FINITE ELEMENT ANALYSIS OF STRENGTH AND ADHESION OF CAST POSTS COMPARED TO GLASS FIBER-REINFORCED COMPOSITE RESIN POSTS IN ANTERIOR TEETH

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Statement of problem. Previous studies on the strength of teeth restored with posts have not resolved the controversy as to which post systems provide the greatest strength and longevity.

Purpose. The purpose of this study was to compare the strength of teeth restored using cast posts with those restored using glass fiber-reinforced composite resin posts and to evaluate the bond strength of the posts to dentin.

Material and methods. The investigation was conducted by using finite element analysis, combined with the application of contact elements. Three-dimensional (3-D) models of the maxillary central incisors were generated: IT, an intact tooth; CC, a tooth with a ceramic crown; FP, a tooth restored with an FRC (glass fiber-reinforced composite resin) post; CPAu, a tooth restored with a gold alloy cast post; and CPNi, a tooth restored with an NiCr (nickel chromium alloy) cast post. Each model was subjected to vertical and oblique loads with a force of 100 N. To evaluate the strength of the restored tooth, ceramics, and composite resin, the modified von Mises failure criterion was used, the Tsai-Wu criterion for FRC, and the von Mises criterion for gold and NiCr alloy. The equivalent stresses found in the tested models were compared with the tensile strength of the respective materials. Contact stresses in the luting cement-dentin interface were calculated.

Results. The maximum mvM (modified von Mises failure criterion) stresses in the dentin of the teeth restored with FRC posts were reduced by 21%, and in those restored with cast NiCr posts, stresses were reduced by 25% when compared to the stresses in the intact tooth. The equivalent stresses in metal posts were several times higher than in FRC posts, but did not exceed the tensile strength of the materials. The highest mvM stress in the luting resin cement around the FRC post was 55% higher than in the luting resin cement around the metal post, under an oblique load. In the ceramic crown, which covered the composite resin post and core, the highest mvM stress was 30.7 MPa, whereas with the metal post and core, it was 23 MPa.

Conclusions. Cast metal posts resulted in lower stresses in the dentin of the restored teeth than did FRC posts. Irrespective of the material, the equivalent stresses in the posts did not exceed their tensile strength. Lower stresses were present in the luting cement and the cement-dentin interface around cast posts than around FRC posts. In the ceramic crown supported by a metal post and core, the stresses were lower than those observed in the crown supported by a composite resin core foundation. (J Prosthet Dent 2011;105:115-126)

CLINICAL IMPLICATIONS

Posts made of materials with a higher modulus of elasticity than dentin strengthen tooth structure. Teeth restored with metal posts should be more resistant to fracture than teeth with FRC posts. Under physiological loads, ideally cemented posts in anterior teeth, regardless of whether they are made of metal or FRC, are not prone to damage or debonding. Ceramic crowns supported by metal cores are potentially more resistant to failure than those with composite resin core foundations.

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Posts and cores are recommended for endodontically treated, weakened teeth as a foundation for prosthetic crowns.[1] Of the various post systems available, custom metal posts or prefabricated fiber-reinforced composite resin (FRC) posts are commonly recommended for clinical use.[2]

Custom posts and cores are cast from alloys that are characterized by high elastic moduli (95 GPa for gold alloys[3] and 188 GPa for nickel-chromium alloys[4]). FRC posts exhibit mechanical anisotropic properties.[5] The Young's modulus along the longitudinal axis of the post (fiber alignment direction) is 37 GPa, whereas it is 9.5 GPa[5] in the perpendicular direction. Gold-alloy posts have 7 times the flexural strength (1545 MPa) of dentin (213 MPa).[6] FRC posts have a lower flexural strength (879 MPa), although it is still 4 times that of dentin.[6,7]

The strength and longevity of a restoration depend on the post material, its length, the thickness of the root walls, the length of the root, the post's bond to dentin, the remaining coronal tooth structure, the presence of a ferrule, as well as the load on the tooth.[8] Despite numerous finite element analysis (FEA) studies, it remains undetermined which post system provides the greatest strength to a restored tooth. According to some authors, the higher the elastic modulus of the post material, the higher the stress concentration in the post itself and the lower the stresses transferred to the dentin, crown, and cement.[9-12] However, it has been noted in several studies that lower and more favorably distributed stresses occur in teeth with FRC posts than in teeth with metal posts.[13-19]

In vitro strength tests have not resolved the question as to which post system is better. Some authors have reported that teeth restored with FRC posts have a higher fracture resistance than teeth restored with metal posts.[20,21] Others have shown that a higher static force is needed to fracture teeth with cast posts than those with FRC posts, although in both situations, the load exceeded the average masticatory force.[22-26] In these studies, the force most often caused damage to the tooth structure and not to the post, regardless of post type. Fractures in teeth with FRC posts usually occurred in the cervical area, while custom metal posts were associated with root fractures.[27-30] Goto et al [31] and Hu et al[32] found that, in vitro, teeth restored with FRC posts were more fatigue resistant. Forberger and Göhring[33] demonstrated that stiff metal cores provide better marginal continuity of ceramic crowns than composite resin cores. However, long-term clinical observations did not show any statistically significant differences between the performance of teeth restored with cast systems and those restored with FRC post systems.[34,35]

The purpose of this study was to compare the strength of maxillary central incisors restored with cast posts to those restored with glass fiber-reinforced composite resin posts and to evaluate the bond strength of the posts to dentin.

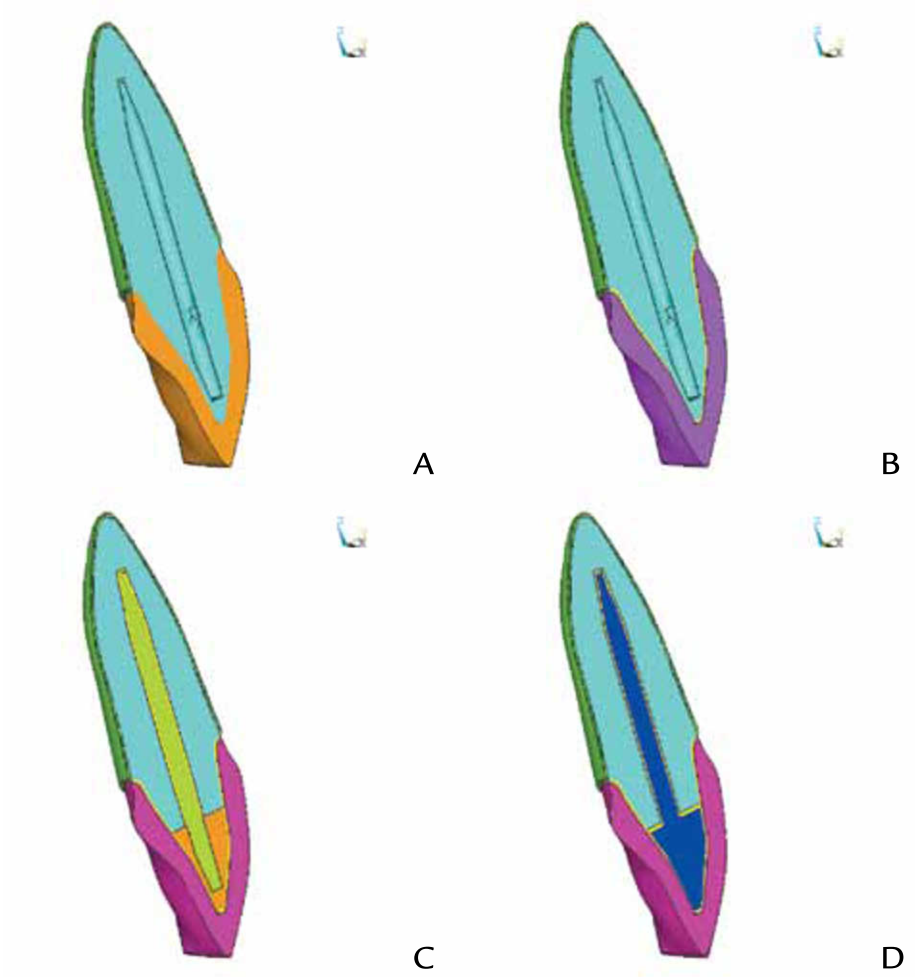
MATERIAL AND METHODS

Scans of the surfaces of a maxillary first central incisor were made with a laser scanner (D250 3D Dental Scanner; 3Shape A/S, Copenhagen, Denmark). The scans were processed with software (3Shape DentalDesigner; 3Shape A/S). Other scans of the examined tooth were made with cone-beam computerized tomography (CBCT) (GXCB-500/i-CAT; Gendex Dental Systems, Des Plaines, Ill). Files with coordinates of the points on the tooth surfaces (obtained from the scanner) and the points on the enamel-dentin-pulp junction (obtained from the CBCT), in horizontal layers (every 1 mm), were introduced into the finite element analysis FEA software (ANSYS v. 10; ANSYS, Inc, Canonsburg, Pa).[36] The points were connected with splines, and then the cross-sections of the tooth were created in an ANSYS code preprocessor. Connecting those cross-sections allowed for the creation of a solid model of the central incisor, divided into enamel, dentin, and pulp (Fig. 1, A). The size and shape of the tooth were similar to published anatomical values.[37] The crown was 10.5 mm long, 8.5 mm in mesiodistal width, with a root length of 13 mm. A 0.2-mm periodontal ligament was modeled around the tooth root (model IT). The tooth model was located in the system of coordinates in such a way that the Z axis was parallel to the long axis of the tooth, the X axis was oriented mesiodistally, and the Y axis was oriented buccolingually.

The tooth was prepared for a ceramic crown in accordance with standard clinical recommendations,[38] with a 10-degree axial wall inclination, a 2-mm incisal reduction, and a 0.8-mm rounded shoulder at the gingival margin. The prepared tooth was scanned (D250 3D Dental Scanner; 3Shape A/S). A cloud of points was introduced into the ANSYS application, and the surface of the prepared tooth crown was generated in the software. The IT model was cut with the surfaces shown; thus, a model of the incisor restored with a ceramic crown was developed (CC model) (Fig. 1, B). An additional 0.1-mm-thick layer surrounding the prepared tooth was made to simulate the cement layer.

In the ANSYS code preprocessor, a 15 x 1.2-mm cylinder surrounded by a 0.1-mm cement layer was generated; the cylinder had a truncated cone at the end. That solid was introduced in the tooth root and in the pulp chamber and then was added to the CC tooth model. In this way, a tooth model with a standard FRC post and a prosthetic crown was generated (FP model) (Fig. 1, C).

Similarly, a 10-mm-long cylinder with a diameter of 1.2 mm and a truncated cone at the end was formed. The cylinder was introduced into the tooth canal and added to the CC tooth model. The tooth model was sectioned perpendicularly to the longitudinal axis, at a distance of 2 mm



1 Cross-section of maxillary central incisor models with various restorations. A, IT: intact tooth. B, CC: tooth with ceramic crown. C, FP: tooth with glass fiber-reinforced resin composite post (FRC). D, CP: tooth with cast post.

from the cemento-enamel junction. Thus, a tooth model with a custom cast post and a prosthetic crown was created (CP model) (Fig. 1, D).

Custom cast posts were modeled from a gold alloy (CPAu model) and a nickel-chromium alloy (NiCr) (CPNi model); in addition, a prefabricated post made of glass fiber-reinforced composite resin (FRC) was used (FP model). The crown was modeled from leucite-reinforced ceramic (IPS Empress Esthetic; Ivoclar Vivadent AG, Schaan, Liechtenstein). Both posts were ideally adhesively bonded to the tooth structure with composite resin cement (Variolink II; Ivoclar Vivadent AG).

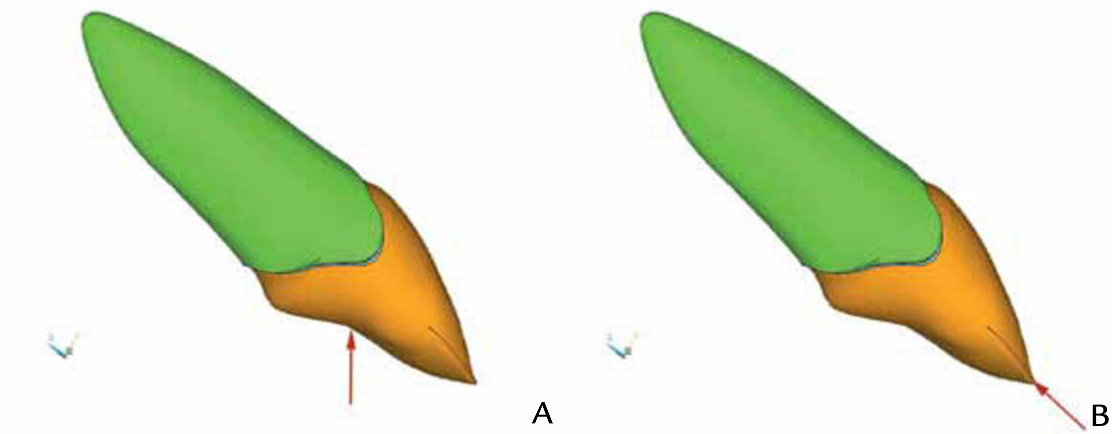
The values for Young's modulus, Poisson's ratio, compressive strength, and tensile strength were entered for enamel,[3,39,40] dentin,[3,41-43] periodontium,[44,45] gold alloy (type IV), [3,46] NiCr alloy,[4] FRC,[5,47] luting composite resin cement,[48,49] core composite resin,[50,51] and ceramic.[52,53] The models were considered to be linear, elastic, homogeneous, and isotropic (except for the FRC post). Modulus of elasticity, Poisson's ratio, tensile strength, and compressive strength data for all materials used in the models are listed in Table I.

For calculation purposes, each tooth model was divided into 10-node structural solid elements (Solid 187). In the intact tooth model (IT), 71,243 elements joined at 98,476 nodes were used. The complete crown model (CC) was composed of 76,885 elements, 104,212 nodes; the prefabricated post (FP): 85,916 elements, 114,959 nodes; and a custom cast post (CPNi, CPAu): 86,480 elements, 115,645 nodes. Pairs of bonded contact elements, Targe 170 and Conta 174, were used around the restorations, at the interface of the luting cement-dentin bond.

The IT, CC, FP, CPNi, and CPAu models were fixed in nodes on the outer surface of the periodontium, and 2 load directions, vertical and oblique, were applied. These forces simulated loads acting on the incisor during clenching (in maximum intercuspation) and incising. Their total value was equal to 100 N.[54] The vertical forces were applied along the incisal edge, parallel to the longitudinal axis of the tooth (Fig. 2, A); the oblique forces were applied to the nodes under the lingual cingulum, at 130 degrees to the longitudinal axis

TABLE I. Properties of materials used in models

Material	Modulus of Elasticity (GPa)	Poisson's Ratio	Tensile Strength (MPa)	Compressive Strength (MPa)
Enamel	84.1[39]	0.33	11.5[40]	384.0[3]
Dentin	18.6[41,42]	0.31	105.5[43]	297.0[3]
Periodontium	0.05[44]	0.45	–	–
Gold alloy post	95.0[3]	0.33	457.0[46]	–
NiCr alloy post	188.0[4]	0.33	710.0[4]	710.0[4]
Fiberglass post (along direction of fibers)	37.0[5]	0.34	1200.0[47]	1000.0[47]
Fiberglass post (perpendicular to direction of fibers)	9.5[5]	0.27	73.0[47]	160.0[47]
Crown leucite ceramics	65.0[52]	0.19	48.8[53]	162.9[53]
Composite resin core	14.1[50]	0.24	41.0[51]	293.0[51]
Composite resin luting cement	8.3[48]	0.35	45.1[49]	178.0[49]



2 Central incisor models subjected to force. A, Obliquely acting on palatal surface below cusps. B, Vertically acting on incisal edge.

(Fig. 2, B).[55]

The contact simulation conducted with FEA is a nonlinear analysis; it therefore required the load to be divided into steps. In the ANSYS code, there was an automatic division into steps and an iterative procedure was applied. The components of stresses (normal, shear, and principal stresses) in 5 models for 2 variants of load, vertical and oblique, were calculated.

One of the criteria used to evaluate the strength of materials under compound stress states is the modified von Mises (mvM) failure criterion,[56] which considers the ratio between the compressive and tensile strength (enamel, 33.4; dentin, 2.8; ceramic, 3.3; composite resin and cement, 3.9). For the NiCr alloy and gold alloy, this ratio is equal to 1; therefore, the criterion takes the form of the von Mises criterion (vM). According to the failure criteria, the material will fail when the values of the equivalent stresses exceed the tensile strength of the material. To evaluate the strength of FRC posts, which have strong orthotropic properties, the Tsai-Wu criterion was applied.[57] If the value of the inverse Tsai-Wu strength ratio index (ITWSR) is less than 1, then the material will not fracture. However, if this value is higher than 1, then damage to the material may occur.[57] The results of the calculation are presented in the form of maps of stress distribution in the separate materials of the models. The maximum values of equivalent stresses that occurred in the model materials were compared to one another and to their respective tensile strength.

Compressive, tensile, and shear contact stresses at the luting cement-dentin interface around posts and under the crown were also calculated. They were graphically depicted as maps on the contact surfaces of the restoration and dentin. The maximum values of contact stresses in the models were compared with one another.

RESULTS

The values of the maximum mvM stresses occurring in the materials of models under an oblique load are presented in Table II, and under a vertical load, in Table IV. The values of the maximum tensile, compressive, and shear contact stresses are shown in Tables III and V for the oblique and vertical loads, respectively.

The maximal mvM stresses (21.6 MPa) in the intact tooth (model IT) were concentrated in the enamel, near the cingulum, under the oblique load (Fig. 3, A) (Table II), and on the incisal edge (21.1 MPa) with vertical forces (Table IV). In dentin, the highest mvM stress of 14.0 MPa occurred in the palatal wall of the root during oblique loading (Fig. 3, B) (Table II). The forces acting along the axis caused low stresses of 3.7 MPa in dentin (Table IV).

The mvM stresses in the dentin of the CC model decreased to 11.0 MPa with oblique loading and increased slightly to 4.2 MPa with vertical loading. In the FP model, mvM stresses in dentin were similar to those observed in the CC model (Fig. 3, C). The restoration of the tooth with a metal post (model CPNi) resulted in a reduction in mvM stresses to 10.5 MPa in dentin with oblique loading (Fig. 3, D) and 3.2 MPa with vertical loading (Tables II and IV).

In the ceramic crown of the CC model, mvM stresses did not exceed the value of 29.0 MPa. In the ceramic crown supported by an FRC post (model FP), mvM stresses of 30.7 MPa were concentrated in the area to which the forces were applied, and along the gingival edge of the restoration (Fig. 4, A) (Table II). In the composite resin cement bonding the crown with the core, the maximum mvM stresses of 13.8 MPa were localized near the palatal finish line (Fig. 4, B) (Table II). In this location, the maximum contact tensile stresses of 11.3 MPa occurred, as well (Fig. 4, C) (Table III). The highest contact shear stresses were observed near the labial finish line (Fig. 4, D) (Table III). In the FRC post, the Tsai-Wu criterion did not exceed 0.07 (Fig. 4, E) (Table II). Under the vertical load, around the post, mvM stresses in the cement and contact stresses at the cement-tissue interface were low (Table IV, V). Under the oblique load, in the cement around the post, stresses reached 9.6

TABLE II. Maximum equivalent stresses of mvM failure criterion of central incisor tooth model materials, under oblique load (MPa)

Model Symbol	Central Incisor Model	Ceramic Crown/ Tooth Enamel	Post	Dentin	Resin Cement Under Crown	Resin Cement Around Post
IT	Intact tooth	21.6	–	14.0	–	–
CC	Tooth with ceramic crown	28.8	–	11.0	13.8	–
FP	Tooth with FRC post	30.7	0.07 (ITWSR)	10.9	13.8	9.6
CPAu	Tooth with gold cast post	24.5	38.6	10.7	12.6	6.8
CPNi	Tooth with NiCr cast post	23.0	64.8	10.5	12.6	6.2

FRC post: glass fiber-reinforced composite resin post; NiCr post: nickel chromium alloy post; Gold post: gold alloy post; ITWSR: inverse Tsai-Wu strength ratio index

Table III. Maximum contact tensile and shear stresses in luting cement-dentin adhesive interface in tooth models, under oblique load (MPa)

Model Symbol	Central Incisor Model	Under Crown		Around Post	
		Tensile Stress (MPa)	Shear Stress (MPa)	Tensile Stress (MPa)	Shear Stress (MPa)
CC	Tooth with ceramic crown	11.1	3.3	–	–
FP	Tooth with FRC post	11.3	3.4	5.2	1.6
CPAu	Tooth with gold cast post	8.9	3.1	5.1	1.0
CPNi	Tooth with NiCr cast post	8.8	3.0	4.8	0.9

Table IV. Maximum equivalent stresses of mvM failure criterion of materials in central incisor tooth models, under vertical load (MPa)

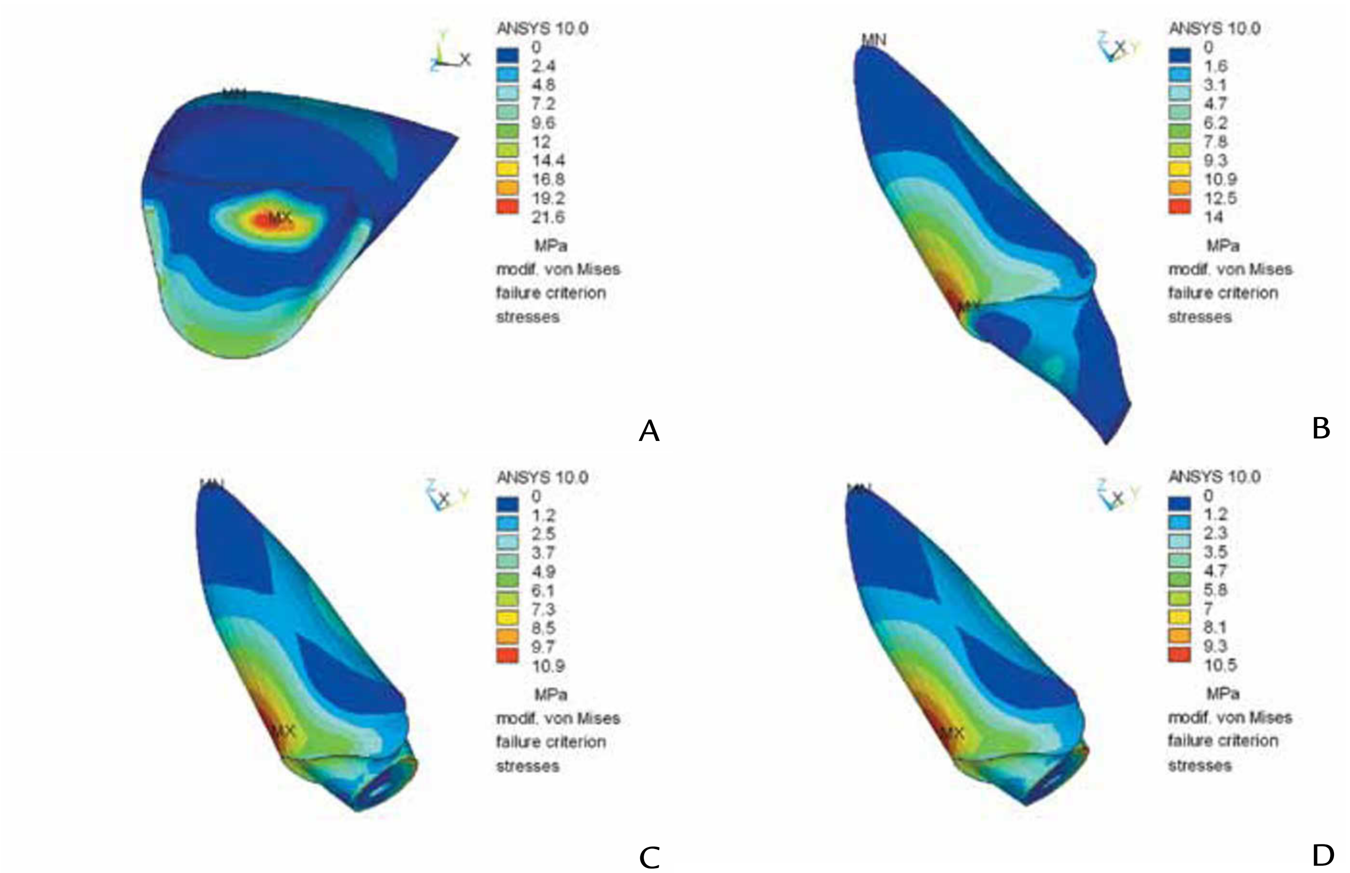
Model Symbol	Central Incisor Model	Ceramic Crown/ Tooth Enamel	Post	Dentin	Resin Cement Under Crown	Resin Cement Around Post
IT	Intact tooth	21.1	–	3.7	–	–
CC	Tooth with ceramic crown	28.6	–	4.2	3.7	–
FP	Tooth with FRC post	30.4	0.02 (ITWSR)	4.3	3.8	0.7
CPAu	Tooth with gold cast post	26.2	23.0	3.5	3.3	0.9
CPNi	Tooth with NiCr cast post	21.3	45.2	3.2	3.1	1.4

MPa (Table II). Contact tensile stresses of 5.2 MPa were concentrated around the core-post junction (Fig. 4, F), whereas contact shear stresses of 1.6 MPa occurred at the core-dentin bond (Fig. 4, G) (Table III).

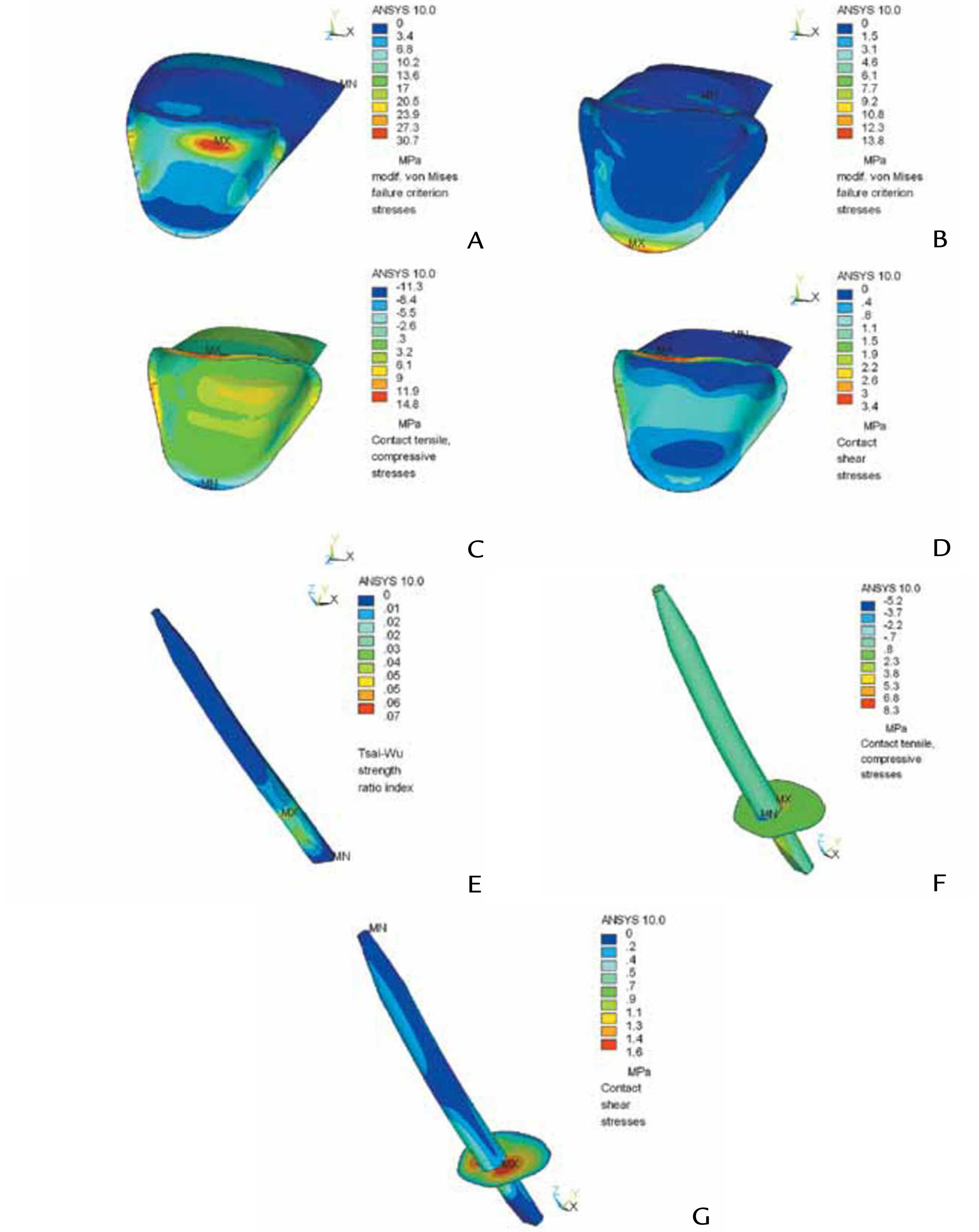
The mvM stress distribution in the tooth with a cast NiCr post (model CPNi) was similar to that in the tooth with an FRC post (model FP), but the values were reduced. The maximum mvM stresses of 23 MPa occurred at the gingival edge of the ceramic crown (Fig. 5, A) (Table II). In the resin cement, at the palatal finish line, mvM stresses reached 12.6 MPa (Table II). The highest contact tensile stresses (3 MPa) were found in the same location (Table III). The concentration of the maximum equivalent vM stresses (64.8 MPa) occurred in the core-metal post junction under oblique loading (Fig. 5, B) (Table II). Around the post in cement, the highest mvM stresses were equal to 6.2 MPa (Table II). Contact tensile stresses (4.8 MPa) and contact shear stresses (0.9 MPa) were concentrated around the core-dentin bond (Fig. 5, C and D) (Table III). Under the axial load, mvM stresses

TABLE V. Maximum values of contact tensile and shear stresses in luting cement-dentin adhesive interface in models of teeth with various restorations, under vertical load (MPa)

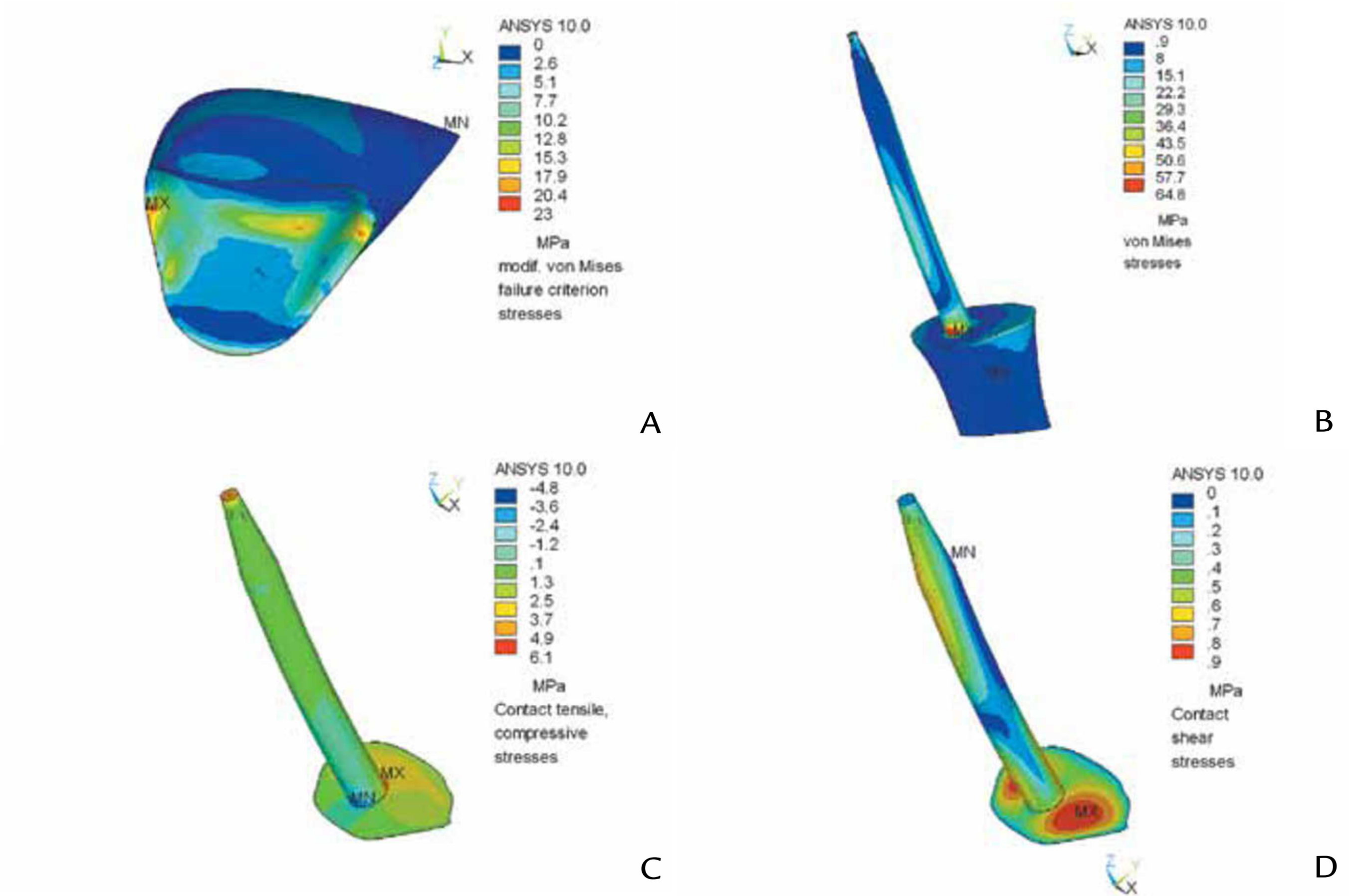
Model Symbol	Central Incisor Model	Under Crown		Around Post	
		Tensile Stress (MPa)	Shear Stress (MPa)	Tensile Stress (MPa)	Shear Stress (MPa)
CC	Tooth with ceramic crown	2.0	2.7	–	–
FP	Tooth with FRC post	2.1	3.1	0.5	0.2
CPAu	Tooth with gold cast post	1.9	2.1	0.6	0.4
CPNi	Tooth with NiCr cast post	1.8	2.0	0.7	0.6



3 Distribution of stresses of modified von Mises failure criterion under oblique load in: A, enamel of intact central incisor (model IT); B, dentin of intact central incisor (model IT); C, dentin of central incisor with FRC post (model FP); D, dentin of central incisor with cast CPNi post. Highest values of mvM stresses are marked in red color; MX denotes maximum value.



4 Distribution of stresses in different materials of tooth model with FRC post (FP model) under oblique load: A, Distribution of mvM stresses in ceramic crown supported by FRC post and core. B, Distribution of mvM stresses in luting resin cement between ceramic crown and dentin. C, Compressive and tensile contact stresses distribution in cement-dentin interface under ceramic crown. D, Shear contact stresses distribution in adhesive cement-dentin interface under ceramic crown. E, Distribution of index Tsai-Wu ratio in FRC post. F, Compressive and tensile contact stresses distribution in cement-dentin interface around FRC post. G, Shear contact stresses distribution in cement-dentin interface around FRC post. Highest values of mvM stresses, index Tsai-Wu ratio, contact compressive stresses, and shear stresses are marked in red color; MX denotes maximum value. Highest contact tensile stresses are marked in dark blue color; MN denotes maximum value.



5 Distribution of mvM stresses in different materials of tooth model with cast NiCr post (CPNi model) under oblique load: A, Distribution of mvM stresses in ceramic crown supported by cast post and core. B, Distribution of mvM stresses in cast post. C, Compressive and tensile contact stresses distribution in adhesive cement-dentin interface around cast post. D, Shear contact stresses distribution in adhesive cement-dentin interface around cast post. Highest values of mvM stresses, contact compressive stresses, and shear stresses are marked in red color; MX denotes maximum value. Highest contact tensile stresses are marked in dark blue color; MN denotes maximum value.

around the post were lowest (Table V).

The values of mvM stresses and contact stresses in the tooth with a cast gold post (model CPAu) were slightly higher than in CPNi model, except for tensile and shear contact stresses around the gold cast post under the vertical load (Tables II-V). von Misses stresses were 40% to 49% lower in the gold post than in the NiCr post.

DISCUSSION

It follows from the analyses performed in this study that the use of posts caused a 21% to 25% reduction in stresses in dentin under an oblique load, whereas the use of posts did not cause major changes in stresses in dentin under a vertical load (Tables II and IV). For the tooth with an FRC post, the distribution and values of stresses were similar to those observed in the tooth with a ceramic crown only. However, in tooth structures with cast posts, lower stresses were recorded than in teeth with FRC posts. The higher the elastic modulus of the post material, the lower the stresses that occurred in the dentin of the restored teeth. This finding is in agreement with the results of FEA studies performed by other authors,[9,10,11,12] which showed that the use of posts made from rigid materials causes a decrease in stresses in tooth tissue, especially in the cervical dentin. This was confirmed by the strength tests conducted by Qing et al[23] and Bonfante et al,[26] in which teeth with metal posts failed when subjected to forces that were significantly higher than the force which fractured teeth with FRC posts. Furthermore, Kivanç et al,[22] Martínez-Insua et al,[24] and Marchi et al[25] showed that cast posts ensured better fracture resistance of teeth as compared to fiber-reinforced posts.

The stress values in posts depend on the elastic modulus of the post material.[5,16] The present study demonstrated that equivalent mvM stresses in the metal posts increased with the increasing elastic modulus of the post materials. The stresses were 11-12 times lower than the tensile strength of those materials (for gold, 36.8 MPa as compared to 457 MPa, and for NiCr alloys, 64.8MPa as compared to 710 MPa).[4,46] For the FRC post, the Tsai-Wu criterion recorded a value of 0.07 (the danger level for the material is a 1 ratio). According to these criteria, under physiological loads, there is no risk of damage being caused to posts, irrespective of the material of which they are made.

Contact tensile and shear stresses at the cement-dentin interface around cast posts under an oblique load were 10 times higher than under a vertical load. With regard to the oblique load, the more rigid the post, the lower the mvM stresses in the luting cement around it and the lower the contact stresses in the cement-dentin interface.

The maximum mvM stresses in ceramic crowns occurred in the areas where the forces were applied (on the incisal edge and the cingulum) and in the cervical margins of the restorations. The stresses did not exceed the tensile strength of leucite ceramics.[53] In the ceramic crown supported by an NiCr post and core, the stresses were 25% to 30% lower (depending on the tooth load) than in the crown with an FRC and composite resin core. Moreover, in the luting cement between the prosthetic crown and the metal core, mvM stresses were 9% to 18% lower than those of the composite resin core. The higher the elastic modulus of the core, the lower the mvM stresses in the prosthetic crown and the cement bonding it to tooth tissue, and the lower the contact stresses in the cement-dentin interface under the crown. These results agree with in vitro tests conducted by Forberger and Gohring[33]; according to their findings, the more rigid the crown core, the higher the fracture resistance and the better the marginal continuity of the crown under thermal cycling.

Similar 3-D FEA studies were conducted by Silva et al,[5] Bosichaian et al,[13] Lanza et al,[14] and Okada et al,[15] while 2-D FEA research was performed by others.[16,17,18] These authors concluded that FRC posts generated lower and more homogeneously distributed stresses under a load in dentin than metal posts. In those studies, stresses in entire models were analyzed. To evaluate the material strength, these authors used the von Mises criterion, which does not account for differences in the tensile and compressive strength of the materials. In the present study, the modified von Mises failure criterion for tissues, ceramics, and composite resin, and the Tsai-Wu failure criterion for FRC, were used. These criteria allow for an evaluation of material strength that more closely matches clinical situations. In the previously mentioned studies, contact stresses at the post-dentin interface were not studied. In these situations, bonded contact elements were applied around restorations on the cement-dentin bonding interface, which made it possible to calculate contact tensile, compressive, and shear stresses and visualize their distribution in the area of the cement-dentin interface around posts and cores.

It is impossible for a computer simulation to include all of the factors encountered in the oral environment. The applicability of FEA results to oral conditions depends, among other factors, on the similarity between the shape, dimensions, material data, load nature of the model, and the structures being analyzed. In the calculations made, the 3-D model of the incisor corresponded to the shape and dimensions of an average maxillary central incisor.[37] It was assumed that the materials used in the model were linearly elastic, homogeneous, and isotropic (except the fiber-reinforced posts), but they had different compressive and tensile strengths. The properties of tooth structures are not homogeneous and are anisotropic (dentin, due to its capillary morphological structure; enamel, due to its prismatic structure[39]; and periodontium, due to the ligament oriented in a different direction). There are not considerable differences in the elastic moduli of tooth structures, depending on the direction (for enamel, E_x=87.5; E_y=72.7).[39] However, glass fiber-reinforced posts exhibit strong orthotropic properties that have been considered in this research.[5,14] In the current study, the modulus of elasticity for the PDL used was 5×10^{-2} GPa, based upon the study by Rees and Jacobsen,[44] and, therefore, 3 orders of magnitude higher than the appropriate value of 1-3 $\times 10^{-5}$ GPa reported by Ruse.[45] These studies also assumed that the bonds between the restorations and tooth structures were ideal. Under clinical conditions, the bond strength of luting resin cement to tooth structures and restorations depends on many factors: the preparation of the restoration surfaces, etching, and the application of the bonding agent to enamel and dentin, as well as the polymerization of the luting cement. The post-dentin bonding can be degraded by contamination with water, blood, and saliva.[1]

CONCLUSIONS

Within the limitations of this study, the following conclusions were drawn:

1. Lower stresses of modified von Mises failure criterion were observed in tooth structures restored with metal posts than in teeth restored with FRC posts. Teeth restored with metal posts have a higher fracture resistance than those with FRC posts.
2. Equivalent stresses in metal and FRC posts were several times lower than the tensile strength of those materials. Under physiological loads, ideally cemented posts in incisors are not exposed to damage, regardless of whether they are made of metal or fiber-reinforced composite resin.
3. The use of a metal core with a high elastic modulus results in lower stresses in the ceramic crown, the luting cement, and the cement-dentin bonding interface under the crown, as compared with a composite resin core. Ceramic crowns supported by metal posts and cores are potentially more resistant to failure and exhibit greater integrity than those with composite resin posts and cores.

REFERENCES

1. Rosenstiel SF, Land MF, Fujimoto J. Contemporary fixed prosthodontics. 4th ed. St. Louis: Mosby; 2006. p. 336-8.
2. Al-Ansari A. Which type of post and core system should you use? Evid Based Dent. 2007;8:42.

3. Powers JM, Sakaguchi R. Craig's restorative dental materials. 12th ed. St. Louis: Mosby; 2006. p. 61, 65, 391.
4. Morris HF. Veterans Administration Cooperative Studies Project No. 147/242. Part VII: The mechanical properties of metal ceramic alloys as cast and after simulated porcelain firing. J Prosthet Dent 1989;61:160-9.
5. Silva NR, Castro CG, Santos-Filho PC, Silva GR, Campos RE, Soares PV, Soares CJ. Influence of different post design and composition on stress distribution in maxillary central incisor: Finite element analysis. Indian J Dent Res 2009;20:153-8.
6. Plotino G, Grande NM, Bedini R, Pameijer CH, Somma F. Flexural properties of endodontic posts and human root dentin. Dent Mater 2007;23:1129-35.
7. Lassila LV, Tanner J, Le Bell AM, Narva K, Vallittu PK. Flexural properties of fiber reinforced root canal posts. Dent Mater 2004;20:29-36.
8. Fernandes AS, Shetty S, Coutinho I. Factors determining post selection: a literature review. J Prosthet Dent 2003;90:556-62.
9. Pierrisnard L, Bohin F, Renault P, Barquins M. Corono-radicular reconstruction of pulpless teeth: A mechanical study using finite element analysis. J Prosthet Dent 2002;88:442-8.
10. Asmussen E, Peutzfeldt A, Sahafi A: Finite element analysis of stresses in endodontically treated, dowel-restored teeth. J Prosthet Dent 2005;94:321-9.
11. Okamoto K, Ino T, Iwase N, Shimizu E, Suzuki M, Satoh G, Ohkawa S, Fujisawa M. Three-dimensional finite element analysis of stress distribution in composite resin cores with fiber posts of varying diameters. Dent Mater J 2008;27:49-55.
12. Pegoretti A, Fambri L, Zappini G, Bianchetti M. Finite element analysis of a glass fibre reinforced composite endodontic post. Biomaterials 2002;23:2667-82.
13. Boschian Pest L, Guidotti S, Pietrabissa R, Gagliani M. Stress distribution in a post-restored tooth using the three-dimensional finite element method. J Oral Rehabil 2006;33:690-7.
14. Lanza A, Aversa R, Rengo S, Apicella D, Apicella A. 3D FEA of cemented steel, glass and carbon posts in a maxillary incisor. Dent Mater 2005;21:709-15.
15. Okada D, Miura H, Suzuki C, Komada W, Shin C, Yamamoto M, Masuoka D. Stress distribution in roots restored with different types of post systems with composite resin. Dent Mater J 2008;27:605-11.
16. Adanir N, Belli S. Stress analysis of a maxillary central incisor restored with different posts. Eur J Dent 2007;1:67-71.
17. Albuquerque RC, Polleto LT, Fontana RH, Cimini CA. Stress analysis of an upper central incisor restored with different posts. J Oral Rehabil 2003;30:936-43.
18. Nakamura T, Ohyama T, Waki T, Kinuta S, Wakabayashi K, Mutobe Y, Takano N, Yatani H. Stress analysis of endodontically treated anterior teeth restored with different types of post material. Dent Mater J 2006;25:145-50.
19. Maceri F, Martignoni M, Vairo GJ. Mechanical behaviour of endodontic restorations with multiple prefabricated posts: a finite-element approach. J Biomech 2007;40:2386-98.
20. Rosentritt M, Sikora M, Behr M, Handel G. In vitro fracture resistance and marginal adaptation of metallic and tooth-coloured post systems. J Oral Rehabil 2004;31:675-81.
21. González-Lluch C, Rodríguez-Cervantes PJ, Sancho-Bru JL, Pérez-González A, Barjau-Escribano A, Vergara-Monedero M, Forner-Navarro L. Influence of material and diameter of pre-fabricated posts on maxillary central incisors restored with crown. J Oral Rehabil 2009;36:737-47.
22. Kivanç BH, Alaçam T, Ulusoy OI, Genç O, Görgül G. Fracture resistance of thin-walled roots restored with different post systems. Int Endod J 2009;42:997-1003.
23. Qing H, Zhu Z, Chao Y, Zhang W. In vitro evaluation of the fracture resistance of anterior endodontically treated teeth restored with glass fiber and zircon posts. J Prosthet Dent 2007;97:93-8.
24. Martínez-Insua A, da Silva L, Rilo B, Santana U. Comparison of the fracture resistances of pulpless teeth restored with a cast post and core or carbon-fiber post with a composite core. J Prosthet Dent 1998;80:527-32.
25. Marchi GM, Mitsui FH, Cavalcanti AN. Effect of remaining dentine structure and thermal-mechanical aging on the fracture resistance of bovine roots with different post and core systems. Int Endod J 2008;41:969-76.
26. Bonfante G, Kaizer OB, Pegoraro LF, do Valle AL: Fracture strength of teeth with flared root canals restored with glass fibre posts. Int Dent J 2007;57:153-60.
27. Hayashi M, Takahashi Y, Imazato S, Ebisu S. Fracture resistance of pulpless teeth restored with post-cores and crowns. Dent Mater 2006;22:477-85.
28. Cormier CJ, Burns DR, Moon P. In vitro comparison of the fracture resistance and failure mode of fiber, ceramic and conventional post systems at various stages of restoration. J Prosthodont 2001;10:26-36.
29. Newman MP, Yaman P, Dennison J, Rafter M, Billy E. Fracture resistance of endodontically treated teeth restored with composite posts. J Prosthet Dent 2003;89:360-7.
30. Fokkinga WA, Kreulen CM, Vallittu PK. A structured analysis of in vitro failure loads and failure modes of fiber, metal and ceramic post-and-core systems. Int J Prosthodont 2004;17:476-82.
31. Goto Y, Nicholls JI, Phillips KM, Junge T. Fatigue resistance of endodontically treated teeth restored with three dowel-and-core systems. J Prosthet Dent 2005;93:45-50.
32. Hu S, Osada T, Shimizu T, Warita K, Kawawa T. Resistance to cyclic fatigue and fracture of structurally compromised root restored with different post and core restorations. Dent Mater J 2005;24:225-31.
33. Forberger N, Göhring TN. Influence of the type of post and core on in vitro marginal continuity, fracture resistance, and fracture mode of lithia disilicate-based all-ceramic crowns. J Prosthet Dent 2008;100:264-73.
34. Bolla M, Muller-Bolla M, Borg C, Lupi-Pegurier L, Laplanche O, Leforestier E. Root canal posts for the restoration of root filled teeth. Cochrane Database Syst Rev 2007;24:CD004623.
35. Jung R; A comparison of composite post buildups and cast gold-and-core buildups for the restoration of nonvital teeth after 5 to 10 years. Int J Proshodont 2007;20:63-69.
36. Zienkiewicz OC, Taylor RL, Zhu JZ. The finite element method: its basis and fundamentals 6th ed. Amsterdam: Elsevier-Butterworth-Heinemann; 2005. p. 103-28.
37. Nelson SJ, Ash MM Jr. Wheeler's dental anatomy, physiology and occlusion. 9th ed. St. Louis: Saunders; 2009, p. 99-105.
38. Shillingburg HT, Hobo S, Whitsett LD, Jacobi R, Bracket SE. Fundamentals of fixed prosthodontics. 3rd ed. Quintessence: Chicago; 1997. p.433-54.
39. Habelitz S, Marshall S, Marshall G, Balooch M. Mechanical properties of human dental enamel on the nanometre scale. Arch Oral Biol 2001;46:173-83.
40. Giannini M, Soares CJ, Carvalho RM. Ultimate tensile strength of tooth structures. Dent Mat 2004;20:322-9.
41. Craig RG, Peyton FA. Elastic and mechanical properties of human dentin. J Dent Res 1958;37:710-8.
42. Kinney JH, Marshall SJ, Marshall GW. The mechanical properties of human dentin: a critical review and re-evaluation of the dental literature. Crit Rev Oral Biol Med 2003;14:13-29.
43. Sano H, Ciucchi B, Matthews WG, Pashley DH. Tensile properties of mineralized and demineralized human and bovine dentin. J Dent Res 1994;73:1205-11.
44. Rees JS, Jacopsen PH. Elastic modulus of the periodontal ligament. Biomaterials 1997;18:995-9.
45. Ruse ND. Propagation of erroneous data for the modulus of elasticity of periodontal ligament and gutta percha in FEM/FEA papers: a story of broken links. Dent Mater 2008:24:1717-9.
46. Oilo G, Gjerdet NR. Dental casting alloys with a low content of noble metals: physical properties. Acta Odontol Scand. 1983;41:111-6.
47. Philips LN. Design with advanced composite materials. New York: Springer-Verlag; 1989. p.18.
48. Magne P, Perakis N, Belser U, Krejci I. Stress distribution of inlay-anchored adhesive fixed partial dentures: a element analysis of the influence of restorative materials and abutment preparation design. J Prosthet Dent 2002;87:516-27.
49. White SN, Yu Z. Compressive and diametral tensile strengths of current adhesive luting agents. J Prosthet Dent 1993;69:568-72.
50. Willems G, Lambrechts P, Braem M, Celis JP, Vanherle G. A classification of dental composites according to their morphological and mechanical characteristics. Dent Mater 1992; 8:310-19.
51. Eldiwany M, Powers J, George L. Mechanical properties of direct and post-cured composites. Am J Dent 1993;6:222-4.

52. Albakry M, Guazzato M, Swain M. Biaxial flexural strength, elastic moduli, and x-ray diffraction characterization of three pressable all-ceramic materials. J Prosthet Dent 2003;89:374-80.
53. Pröbster L, Geis-Gerstorfer J, Kirchner E, Kanjantra P. In vitro evaluation of a glass--ceramic restorative material. J Oral Rehabil 1997;24:636−45.
54. Fontijn-Tekamp FA, Slagter AP, Van der Bilt A, Van' T Hof MA, Witter DJ, Kalk W, Jansen JA. Biting and chewing overdentures, full dentures and natural dentitions. J Dent Res 2000;79:1519-24.
55. Kraus BS, Jordan RE, Abrams L. Dental anatomy and occlusion. Baltimore: Williams & Wilkins; 1969. p. 227.
56. De Groot R, Peters MC, De Haan YM, Dop G, Plasschaert AJ. Failure stress criteria for composite resin. J Dent Res 1987;66:1748-52.
57. Tsai SW, Hahn HT. Introduction to composite materials. Westport: Technomic Publishing; 1980. p. 276-81, 302-6.

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NOTEWORTHY ABSTRACTS OF THE CURRENT LITERATURE

Marginal bone loss with mandibular two-implant overdentures using different loading protocols: A systematic literature review

Ma S, Payne AG.
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Purpose. Mandibular two-implant overdentures opposing conventional complete maxillary dentures have been proposed as the standard for complete denture service. Monitoring marginal bone loss around implants is regarded as the most important criterion in determining the success of implants. The aim of this systematic literature review was to critically evaluate the literature on short- and long-term marginal bone loss associated with mandibular two-implant overdentures using different loading protocols.

Materials and Methods. The MEDLINE, EMBASE, and PubMed (using medical subject headings) databases were searched using the restriction of articles in English only. Other articles were identified from the reference lists of the articles found, as well as from early online articles. Reviewed studies were those on two oral implants supporting mandibular overdentures with different loading protocols. Marginal bone loss was evaluated as well as the validity of using marginal bone loss measurements for determining the success of implants.

Results. Twenty-five studies met the review criteria. Clinical studies involving conventional loading showed long-term results; however, early and immediate loading protocols were only in the short term. High success or survival rates of two implants supporting mandibular overdentures were reported, regardless of the loading protocol. A lack of standardization was revealed in the radiographic methods used for measuring marginal bone loss and the success criteria on which results were based. Long-term outcomes of the effect of different loading protocols on marginal bone loss were not found. Due to the wide methodologic variation among the included studies, it was difficult to compare data between studies or to determine long-term marginal bone loss patterns with this treatment. For conventional two-stage and one-stage loading protocols, the range of marginal bone loss seen in the first year was 0.2 to 0.7 mm and 0.0 to 2.0 mm, respectively. For early loading protocols, the range was 0.0 to 0.2 mm; immediate loading protocols saw a marginal bone loss of around 0.7 mm in the first year.

Conclusions. Short-term findings indicate that so far, there is no detrimental effect on marginal bone levels with early and immediate loading protocols. However, to recommend these protocols in the long-term for two implants supporting mandibular overdentures may be premature.

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