BASIC RESEARCH – TECHNOLOGY

Fracture Resistance and Biomechanical Behavior of Retreated Teeth Obturated with Different Sealers: Combined Laboratory Testing and Finite Element Analysis

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ABSTRACT

Introduction: This study evaluated the effect of different sealers on fracture resistance of retreated mandibular premolars and characterized their biomechanical behavior using three-dimensional finite element analysis (FEA). **Methods:** One hundred twenty-four single-rooted premolars were instrumented and initially obturated with AH Plus. Twelve teeth with intact fillings served as positive controls, and 12 retreated but unfilled teeth served as negative controls. The remaining samples were retreated and randomly assigned to 5 sealer groups ($n = 20$): AH Plus, GuttaFlow Bioseal, TotalFill BC, BioRoot RCS, and NeoSealer Flo. After thermocycling, fracture resistance was tested under 45° oblique loading. Corresponding micro-computed tomography–based FEA models were generated to compare von Mises stress distributions with and without a simulated periapical lesion. **Results:** Fracture resistance differed significantly among groups ($P < .001$). The negative control showed the lowest resistance, whereas the positive control exhibited the highest values ($P < .05$). No statistically significant differences were observed among the experimental sealer groups ($P > .05$). FEA demonstrated distinct stiffness-dependent patterns: NeoSealer Flo and TotalFill BC concentrated stresses within the sealer, whereas limiting dentinal stress; GuttaFlow Bioseal transmitted greater stresses to dentin; AH Plus and BioRoot RCS showed intermediate responses. **Conclusions:** In retreatment conditions, sealer type influences internal stress distribution even when fracture resistance values are comparable. Bioceramic sealers with higher elastic modulus may reduce dentinal stress and enhance biomechanical compatibility. Clinicians should consider not only biological performance but also mechanical compatibility when selecting sealers to support long-term structural preservation of retreated teeth. *(J Endod 2026;■:1–9.)*

SIGNIFICANCE

Bioceramic-based sealers with higher stiffness may help reduce dentinal stress in retreated premolars by concentrating functional loads within the sealer. This biomechanical advantage could support long-term structural preservation even when overall fracture resistance appears similar among different sealers.

KEY WORDS

Endodontic retreatment; calcium silicate–based sealer; fracture resistance; finite element analysis; biomechanical behavior

Root canal treatment aims to eliminate intraradicular microorganisms and prevent reinfection by achieving a three-dimensional seal with biocompatible, impervious materials[1,2]. Primary treatment demonstrates high success rates of 86%–98%[3], assessed by clinical and radiographic criteria such as absence of symptoms, resolution of periapical inflammation, and radiographic repair with re-establishment of the lamina dura[4].

When infection or procedural complications persist and the tooth remains periodontally sound and restorable, nonsurgical retreatment or apical surgery may be indicated[5]. The decision depends on patient- and tooth-related factors[6]. Although results vary across studies, nonsurgical retreatment generally offers superior long-term outcomes and is preferred in most cases[5,7,8]. The goal of retreatment is complete removal of filling materials and the re-disinfection to the apical foramen to

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TABLE 1 - Mechanical Properties of Dental Tissues and Materials Used in the FEA

Material	Elastic modulus (E) (MPa)	Poisson ratio (m)
Dentin	18600	0.31
Enamel	41000	0.31
Gutta-percha	140	0.45
Periodontal ligament	0.0689	0.45
Cortical bone	13700	0.30
Trabecular bone	1370	0.30
Cementum	8200	0.31
Lesion	0.69	0.45
Flowable composite	11530	0.31
Resin composite	24494	0.31
BioRoot RCS	3200	0.33
AH Plus	300	0.30
NeoSealer Flo[a]	40000	0.20
Endosequence BC Sealer	18150	0.43
GuttaFlow Bioseal[a]	15	0.30

FEA, finite element analysis.
[a]Value provided by manufacturer. Remaining material properties were compiled from relevant peer-reviewed publications[15-20].

enable periradicular healing[9]. However, reshaping can remove additional dentin, weakening the root and predisposing it to fracture. Sealers thus play a crucial role, as gutta-percha lacks adhesive bonding. Epoxy-based sealers remain the reference standard for their stability, low solubility, and good bonding, while calcium silicate–based sealers offer potential advantages in bonding and bioactivity[10,11]. Calcium silicate–based sealers are often referred to as "bioceramic" in the endodontic literature, a term that broadly describes their inorganic composition rather than a distinct material class. Hydrophilic calcium silicate–based sealers further interact with dentinal moisture to form hydroxyapatite, potentially enhancing structural integrity[12]. Yet, evidence linking these interfacial interactions to fracture resistance after retreatment remains limited.

This study therefore compared the effects of current-generation root canal sealers on fracture resistance of retreated teeth and analyzed their biomechanical behavior using three-dimensional finite element analysis (FEA). It was hypothesized that new-generation sealers would enhance fracture resistance and produce a more uniform dentinal stress distribution compared with conventional formulations.

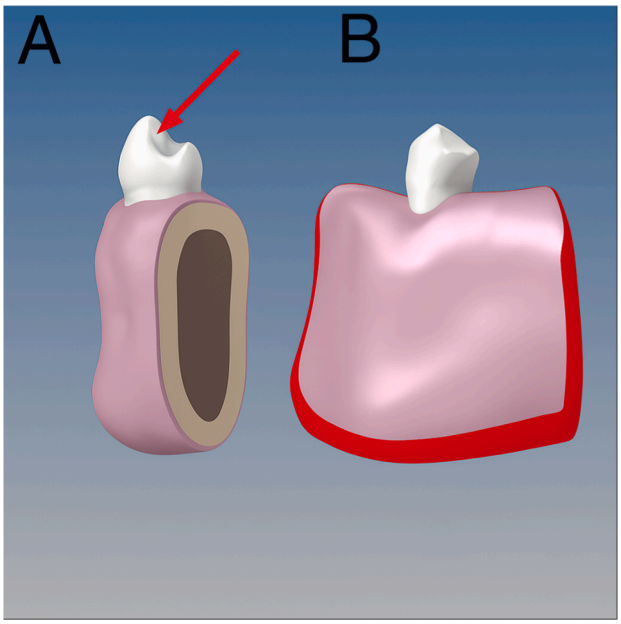

FIGURE 1 – Three-dimensional finite element model showing (*A*) the oblique loading configuration, applied force direction, and a 300 N load on the crown, and (*B*) fixed boundary constraints at the mesial and distal aspects of the root.

MATERIAL AND METHODS

This *in vitro* study evaluated fracture resistance of retreated mandibular premolars filled with different root canal sealers and corresponding stress behavior using FEA. The protocol was approved by the institutional ethics committee (Approval No.164073).

Sample Selection and Standardization

One hundred twenty-four freshly extracted mandibular premolars with single straight canals, intact roots, and fully formed apices

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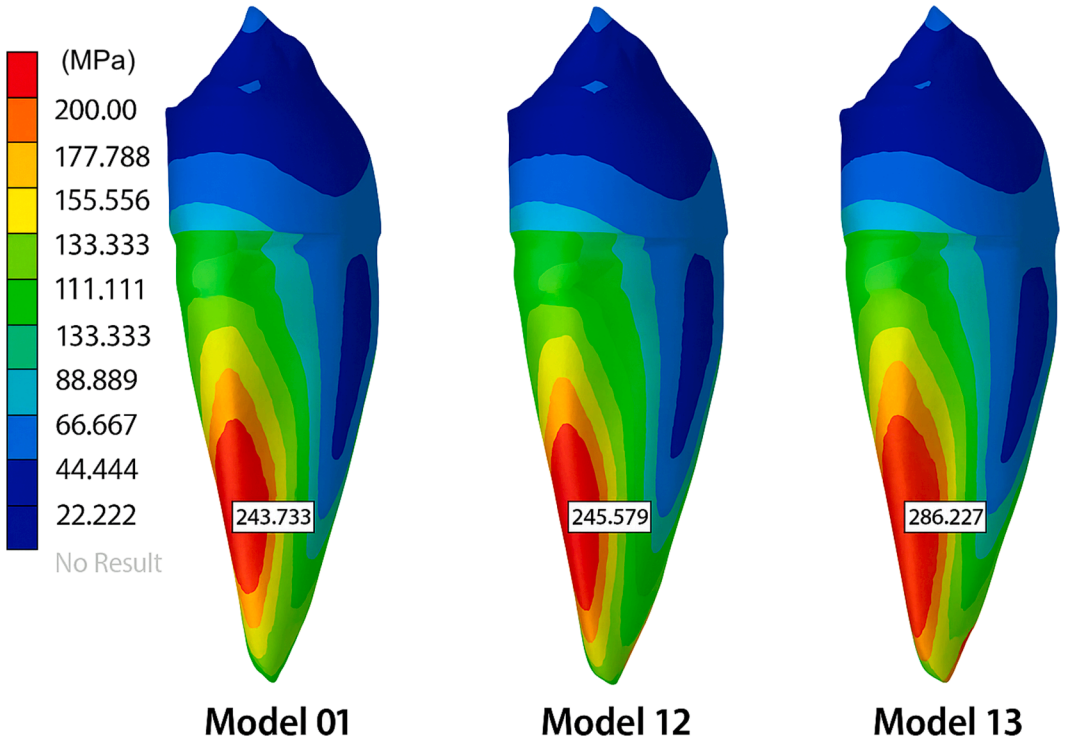

FIGURE 2 – Dentin von Mises stress distributions for Model 01 (positive control group), Model 12 (negative control group – without lesion), and Model 13 (negative control group – with lesion) under standardized loading conditions. Stress intensity is visualized using a global von Mises scale ranging from 0 to 200 MPa, demonstrating progressive increases in stress concentration from the intact control to the lesion-present model.

were included. Teeth with cracks, caries, restorations, resorption, calcification, or multiple canals were excluded. Dimensions were standardized (21 ± 1 mm length; ±20% root width). Specimens were stored in 0.1% thymol solution until use.

Primary Treatment and Retreatment

Canals were prepared to size 40/.04 with sodium hypochlorite (NaOCl) irrigation and obturated with AH Plus and gutta-percha using lateral compaction. After 2 weeks of storage (37 °C, humid conditions), 12 teeth served as positive controls. Remaining specimens were retreated with rotary instruments without solvents, irrigated with NaOCl, and re-instrumented to size 50/.04. Filling removal was verified radiographically. Final irrigation was NaOCl, ethylenediaminetetraacetic acid, and saline.

Experimental Groups

After retreatment, specimens were randomized into 2 control groups and 5 experimental sealer groups.

- Positive control (n = 12): size 40/.04, AH Plus
- Negative control (n = 12): size 50/.04, unfilled.
- AH Plus (epoxy resin–based sealer; lateral compaction)
- GuttaFlow Bioseal (silicone-based sealer containing bioactive glass; single-cone)
- TotalFill BC (calcium silicate–based sealer; single-cone)
- BioRoot RCS (calcium silicate–based sealer; lateral compaction)
- NeoSealer Flo (calcium silicate–based sealer; single-cone)

Access cavities were restored with an adhesive composite resin. Randomization was computer-generated, and the examiner recording fracture loads was blinded to group allocation.

TABLE 2 - Descriptive Statistics for Fracture Resistance (N) by Group: Median (IQR) and Minimum–Maximum

	Median	IQR	Min	Max
BioRoot RCS	**188.3**	**105.0**	**103.9**	**311.4**
GuttaFlow Bioseal	180.2	76.2	87.9	366.5
NeoSealer Flo	199.5	117.4	83.6	466.2
TotalFilL BC	196.7	153.6	70.7	492.2
AH Plus	162.7	56.7	63.4	326.0
Negative control	90.0	52.1	20.8	127.1
Positive control	340.6	168.7	222.1	465.3

IQR, interquartile range; N, Newtons.

Periodontal Ligament Simulation and Thermocycling

Root surfaces were coated with wax and embedded in self-curing acrylic resin blocks. After polymerization, the wax was removed and the space was filled with light-body silicone to simulate the periodontal ligament. Specimens were stored under humid conditions and thermocycled 5,000 cycles between 5 °C and 55 °C.

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TABLE 3 - Multiple Comparisons of Fracture Resistance among Groups (Dunn–Bonferroni)

	BioFoot RCS	GuttaFlow	NeoSealer Flo	BC sealer	AH Plus	Negative control	Positive control
BioRoot RCS	—	1.00	1.00	1.00	1.00	$P < .05$*	$P < .05$*
GuttaFlow Bioseal	1.00	—	1.00	1.00	1.00	$P < .05$*	$P < .05$*
NeoSealer Flo	1.00	1.00	—	1.00	1.00	$P < .001$*	$P > .05$
BC sealer	1.00	1.00	1.00	—	1.00	$P < .001$*	$P > .05$
AH Plus	1.00	1.00	1.00	1.00	—	$P < .05$*	$P < .05$*
Negative control	$P < .05$*	$P < .05$*	$P < .001$*	$P < .001$*	$P < .05$*	-	$P < .001$*
Positive control	$P < .05$*	$P < .05$*	$P > .05$	$P > .05$	$P < .05$*	$P < .001$*	—

Note: Overall group comparison was performed using the Kruskal–Wallis test (H[6] = 45.1, $P < .001$; $\varepsilon^2 = 0.33$).
Post hoc pairwise comparisons were conducted using two-sided Dunn tests with Bonferroni adjustment.
*Indicates statistically significant pairwise differences after Dunn–Bonferroni correction ($P < .05$).

Fracture Resistance Testing

Each specimen was mounted in a universal testing machine, and a compressive load was applied at 45° to the buccal cusp using a metallic loading tip with a rounded contact surface at a crosshead speed of 1 mm/min until fracture. Maximum fracture load (N) was recorded, and failures were classified as repairable (above the cemento-enamel junction) or irreparable (below cemento-enamel junction). Each tooth was tested once.

FEA

A representative premolar was scanned by micro-computed tomography at sizes 40/.04 taper and 50/.04 taper to simulate retreatment. Segmented datasets were converted to geometric models, meshed, and analyzed using a commercial software. The model included enamel, dentin, cementum (0.2 mm), periodontal ligament (0.2 mm), lamina dura (0.3 mm), and a composite coronal build-up. Bone geometries were obtained from an anatomical dataset. Root fillings were modeled according to obturation technique using reported volume fractions for gutta-percha, sealer, and voids[13]. A periapical lesion was simulated as an apical radiolucency[14].

All material interfaces, including the dentin–sealer and sealer–gutta-percha interfaces, were assumed to be perfectly bonded, representing an idealized interfacial condition. Thirteen finite element models (positive control, 5 sealer groups with and without simulated periapical lesions, and 2 negative controls) were analyzed under the same oblique loading conditions described above. Maximum von Mises stresses were extracted on an element-averaged basis from predefined regions of interest located in the apical and middle thirds of radicular dentin and sealer materials for intergroup comparison.

TABLE 4 - Fracture Mode Distribution by Experimental Group (Repairable vs. Irreparable)

Group	Repairable (n)	Irreparable (n)	Total (n)	Repairable (%)	Irreparable (%)
Positive control	4	8	12	33.3	66.7
Negative control	2	10	12	16.7	83.3
AH Plus	7	13	20	35.0	65.0
GuttaFlow Bioseal	11	9	20	55.0	45.0
BioRoot RCS	5	15	20	25.0	75.0
NeoSealer Flo	6	14	20	30.0	70.0
BC sealer	6	14	20	30.0	70.0

Notes: Chi-square analysis showed no significant association between experimental group and fracture mode ($\chi^2 = 6.60$, df = 6, $P > .05$). Cramer's V = 0.23 indicates a small effect size.

Material Properties

All materials were assumed to be linearly elastic, homogeneous, and isotropic based on previously published literature and manufacturer data (Table 1)[15-20].

Models were discretized using tetrahedral solid elements in HyperMesh (Altair Engineering), yielding approximately 1.3–1.4 million elements per model, and solved using OptiStruct. A static linear analysis was performed by applying a 300-N oblique load at 45° to the palatal incline of the buccal cusp (Fig. 1*A*), distributed across contact nodes. Mesial and distal root surfaces were constrained to prevent rigid-body motion (Fig. 1*B*).

Stress distributions in dentin, periodontal ligament, and sealer materials were evaluated using von Mises stress to enable consistent comparative assessment across materials, while maximum principal stresses were calculated for cortical and trabecular bone. Although dentin is not a ductile material, von Mises stress was used as a scalar metric to enable consistent intergroup comparison of stress distributions rather than as a failure criterion.

Maximum stress values (MPa) were obtained as element-averaged values within predefined regions of interest located in the coronal, middle, and apical thirds of root dentin and root filling materials, rather than from single nodal peaks, to reduce numerical artifacts and allow meaningful intergroup comparison.

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics (version 26.0; IBM Corp, Armonk, NY, USA). Fracture-resistance data were non-normally distributed by the Shapiro–

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TABLE 5 - Dentinal von Mises Stress—Element-Averaged Maximum per Model (FEA)

Model	von Mises (MPa)
Model 01	243.7
Model 02	245.6
Model 03	286.2
Model 04	245.4
Model 05	286.0
Model 06	244.7
Model 07	285.2
Model 08	245.6
Model 09	286.2
Model 10	243.6
Model 11	284.1
Model 12	245.6
Model 13	286.2

FEA, finite element analysis.
Note: A static 300-N oblique load was applied at 45°. Reported values represent element-averaged maximum von Mises stresses extracted from predefined regions of interest in the apical and middle thirds of radicular dentin, rather than isolated nodal peak values. Descriptions of Models 1–13 are provided in Supplemental Table S1.

Wilk test and are reported as median and interquartile range (IQR). Group comparisons were conducted with the Kruskal–Wallis test, followed by Dunn–Bonferroni post hoc tests when indicated, with $\alpha = 0.05$.

Fracture-mode distributions (repairable vs. irreparable) were analyzed using the chi-square test of independence or Fisher's exact test when expected cell counts were <5, and effect sizes were expressed as Cramer's V. FEA outputs were evaluated descriptively; no inferential statistics were applied, and comparisons relied on qualitative and quantitative assessment of von Mises and principal-stress maps across models.

RESULTS

Fracture Resistance across Groups

Fracture-resistance values were non-normally distributed (Shapiro–Wilk) and are presented as median (IQR). Comparisons were conducted using Kruskal–Wallis test with Dunn–Bonferroni adjustment ($\alpha = 0.05$). Sample sizes were $n = 20$ for all sealer groups and $n = 12$ for controls. Three specimens were lost during initial retreatment and replaced; thereafter, no losses occurred. Median fracture-resistance values were highest in the positive control and lowest in the negative control, with intermediate values observed among the 5 sealer groups.

Overall differences were significant ($\varepsilon^2 = 0.33$, H(6) = 45.08, $P < .001$). The negative control was significantly lower than all other groups ($P < .05$). The positive control exceeded AH Plus, BioRoot RCS, and GuttaFlow Bioseal ($P \leq .014$) but did not differ from NeoSealer Flo or TotalFill BC ($P > .05$). No pairwise differences were detected among the sealer groups themselves (all $P > .05$). Maximum load findings paralleled the median results (Tables 2 and 3).

Fracture Mode Distribution

Fracture patterns did not differ significantly among groups ($\chi^2 = 6.598$, df = 6, $P = .359$; Cramer's V = 0.231). Irreparable failures predominated overall. The negative control exhibited the highest irreparable rate (83.3%), whereas GuttaFlow Bioseal showed the greatest proportion of repairable fractures (55.0%). The remaining sealers demonstrated intermediate distributions. Although differences were not statistically significant, elastomeric materials tended to exhibit more repairable failures (Table 4).

Stress Analysis by FEA

Stress distributions were quantified using von Mises stresses for ductile tissues and principal stresses for bone. The unfilled negative controls demonstrated the highest dentinal stress, and periapical lesions increased stress magnitude and shifted peak concentrations apically. Among filled models, dentinal stress inversely correlated with sealer modulus. NeoSealer Flo and TotalFill BC transferred lower stresses to dentin, while GuttaFlow Bioseal generated higher dentinal stress. AH Plus and BioRoot RCS showed intermediate behavior (Table 5; Figs. 2 and 3). Overall dentinal stress patterns for all models are provided in Supplemental Figure S1.

Intrasealer Stress Distribution

Intrasealer stresses increased with higher sealer modulus. Bioceramic sealers accumulated the greatest internal stress, whereas silicone-based GuttaFlow Bioseal showed the lowest intrasealer values. AH Plus demonstrated low-to-moderate internal stress with apical concentration. These trends were consistent across lesion and nonlesion conditions (Table 6).

Periodontal Ligament and Bone Response

Periodontal ligament stresses were comparable across models, and principal bone stresses showed no meaningful group differences. Material-dependent effects were therefore localized to the root–filling complex with minimal influence on supporting structures.

DISCUSSION

The present *in vitro* investigation evaluated 5 root canal sealers—AH Plus, BioRoot RCS, GuttaFlow Bioseal, TotalFill BC, and NeoSealer Flo—with respect to fracture resistance of retreated teeth and sealer-specific stress behavior using micro–computed tomography–based FEA. Canals left unfilled after retreatment exhibited the lowest fracture resistance, whereas primarily treated teeth showed the highest values, confirming that obturation reinforces residual dentin[21]. Among refilled, retreated groups, no statistically significant differences in peak fracture load were detected, indicating that, under standardized preparation and oblique loading, refilling per se provides comparable reinforcement regardless of sealer type, although the study was not powered for formal equivalence. FEA revealed a stiffness-dependent pattern of stress transfer: higher-modulus bioceramic sealers (NeoSealer Flo, TotalFill BC) retained a greater proportion of applied load within the sealer mass and reduced stress transmission to dentin, whereas the silicone-based GuttaFlow Bioseal transferred more stress to the root structure, and AH Plus and BioRoot RCS showed intermediate behavior[19,22,23]. These findings align with previous work demonstrating that materials with elastic moduli approximating dentin generate lower stress concentrations in surrounding tissues and enhance biomechanical compatibility[16,19,22,23].

The experimental protocol incorporated positive and negative controls, thermal aging, and oblique loading at 45° to simulate clinical masticatory forces, with failure defined as ≥10% load drop[24,25]. Within this framework, FEA demonstrated that increasing elastic modulus led to higher von Mises stresses within the sealer and lower stresses in dentin, with stress concentrations mainly in the apical and middle thirds[19]. Although dentinal von Mises stresses were comparable among sealer groups, distinct differences were observed in intrasealer stress distribution. NeoSealer Flo and TotalFill BC exhibited higher intrasealer stresses, whereas GuttaFlow Bioseal showed lower intrasealer stresses, consistent with greater stress transfer to radicular dentin. Accordingly, intrasealer stress values were interpreted comparatively as indicators of stress redistribution rather than as absolute predictors of sealer fracture, given that fracture thresholds for root canal sealers under complex multiaxial loading are not well established. Accordingly, bioceramic sealers absorbed and redistributed stresses within

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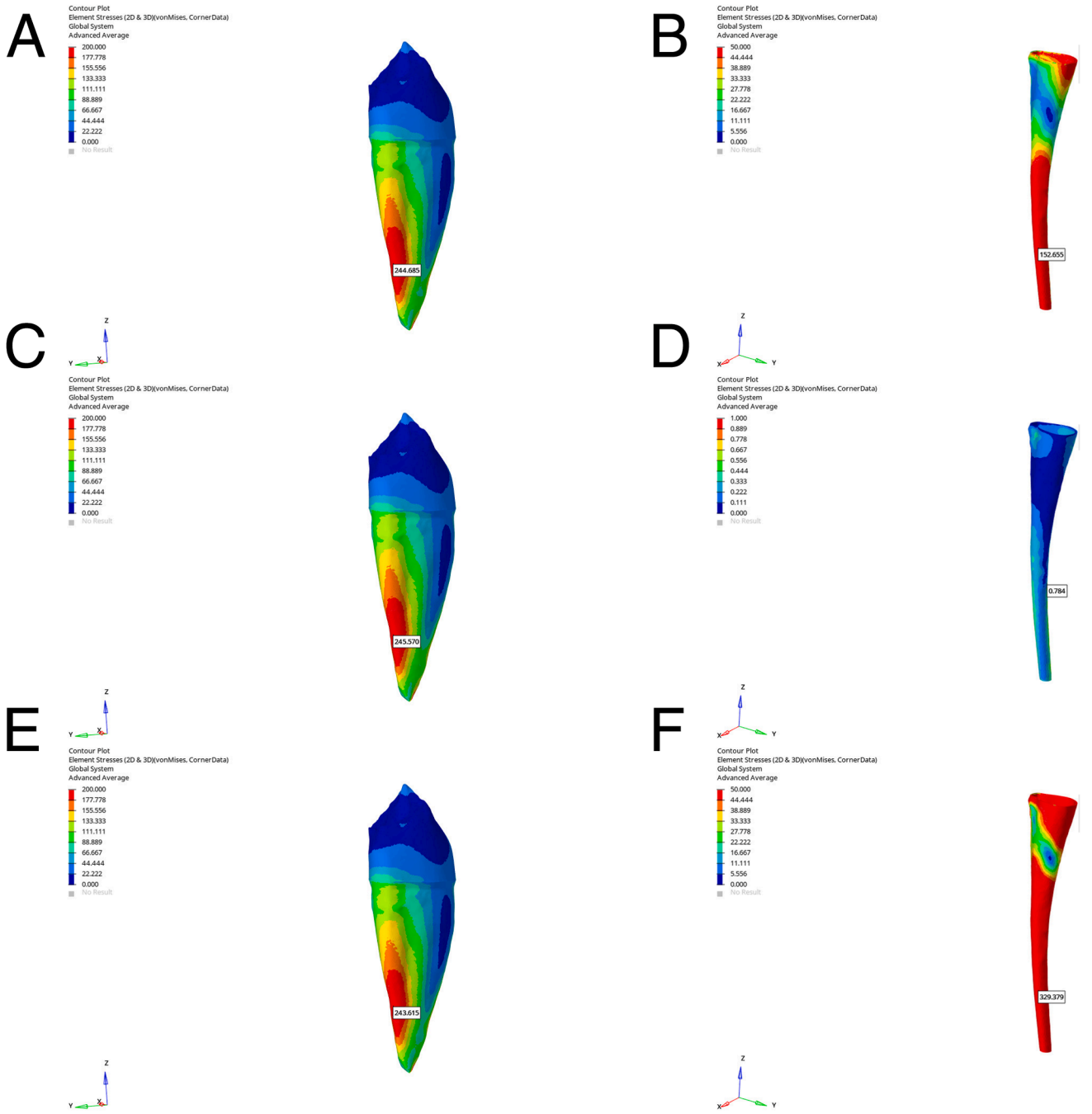

FIGURE 3 – Von Mises stress distribution under a 300-N oblique load applied at 45° for representative sealers with different elastic moduli. (*A* and *B*) TotalFill BC: stress distribution in radicular dentin (*A*) and sealer (*B*). (*C* and *D*) GuttaFlow Bioseal: stress distribution in radicular dentin (*C*) and sealer (*D*). (*E* and *F*) NeoSealer Flo: stress distribution in radicular dentin (*E*) and sealer (*F*). All panels share the same viewing orientation and color scale. Stress values represent element-averaged von Mises stresses extracted from predefined regions of interest rather than isolated nodal peaks.

their own structure, whereas lower-modulus materials such as GuttaFlow Bioseal showed minimal intrasealer stress and limited capacity to bear load, instead transmitting stresses to dentin[19,23]. These observations are consistent with prior studies on BioRoot RCS, Biodentine, MTA, and monoblock/post systems, which collectively indicate that dentin-like stiffness and reduced interface complexity favor promote favorable stress transfer and may decrease the risk of catastrophic failures[16,19,26-28]. In this context, materials with low stiffness such as Resilon and gutta-percha provide limited reinforcement, and adhesive procedures alone cannot compensate when the core or sealer lacks adequate modulus[27-29]. The stress values discussed in this section correspond to the dentinal von Mises stresses reported in Table 5. Although the absolute differences in peak dentinal stress among sealer groups were relatively small, their clinical relevance lies not in stress magnitude alone but in the pattern of stress redistribution

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TABLE 6 - Intrasealer von Mises Stress—Element-Averaged Maximum per Model (FEA)

Model	von Mises (MPa)
Model 01	2.8
Model 02	3.0
Model 03	4.1
Model 04	31.1
Model 05	43.2
Model 06	152.7
Model 07	207.6
Model 08	0.8
Model 09	0.9
Model 10	329.4
Model 11	434.1

Note: A static 300-N oblique load was applied at 45°. Reported values represent element-averaged maximum von Mises stresses extracted from predefined apical and middle third regions of interest within the sealer material, rather than isolated nodal peak values. Descriptions of Models 1–13 are provided in Supplemental Table S1.

between dentin and the sealer (Table 5 and 6). Accordingly, bioceramic sealers with higher elastic moduli, such as NeoSealer Flo and TotalFill BC, absorbed and redistributed a greater proportion of the applied load within the sealer mass, whereas lower-modulus materials such as GuttaFlow Bioseal exhibited minimal intrasealer stress and transmitted stresses to radicular dentin.

Synthesizing the experimental and computational evidence, the present study supports that bioceramic sealers with elastic moduli close to dentin promote more uniform stress distribution, lower localized dentinal stress, and potentially contribute to long-term tooth preservation[16,19]. The lack of large, consistent differences in fracture resistance across sealers, together with the heterogeneity highlighted in systematic reviews, suggests that macroscopic fracture load alone is insufficient to rank materials and that stress maps should be interpreted as surrogate indicators of crack initiation risk rather than direct predictors of failure[10,21]. Methodologically, micro-CT–based model reconstruction and retreatment simulation within the same tooth improved internal validity by minimizing geometric variability. Mesh convergence was ensured, and stress analysis employed von Mises criteria for dentin, sealer, and periodontal ligament, with principal stresses used for bone. This approach enabled a detailed characterization of stress distributions under clinically relevant oblique loading[25,30,31]. Nonetheless, limitations related to the *in vitro* nature of the study—including the use of a single tooth type, idealized homogeneous and perfectly bonded materials, and the absence of cyclic and multiaxial fatigue loading—limit extrapolation to long-term clinical conditions. In particular, modeling all material interfaces as perfectly bonded represents an idealized assumption that does not account for potential interfacial defects or debonding under clinical loading. In addition, elastic modulus values were derived from previously published literature and manufacturer data rather than being independently measured for the materials tested, which should be considered when interpreting the finite element outcomes.

Clinically, sealer selection should integrate biomechanical compatibility with dentin—particularly elastic behavior and interfacial stiffness—with sealing ability, bioactivity, and antimicrobial properties[26,32,33]. Bioceramic sealers appear advantageous where dentin preservation and favorable long-term load distribution are priorities, but their use must be balanced against handling characteristics and overall restorative strategy. Future research should incorporate cyclic and multidirectional fatigue loading, different postendodontic restorations (including endocrowns, fiber posts, and post–core systems), and *in vivo* follow-up with larger, more diverse samples to determine whether modulus-driven stress modification translates into durable clinical success[26-29,32,33]. These biomechanical findings should be interpreted alongside clinical judgment, case-specific restorative planning, and the overall tooth prognosis.

Within the limitations of this *in vitro* study, canals left unfilled after retreatment showed the lowest fracture resistance, whereas primarily treated teeth exhibited the highest values, comparable to roots obturated with NeoSealer Flo and TotalFill BC. Among refilled, retreated teeth, no statistically significant differences in peak fracture load were detected among AH Plus, BioRoot RCS, GuttaFlow Bioseal, TotalFill BC, and NeoSealer Flo under standardized conditions.

Despite similar fracture loads, FEA demonstrated distinct biomechanical behavior: higher-modulus calcium silicate–based sealers (NeoSealer Flo and TotalFill BC) concentrated stresses within the sealer and reduced dentinal stress, whereas the lower-modulus silicone-based GuttaFlow Bioseal transmitted greater stresses to root dentin. Fracture-mode analysis suggested a higher proportion of repairable fractures with the elastomeric silicone sealer and a greater incidence of irreparable root-level failures with stiffer systems. It should be acknowledged that the majority of failures observed in the present study were classified as irreparable root fractures, which may not fully reflect clinical failure patterns under functional loading. The wide range of fracture load values observed reflects the inherent biological heterogeneity of extracted human teeth and should not be interpreted as a lack of methodologic validity. This limitation is inherent to static load-to-fracture testing, which applies supraphysiologic forces and tends to induce catastrophic failures. Accordingly, fracture resistance values should be interpreted as comparative indicators of structural behavior rather than direct predictors of clinical fracture risk. In this context, finite element analysis provides complementary insight by illustrating stress redistribution patterns within dentin and sealer materials under controlled loading conditions.

Clinically, these findings indicate that postretreatment sealer selection should extend beyond handling and biological properties to include biomechanical compatibility with dentin. Favoring sealers that limit dentinal stress while considering their influence on fracture mode may support long-term tooth preservation and treatment success.

ETHICS APPROVAL

The research protocol was approved by the Institutional Ethics Committee of Bezmialem Vakif University (Approval No.164073).

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Hümeyra Çapkın: Conceptualization, Methodology, Investigation, Data curation, Writing – original draft, Writing – review & editing. **Fatma Begüm Peker:** Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review & editing. **Mehmet Burak Güneşer:** Conceptualization, Writing – review & editing, Supervision.

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The authors deny any conflicts of interest related to this study.

SUPPLEMENTARY MATERIAL

Supplementary material associated with this article can be found in the online version at www.jendodon.com (https://doi.org/10.1016/j.joen.2026.01.016).

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