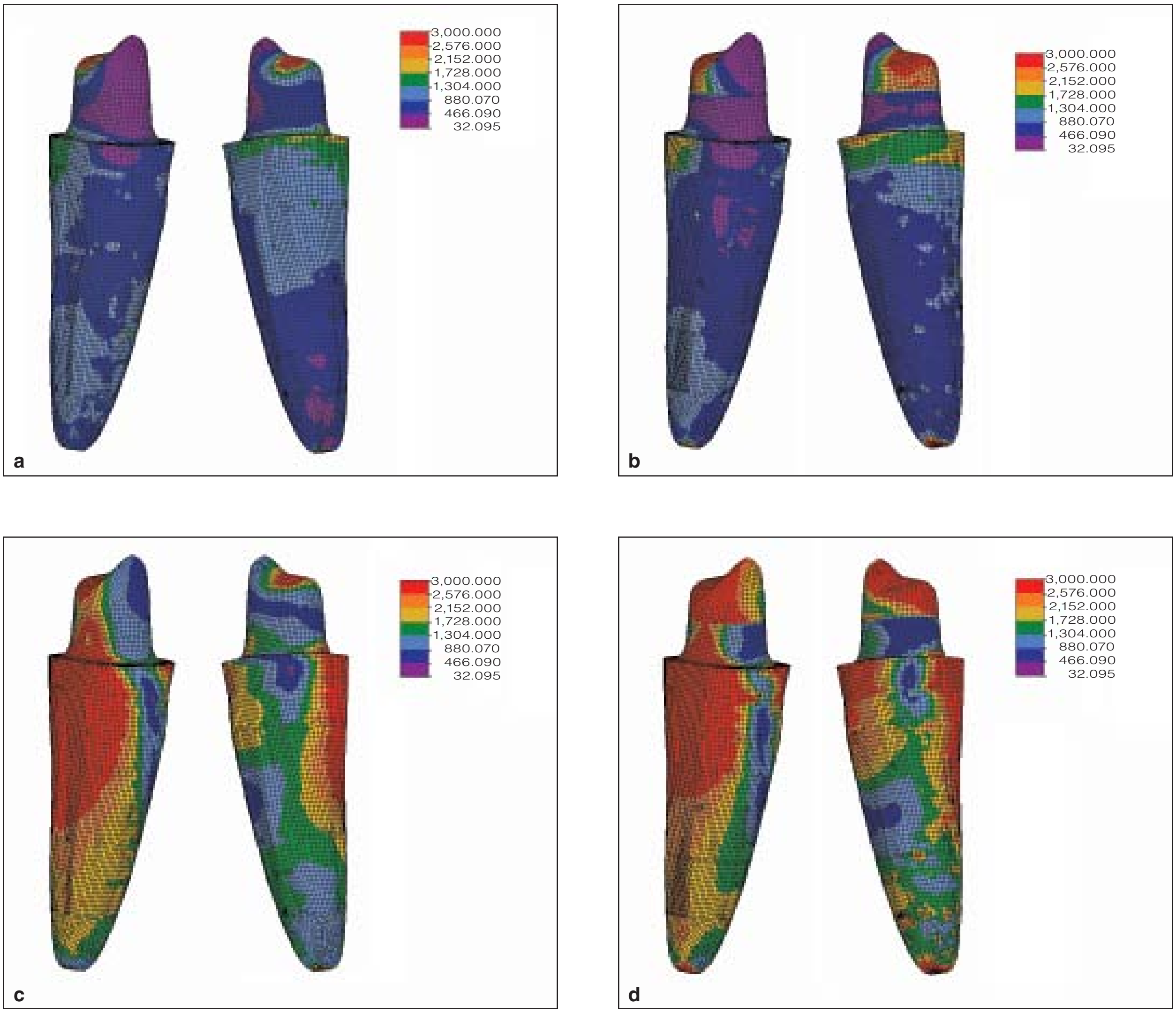

Fig 5 Stress distribution of the end abutment in the *(left)* buccodistal and *(right)* lingual-mesial aspects for: **(a)** no cantilever FDP/vital end abutment, **(b)** no cantilever FDP/post-restored end abutment, **(c)** cantilever FDP/vital end abutment, and **(d)** cantilever FDP/post-restored end abutment. [Au: Please double-check stress scales.]

Table 2 Maximum von Mises Stress Values (MPa) in the Dentin of the Distal Abutment

	No cantilever FDP		Cantilever FDP	
Zone	Vital distal abutment	ET CPC distal abutment	Vital distal abutment	ET CPC distal abutment
B–C	2,759.0	2,049.3	2,836.3	9,433.2
C–D	4,376.5	2,836.3	23,198.0	22,311.0
D–E	2,536.3	3,016.7	9,464.4	7,492.5
E–F	3,281.9	4,977.3	8,012.1	10,742.0
F–G	1,682.9	2,381.9	7,022.2	6,302.8
G–H	2,408.2	1,942.6	5,671.0	5,424.5
H–I	2,097.8	5,193.0	4,719.9	10,981.0
I–J	2,045.6	8,145.7	4,512.3	17,541.0
J–K	1,706.1	1,843.6	4,441.5	4,126.7
K–L	3,124.0	5,346.2	8,259.0	9,325.8

Table 3 Maximum von Mises Stress Values (MPa) in the Post–Gutta-Percha of the ET CPC Distal Abutment

Zone	No cantilever FDP	Cantilever FDP
B–C	3,835.4	6,214.9
C–D	3,171.2	8,966.7
D–E	5,610.5	16,033.0
E–F	4,977.3	15,229.0
F–G	9,980.2	13,686.0
G–H	5,081.2	13,749.0
H–I	17,351.0	39,711.0
I–J	0.3	0.6
J–K	0.2	0.6
K–L	8,763.0	17,382.0

Table 4 Maximum von Mises Stress Values (MPa) in the Pulp of the Vital Distal Abutment

Zone	No cantilever FDP	Cantilever FDP
B–C	0.2	1,323.0
C–D	2,038.0	19,271.0
D–E	0.8	7,556.0
E–F	0.4	1,509.0
F–G	0.3	1,248.0
G–H	0.3	0.6
H–I	0.2	0.8
I–J	0.2	0.8
J–K	0.5	2,199.0
K–L	4,022.0	15,251.0

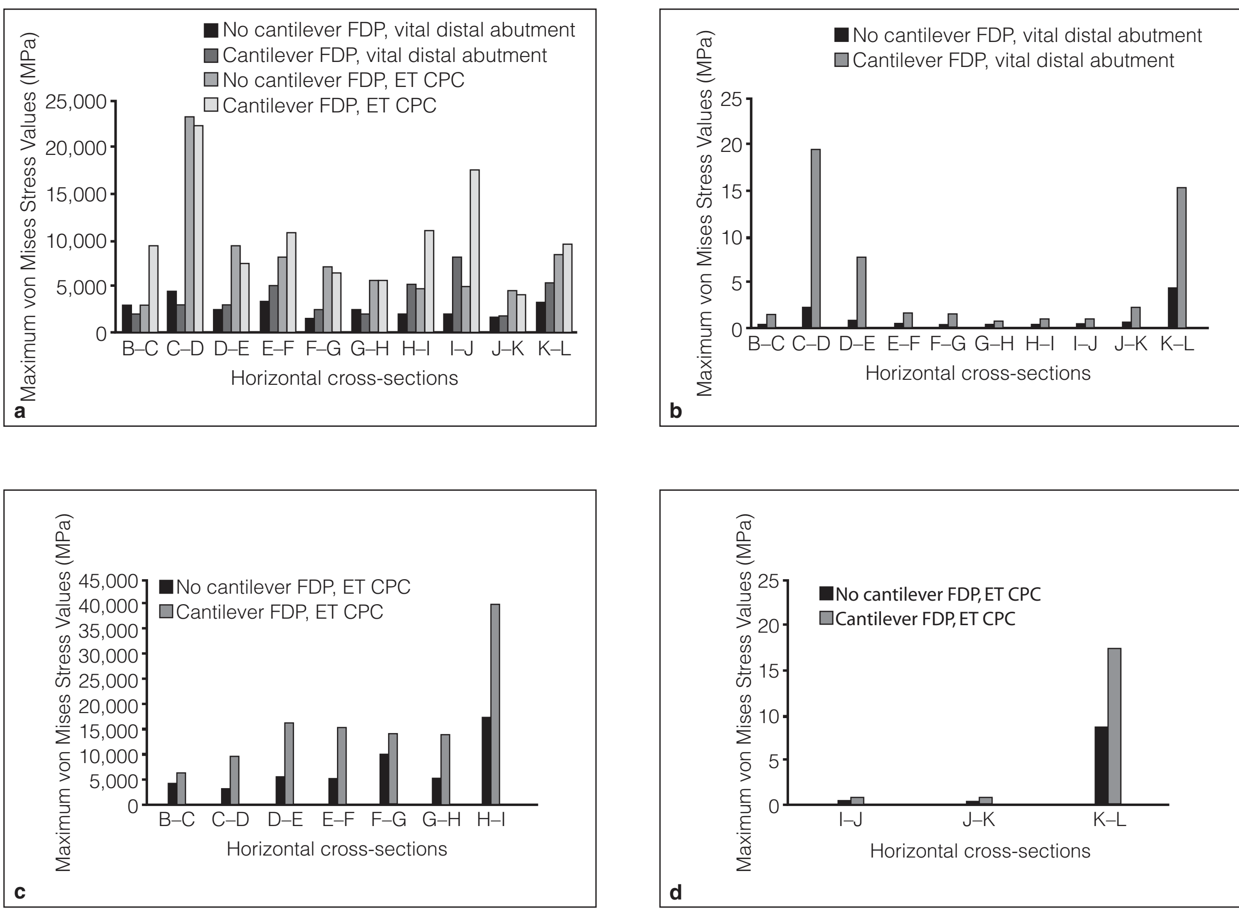

Fig 6 Comparative stress values between the horizontal cross-sections for the **(a)** dentin, **(b)** pulp, **(c)** post, and **(d)** gutta-percha.

No Cantilever FDP: Vital vs ET CPC Distal Abutment

In the frontal cross-sections as well as at the outer surface of the tooth/CPC system (Figs 4a to 4d), the dentin was less stressed under the noncantilever FDPs. The stress distribution patterns were different in the dentin of the vital compared to the ET CPC distal abutments (Figs 4a and 4b). The most pronounced differences were:

- The dentin of the post-restored tooth was less stressed compared to the vital one, while the post presented stress in the lower half of zone 1 (between cross-sections B and C).
- Stress concentration was observed in the dentin area under the preparation finish line, which increased when the distal abutment was restored with CPC. The post in zone 2 was under less stress (between cross-sections C and D).
- The dentin surrounding the post apex experienced the most intense stress field. The post also presented a stress reduction for a large portion of zone 3 (between cross-sections H and I).
- The inner side of the dentin adjacent to the gutta-percha was more stressed (below cross-section K).

Apart from the aforementioned differences, there are two other aspects worth mentioning: *(1)* the lowest stress zones were in the pulp and the gutta-percha, while CPC exhibited the highest stress concentrations (Figs 4a and 4b), and *(2)* a discontinuity in the stress zone was observed in the post-restored distal abutment at the point where the post lies in the dentin ferrule (Figs 5a and 5b).

Single-Unit Cantilever FDP: Vital vs ET CPC Distal Abutment

The distal abutment, vital or post-restored, under the single-unit cantilever FDPs presented considerably higher stresses and completely different stress distributions compared to distal abutments in FDPs without a cantilever (Figs 4c and 4d).

In the frontal cross-sections, the highest stress zones for the dental tissue were presented for the distal area of the vital and post-restored distal abutments, adjacent to the cantilever segment. The highest stress concentrations of the post/tooth assembly occurred for the CPC, though the apical portion of the post experienced stress reduction in the dentin area where stress is primarily concentrated. Moreover, the post-restored tooth also exhibited stress concentration in the dentin area at the post–gutta-percha interface. Pulp and gutta-percha showed the lowest stress fields.

The outer surface of the distal abutment under the cantilever FDPs (Figs 5c and 5d) presented higher stress contours at the distal aspect of the root and ferrule. Similar to the post-restored distal abutment under the restoration without a cantilever, the same stress discontinuity was observed during the transition from the post to the dental tissue.

Discussion

Though still limited by assumptions, FEA is a powerful numeric tool that reveals biomechanical performance by overcoming the standardization issues.[8,25–27] In the present study, the assumed simplifications were related to the lack of well-defined physical properties and the attribution of isotropic and homogenous structures.[28,29] The cementum and cement layer were included in the dentin portion because of their similar elastic moduli.[30] Cortical bone was not simulated because it was so thin and complicated that the resulting mesh would not be valid.[28,29] The application of masticatory loads and the boundary conditions were based on previous experimental tests.[10,21,22] Finally, the analysis performed was linear static, validating the relative resistance to stress.[31]

Within the limitations of the present study, the results demonstrated that even if the stress distribution patterns in dentin were dissimilar, the stress values registered for the vital and ET CPC distal abutment were not considerably different when the two types of FDPs were examined. The lack of difference is attributed to the presence of a remaining 2-mm ferrule, which protects the ET CPC tooth from wedging stresses, providing resistance to masticatory loading.[32–34]

Another factor contributing beneficially to lowering the stresses on the dentin is the higher Young modulus of CPCs compared to that of dentin.[35,36] According to the theory of elasticity for equivalent cross-sections, it is anticipated that the material with the higher Young modulus is under more stress.[37] Since the assembly is assumed to be a deformable body, its parts are compatible in terms of displacement and strain. Thus, from two compatible parts, the one with the higher Young modulus is more stressed.[38] The stress discontinuity shown in Fig 5b is also explained by the difference in the Young modulus between the dentin and the post material.[37]

As far as the stress reduction of the post in zone 1 is concerned, the explanation lies in the shape of the metal coping surrounding the post, the radius of which increases toward cross-section C. Thus, since the metal coping and post have the same Young modulus, the metal framework is the primary participating factor in carrying externally applied loads, relieving the post.[39]

The stress increase observed just below cross-section C is attributed to the fact that the applied loads are transmitted directly to this cross-section through the loading paths of the porcelain and metal coping. Thus, the shoulder is significantly loaded and experiences high stress loads. This, in combination with the shape and location of the shoulder (a hollow ring away from the tooth axis), results in the appearance of dentin stress concentrations and post stress reduction in zone 2.[40]

The stress reduction of the post observed in zone 3 is attributed to the fact that the lower portion of the post lies in the gutta-percha, which has a Young modulus significantly lower than that of the post. Equivalently, gutta-percha serves as a boundary condition of no-load transmission, the effect of which extends to the adjacent part of the post, as the Saint Venant principle dictates.[41] The dentin stress concentration in the post apex creates a high risk of potential fracture, since even minimal stress concentration proximal to holes (root canal spaces) may initiate the process of failure more easily because of crack formation.[42] With respect to the high stresses near the tooth apex, it is the nature of the appearing strain that causes an increase in stress. Particularly from cross-section D and toward the tooth apex, the tooth is surrounded by the periodontal ligament, which experiences shear strain over its entire surface apart from the apex area, where compression is the predominant phenomenon. The shear modulus, being significantly lower than the Young modulus, results in lower stresses than those caused by tension/compression. Thus, the apex area, under strong compression, presents higher stresses because the periodontal ligament carries greater stress, providing more stiff support to the tooth.[37]

A point of major interest is the effect of the loaded cantilever to the stress field of the distal abutment. The cantilever is loaded with an occlusal force, whose vector is located one coronal width away from the distal abutment, causing substantial oblique bending and torsion. As shown in Figs 5c and 5d, it is the distal aspect (compression side) of the abutment that sustains higher stresses than the mesial aspect. This stress field asymmetry along the root axis indicates the existence of torsion, compared to the symmetric stress field that only pure bending would produce. Bending and torsional loading seem to aggravate the abutment's structure significantly, with higher stresses than if an FDP without a cantilever were used, in which the axial loading would be predominant. Furthermore, the presence of the post causes a significant change in the stress field. Particularly in Figs 4c and 4d, it is obvious that the stresses become lower in the compression zone (from cross-section C to cross-section H). This reduction results from the fact that the post has a higher Young modulus than the dentin. Thus, the post absorbs more stress, simultaneously relieving the dentin.

However, the presence of the post also changes the position of the neutral axis of the abutment-tooth assembly. As shown when comparing Figs 4c to 4d, the zone of low stresses (stresses closer to 0) moves toward the post. In other words, the neutral axis of the assembly moves toward the post, thus widening the tension zone mesial to the tooth. In addition, the presence of the post raises stress levels in the portion of the dentin below cross-section I. This stems from a combination of two factors: one related to the Young modulus of the filling material, and the other, to the amount of dentin actually under the load. More specifically, because of its relatively low Young modulus, the filling material carries a negligible share of the applied loads.

At the same time, the need to accommodate the filling material requires enlarging the pulp cavity of the tooth. This means that filling material (carrying no load) is present against the dentin (supporting the entire load), and as the dentin is reduced in quantity, the stress levels increase. From this, it becomes obvious that the position of the post, as well as its length, diameter, and Young modulus, are beneficial to certain parts of the stress field but detrimental to others, thus presenting an issue for optimization.[43]

Conclusions

Within the limitations of this study, the following conclusions can be drawn:

- The addition of the cantilever along with CPC placement seems to considerably aggravate the stress field of the dentin area around the post–gutta-percha interface.
- Apart from the stress concentration at the post–gutta-percha interface, the CPC induces a stress field similar to that of the natural tooth, while the cantilever addition seems to severely compromise the biomechanical stability of both the biologic and restorative structures.

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