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A three dimensional finite element analysis for evaluation of stress and strain distribution in endodontically treated maxillary central incisor with two different post and core systems

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Abstract---Aim: To assess stress, and strain dissemination characteristics in root canal treated maxillary central incisors restored with two distinct dowel and core materials. Methodology: Five three-dimensional simulations of the central incisor in the maxilla were created with ANSYS (Canonsburg, PA) version 10. MODEL 1 represented a normal morphologic simulation of the incisor. MODEL 2 depicted the incisor with a pre-fabricated fiber-reinforced dowel with a glass ionomer core. The incisor of MODEL 3 consisted of the same pre-fabricated fiber post and composite core. MODEL 4 and MODEL 5 had pre-fabricated light-transmitting posts with a glass ionomer and a composite core, respectively. Each of these simulations was loaded in horizontal, vertical, and oblique directions with a load of 10N, 100N, and 50N, respectively. The resulting Von Mises stress and strain were determined. Results: Maximum stresses and strains were focused at the apex of the glass fiber reinforced post and were minimal in the middle section of the post, whereas maximum stresses and strains were mainly concentrated in the coronal region and were minimal in the middle portion of light-transmitting post. Conclusion: Pre-fabricated optical-transmitting dowel and composite core enhanced dentin stress and strain dispersion throughout various loading parameters.

Keywords---post-core, finite element analysis, Von mises stress, strain.

Introduction

Restorative dentistry frequently encounters the challenge of restoring endodontically treated teeth. Clinical evidence on pulpless tooth restorative procedures remains contentious and usually depends on ambiguous empirical literature[1,2]. The destruction of oro-dental structures as a consequence of caries, substantial tooth reduction, and trauma, along with physical alterations or dehydration in the dentin, is a primary cause of endodontically treated teeth losing their elasticity and fracture strength[3–6]. Posts are utilized to secure the core materials in situ in posterior dentition having mostly compressive masticatory pressures. However, when loaded transversely, as with anterior teeth, it is critical to properly analyze the flexural behavior of posts. Incisal stress, both in magnitude and angle, significantly influences the long-term success of central incisor restoration [7,8].

The prefabricated post and core systems seem to be among the most frequently used systems in endodontically treated teeth. Prefabricated posts are available in various metallic and non-metallic compounds and in predetermined dimensions[9,10]. The kind of post to select is governed by various factors, including the tooth's position in the arches, root morphology, tooth destruction extent, periodontium's health, occlusal stress, and the opposing dentition [11,12]. Two parameters significantly impact the mechanical properties of endodontically treated teeth restored with posts: interface characteristics and substance toughness [9,13].

Metal posts provide a high strength-to-weight ratio and a high retention rate. The disadvantages of these posts include compromised tooth profile (where prefabricated posts exceed available tooth structure), increased corrosive potential, poor aesthetics, and roots that are more prone to fracture due to metal posts' higher modulus of elasticity than dentin [9,12,14,15].

In 1990, fiber-reinforced posts were created to address concerns about stainless steel and titanium alloys. The fiber post has a modulus of elasticity equivalent to dentin (20 GPa) and is 5-10 times less stiff than high-modulus metal posts, allowing the post to absorb stress and avoid root fractures[16–18]. Additionally, they are corrosion resistant and have high tensile strength [19]. Fiber posts are attached to the tooth using an etchant, primer, adhesive, and resin composite method. With the post bonded to the tooth, the low modulus of elasticity of the post allows the fiber post and the tooth to flex together, dispersing any stresses put on the tooth and lowering the risk of root fractures significantly [18,20]. There is currently no consensus in the literature on which material or procedure is best for restoring endodontically treated teeth. The study's goal was to use finite element analysis to assess the stress and strain distribution patterns of a sound maxillary central incisor repaired with two different posts, two different cores, and a ceramic crown.

Methodology

The present study was conducted to assess and compare the various stress and strain dispersal patterns with two distinct post and core systems. Using standard dimensions, a three-dimensional model of the maxillary central incisor was designed for this study [TABLE 1] [21].

Design of finite element model

The spatial and morphological depiction of a post and core restored maxillary central incisor surrounded by appropriate anatomic structures was created using ANSYS version 10. This three-dimensional model was developed to simulate the architecture of a healthy maxillary central incisor, periodontium, and post system. Nonetheless, in order to simplify the design, the thickness of the luting cement and cementum was omitted [8,22].

Five three-dimensional models of the maxillary central incisor were created using ANSYS software. Each of these models was built using similar criteria, except that each model utilized a unique post and core material.
MODEL 1: The maxillary central incisor
MODEL 2: A maxillary central incisor that has been endodontically treated with a prefabricated fiber-reinforced post and a glass ionomer cement core.
MODEL 3: A maxillary central incisor that has been endodontically treated and fitted with a prefabricated fiber-reinforced post and composite core.
MODEL 4: A maxillary central incisor that has been endodontically treated and fitted with a prefabricated light-transmitting post and a glass ionomer cement core.
MODEL 5: A maxillary central incisor that has been endodontically treated and fitted with a prefabricated light-transmitting post and a composite core.

Material characteristics

The model assumed that all materials were analogous, equivalent, and linear elastic. Individual models were created by incorporating the values of Poisson's ratio and young’s modulus into the software [TABLE 2]. Every finite element simulation was subdivided into small elements connected by a network of discrete nodes. All models were connected using tetrahedral nodes with ten nodes and three degrees of freedom. To determine the maximal Von Mises stress within the model, the motion of each node was analyzed. Each model was surrounded by periodontium to simulate the clinical condition of an endodontically treated central incisor [9,23–25].

Loading criteria

All five models were loaded horizontally, vertically, and obliquely before Von Mises stress and strain were determined at various levels. A horizontal load of ten newtons (10N) was applied midway between the cervico-incisal aspect of the crown. A vertical force of a hundred newtons (100N) load was deployed to the crown's incisal edge, and fifty newtons (50N) load of oblique force was applied at a 45-degree angle to the long axis of the tooth.

Results

All five models were subjected to horizontal, vertical, and oblique loadings followed by evaluation and recording of Von Mises stresses and strains.

Stress and strain analysis

Model 1: Vertical loading resulted in a maximum Von Mises stress of 62 MPa incisally and minimal stress of 3.58 MPa at the mid-cervical area. However, when dentin was vertically loaded, the maximum stress of 11.20 MPa was observed in the proximal section of the incisal edge and the mid-cervical area. In contrast, minimum stress of 1.90 MPa was reported at the coronal midpoint of the central incisor [Table 3].

Model 2: The incisal edge witnessed a minimal Von Mises stress of 85 MPa and maximal stress of 406.47 MPa under horizontal and vertical loading, respectively. The core displayed maximum stress of 1.20 MPa when loaded horizontally in the center and minimum stress of 0.85 MPa when loaded vertically. The cervical dentin displayed maximal Von Mises stress of 511 MPa and minimal stress of 139.20 MPa under vertical and horizontal loadings, respectively. The fibre post exhibited a maximal Von Mises stress of 2.75 MPa when loaded vertically towards the apex and minimal stress of 1.24 MPa when loaded obliquely at the post's middle section [Table 3].

Model 3: Vertical loading at the mid coronal part of the incisor resulted in a maximal Von Mises stress of 404.84 MPa, while horizontal loading at the incisal area resulted in a minimum Von Mises stress of 85.50 MPa. The composite core demonstrated maximum stress of 2.34 MPa in the mid-core region and minimal stress of 1.35 MPa in the incisal area and near the cervical region when loaded vertically. The dentin displayed maximal stress of 609.93 MPa at the root dentin cervically and minimal stress of 138.61 MPa at the centre cervical part of the dentin under horizontal loading. The fiber post exhibited a maximal Von Mises stress of 2.36 MPa when loaded vertically toward the tooth apex and minimal stress of 1.29 MPa when loaded obliquely at the centre part of the post [Table 3].

Model 4: Vertical loading at the crown incisally resulted in a maximal Von Mises stress of 408 MPa, while horizontal force resulted in a minimal Von Mises stress of 85.97 MPa. The core displayed maximum stress of 1.10 MPa at the mid-core area and minimum stress of 0.87 MPa near the core's base when subjected to the vertical load. At the cervical region of the root dentin, it demonstrated maximal Von mises stress of 610 MPa under the vertical load and minimal stress of 139.59 MPa under the horizontal load. The fiber post exhibited a maximal Von Mises stress of 1.69 MPa when loaded horizontally at the coronal part and minimal stress of 0.89 MPa when loaded obliquely at the mid-radicular part [Table 3].

Model 5: Vertical loading incisally resulted in a maximal Von Mises stress of 406 MPa and horizontal loading resulted in a minimal Von Mises stress of 85.57 MPa. The core displayed maximal stress of 1.50 MPa when loaded horizontally in the mid-core area and minimum stress of 1.34 MPa when loaded obliquely at the core's base. Cervical part of dentin displayed maximal Von Mises stress of 509 MPa under vertical loading and minimal stress of 139.08 MPa under horizontal loading. The light transmitting post displayed maximal stress of 1.46 MPa when loaded horizontally at the coronal portion and minimal stress of 0.93 MPa when loaded obliquely toward the mid-radicular portion part [Table 3].

Discussion

A root fracture is an undesirable complication in the tooth rehabilitated with post and core [26]. In clinical practice, when a metal post and core with a high elastic modulus is utilized as an intraradicular post and core in endodontically treated teeth, vertical root fractures frequently occur, necessitating tooth extraction [26–28]. Nevertheless, in the recent past prefabricated fiber-reinforced posts have been utilized as a treatment option for endodontically treated teeth restoration. These posts have an elasticity close to dentin and are less rigid than other types of posts. Because the fibre post and tooth have a low modulus of elasticity, they can flex together, dispersing any stresses applied to the tooth and significantly minimizing the chance of root fractures [29,30].

Furthermore, numerous dental materials have been used in core augmentation procedures. According to da Fonseca GF et al., developments in composite materials and the development of enamel-dentin bonding processes have reflected a shift toward more conservative techniques [23,31–33]. Glass ionomer cements with novel compositions have substantially increased their application possibilities, most notably for the cermets that can be utilised for building up cores in restoration for endodontically treated teeth [23,33]. According to E.C. Combe and colleagues[31], the development of resin-modified glass ionomer cement has expanded material selection alternatives. Many dentists use glass ionomers and cermet in core build-up operations due to their chemical adherence to enamel and dentin and release fluoride with anti-cariogenic properties [32].

Stress, like interfaces, concentrates in places with heterogeneous material distributions, as previously mentioned by Roberto Sorrentino and colleagues[8]. The interfaces among materials with varying viscoelastic moduli are the primary area of concern in various restorative systems, as discrepancies in stiffness affect load distribution. In the oral environment, restorative systems are vulnerable to fatigue stress, particularly when stresses less than the yield strength of the restorative materials are continuously exerted. Nonetheless, such cycle stress can create microcracks, which can result in the failure of restorative systems. These microcracks occur in locations of increased stress and decreased local strength. Under static and fatigue loading conditions, systems inherently exhibit areas of maximal stress concentration and similar fatigue patterns. The current study's findings indicate that the biomechanical and physical characteristics of the post and core material influenced the location of concentration areas as well as the magnitude of stress and strain at the dentine/post-core junctions [8,26,34].

Using FEA, this study gave information on the effect of post-core material on the biomechanical behavior of an endodontically treated tooth. On the other hand, a computer simulation cannot account for all of the variables present in the oral environment. Direct comparisons between FEA results and clinical outcomes should be made with caution because the tubular morphologic pattern of dentine and the crystalline structure of enamel prisms indicate that the properties of tooth structures are anisotropic and inhomogeneous[18,35], whereas all structures in this analysis were assumed to be isotropic, homogeneous, linearly elastic, and appropriately bonded.

Conclusions

1. Von Mises stresses & strains were mainly centered at the cervical dentin.
2. Three-dimensional models of endodontically treated teeth restored with light-transmitting post and composite core exhibited the least stress compared to other systems.
3. Restoration of endodontically treated anterior tooth with light-transmitting fiber post can be preferred instead of conventional fiber-reinforced post system because of better curing abilities.
4. Restoration of endodontically treated anterior tooth with the composite core can be a superior choice to glass ionomer core as it exhibits better stress distribution patterns.

Competing interests

The authors declare no competing interests.

Tables and figures

Table-1: Average dimensions of endodontically treated maxillary central incisor and post system

Crown	
Clinical Crown Length	10.5mm
Mesio-Distal width incisally	8.5mm
Mesio-Distal width cervically	7mm
Facio lingual width incisally	7mm
Facio lingual width cervically	6mm
Root	
Average root Length	13mm
Total tooth length	23.5mm
Concavity of crown interproximally (Col area)	3.5 mm(height)
Gutta percha	4 mm with a conical Configuration
Average post length	9 mm with a parallel side configuration
Core Height	7mm(tapering Configuration of 2-5 degree)
Periodontal ligament thickness	0.2mm

Table-2: Properties of tooth and materials used in the finite element analysis

	Young's Modulus (GPa)	Poisson's Ratio
Enamel	41.0	0.31
Dentin	18.6	0.31
Periodontal Ligament	68.9	0.45
Cortical Bone	13.7	0.30
Spongy Bone	1.37	0.30

Gingiva	19.6	0.30
All Ceramic Crown	120	0.28
Guttapercha	0.69	0.45
Resin cement (post)	8.0	0.30
Cement (crown)	22.4	0.25
Fiber post	40	.26
Light transmitting post	20	.26
Composite core	12	.30
Glass ionomer cement core	5.4	.30

Table -3 Von Mises Stress & Strain Values (MPa)

MODEL		POST	CORE	POST (μ)	CORE (μ)	DENTIN		BONE STRESS		BONE STRAIN		VON MISES	
						STRESS	STRAIN	CANCELLOUS	CORTICAL	CANCELLOUS	CORTICAL	STRESS	STRAIN
MODEL-1	Horizontal					1.90	107 μ	.944	13.006	777μ	.0010	3.58	.001
	Vertical					11.20	576 μ	4.57	88.65	.002	.0048	62	.004
	Oblique					3.62	276 μ	3.09	40.62	.002	.0029	31.957	.003
MODEL-2	Horizontal	2.44	1.20	61.2	225	139.20	.0083	5.09	52	.003	.0038	85	.015
	Vertical	2.75	.859	69.0	162	511	.036	15.55	159.35	.011	.0126	406.47	.952
	Oblique	1.24	.95	31.1	177	406.33	.023	8.49	78.9	.006	.0058	259	.050
MODEL-3	Horizontal	1.65	2.34	58.6	138	138.61	.008	5.09	52.54	.003	.0038	85.509	.015
	Vertical	2.36	1.35	59.1	113	609.93	.035	15.61	169.00	.011	.0126	404.83	.095
	Oblique	1.29	1.35	32.6	113	402.79	.023	8.50	78.89	.006	.0058	256.59	.050
MODEL-4	Horizontal	1.69	1.10	84.6	206	139.59	.008	5.09	52.5	.003	.0038	85.974	.015
	Vertical	1.48	.87	74.2	165	610	.036	15.53	159.39	.011	.0126	408.18	.095
	Oblique	.89	.94	44.6	175	406	.023	8.507	79.04	.006	.0058	258.8	.050
MODEL-5	Horizontal	1.46	1.50	73.4	125	139.08	.008	5.0	52.59	.003	.0038	85.57	.015
	Verti	1.2	1.3	60.	11	509	.035	15.61	158.9	.011	.0126	406.6	.094

	cal	0	4	3	3				9			9	
	Oblique	.93	1.34	46.8	112	402.44	.023	8.51	79.05	.006	.0058	256.1	.049

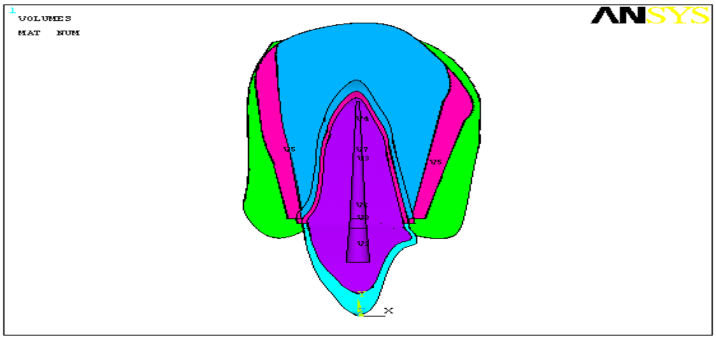

Figure 1 : Sound maxillary central incisor

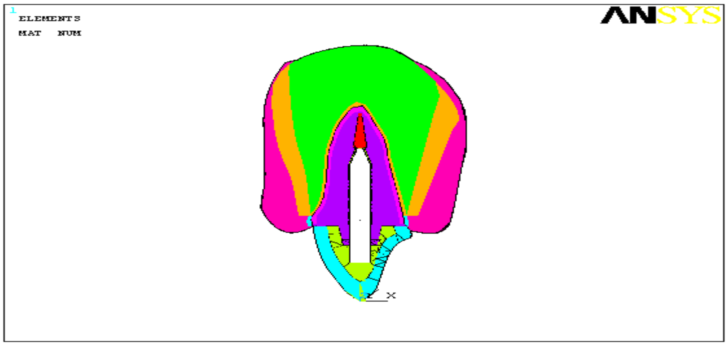

Figure 2 : Central incisor with light transmitting post and composite core build up

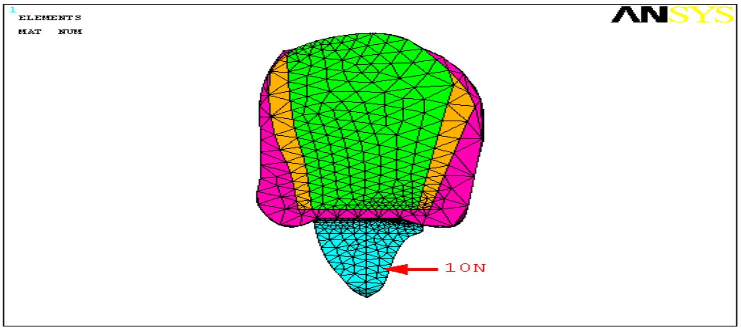

Figure 3 : Horizontal force

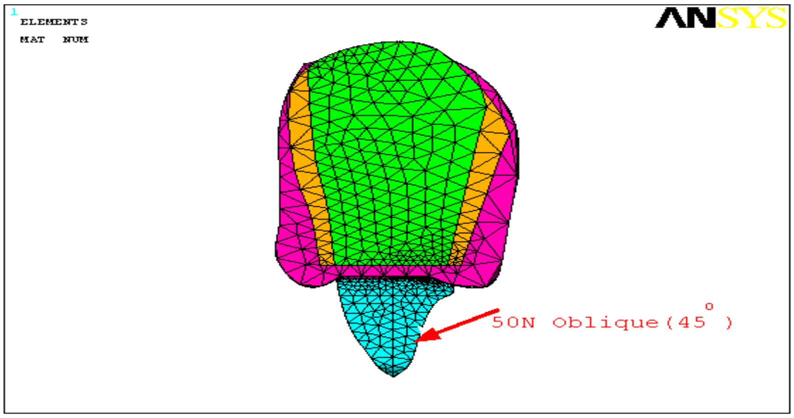

Figure 4 : Oblique force

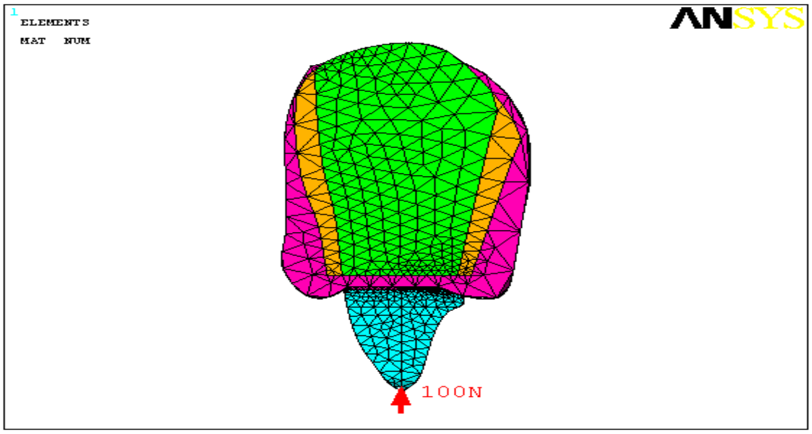

Figure 5 : Vertical force

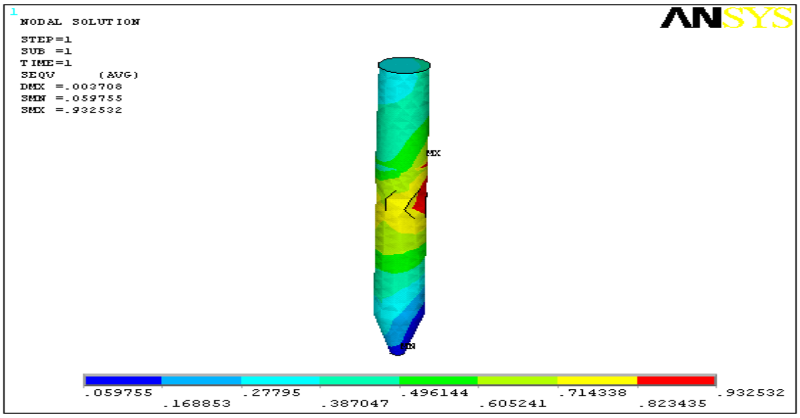

Figure 6 : Minimum stress in light transmitting post under oblique loading

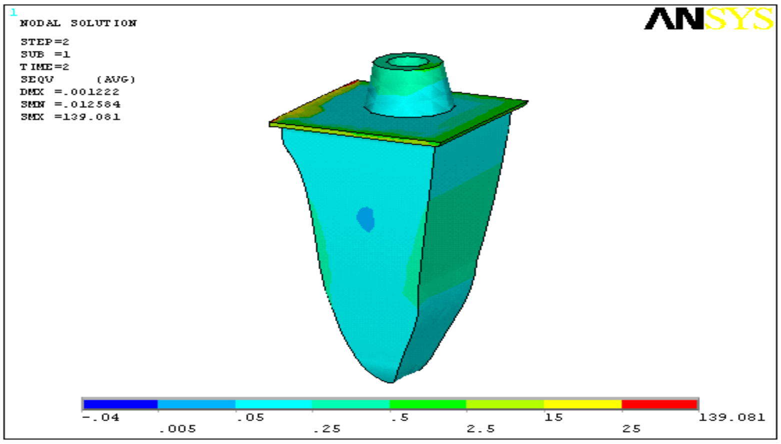

Figure 7 : Minimum stress in dentin under horizontal loading in Model 5

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