

Selective Root Canal Treatment Versus Conventional Root Canal Treatment: Effect of Pulpotomy Extent on Root Dentin Stress Distribution — A Three- Dimensional Finite Element Study

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Abstract

Background

Preservation of vital pulp tissue through selective (partial) pulpotomy has been proposed as a less destructive alternative to complete pulpectomy and conventional root canal treatment (RCT). Whether it is the presence of any preserved vital pulp, or specifically the depth to which pulp tissue is removed, that governs the resulting biomechanical benefit has not been quantified, and prior modeling attempts risk conflating this question with the choice of coronal restorative material.

Methods

A mesh-convergence-verified three-dimensional finite element model of a two-rooted maxillary first premolar (enamel, dentin, pulp chamber, buccal canal, palatal canal) was used, with a fixed access-cavity and canal geometry held constant across all groups. The buccal canal received one of three pulpotomy depths (coronal, partial radicular, or deep radicular) or full instrumentation, modeled with a clinically realistic layered fill (a thin 2 mm MTA cap at the treatment interface, with the remaining coronal space filled by bulk composite resin), while the palatal canal served as a fixed comparator. A 100 N oblique occlusal load was applied, and maximum principal stress was evaluated at the 95th percentile within pericervical, furcal, and apical regions of interest.

Results

Pericervical dentin stress was 11.6–12.4% lower in groups retaining any depth of vital pulp (4.19–4.22 MPa) than with full instrumentation of both canals (4.71 MPa); this pattern was unchanged after replacing a uniform capping assumption with the layered MTA/composite model. Pulpotomy depth itself changed pericervical stress by < 1%, and no consistent pattern was seen at the furcation or apical third. The peak simulated stress (4.71 MPa) corresponded to ~ 11% of the lowest reported dentin ultimate tensile strength (44.4 MPa).

Conclusions

Retaining any vital pulp, rather than the specific pulpotomy depth, was associated with reduced pericervical dentin stress relative to full instrumentation. All simulated stresses remained well below reported dentin failure thresholds under this single static load, and clinical significance under fatigue loading and varying access-cavity designs remains to be established.

INTRODUCTION

Endodontically treated teeth are more fracture-prone than vital teeth, a vulnerability attributed more to loss of tooth structure than to the root canal filling itself [1]. Reeh et al. showed that access-cavity preparation and marginal-ridge loss reduce cuspal stiffness more than canal instrumentation alone [1], a finding with direct methodological consequences for this study, discussed below.

This vulnerability concentrates in the pericervical dentin (PCD), the collar of dentin approximately 4 mm coronal and apical to the alveolar crest, disproportionately important to fracture resistance because of the abrupt change in cross-section there [2], consistent with the stress-riser mechanisms described by Kishen [3]. PCD-preserving access strategies have been proposed to reduce fracture risk [2, 4], and a systematic review and meta-analysis supports this laboratory evidence [5]. Recent finite element work shows that coronal restorative and capping material choice, independent of canal treatment, is itself a major driver of post-pulpotomy cervical stress [10, 11].

Selective pulpotomy preserves a variable amount of radicular pulp relative to conventional RCT. Current AAE guidance extends vital pulp therapy (VPT) indications to teeth with signs of irreversible pulpitis [8], and mixed within-tooth designs — one root treated with VPT, another with RCT — have been reported clinically [9]. Finite element studies comparing instrumented, obturated canals against native pulp consistently show RCT elevates dentin stress under occlusal loading, most markedly at the cervical level [6].

What remains unquantified is whether this penalty scales with how much pulp is removed, or depends simply on whether any is retained. We address this using a three-dimensional finite element model of a two-rooted maxillary premolar, comparing progressively deeper buccal-canal pulpotomy against a fixed, fully instrumented palatal canal. Two scope limitations are stated upfront. First, because access-cavity design itself is a major determinant of tooth stiffness [1], this model holds access-cavity and canal geometry fixed across groups to isolate pulpotomy depth alone; it cannot address how a conservative access combined with full RCT would compare against a wide access combined with partial pulpotomy. Second, because coronal capping/build-up material choice is itself a documented driver of pericervical stress [10, 11], each pulpotomy depth was modeled with a clinically layered fill (a thin MTA cap plus bulk composite) rather than a single uniform material, specifically to avoid conflating a depth effect with a materials-modeling artifact (Methods).

MATERIALS AND METHODS

The manuscript of this laboratory study has been written according to Preferred Reporting Items for Laboratory studies in Endodontology (PRILE) 2021 guidelines. A three-dimensional solid model of a two-rooted maxillary first premolar was built as five discrete bodies: enamel, dentin, pulp chamber, buccal canal, palatal canal (Fig. 2), origin at the cemento-enamel junction (CEJ; Z = 0, apical negative). Access-cavity outline, canal taper, and crown/root dimensions were fixed across all five groups; only the buccal canal's internal fill varied (below). This model does not test access-cavity design as an independent variable (Introduction, Discussion). Body volumes (enamel 142.1 mm³, dentin 315.5 mm³, chamber 22.7

mm³, buccal canal 2.3 mm³, palatal canal 2.3 mm³) fell within expected anatomical ranges. A small, disclosed increase in minimum enamel thickness at the CEJ scallop (mathematical knife-edge to ~ 0.15 mm) and a reduced distal-concavity parameter were required to obtain a self-consistent, meshable solid.

Each body was meshed independently with four-node linear tetrahedra (Tet4); coincident interface nodes (33–37% of nodes, by refinement level) were merged for displacement continuity, and elements with aspect ratio > 500 were excluded. Convergence was assessed at three refinement levels (0.60/0.10, 0.50/0.09, 0.40/0.08 mm max/min edge length; ~51,000, 67,000, 99,000 elements), accepting < 5% change in 95th-percentile ROI stress between the two finest levels. This was met at the furcation (3.1–4.0% across groups) and apical third (1.5–2.5%); the pericervical ROI converged strictly for G1/G4 (1.8–4.7%) and approximately for G2/G3/G5 (5.1–5.6%). An initial apical-third ROI adjacent to the rigid apical boundary was non-convergent (> 20%) and was relocated coronally. Linear Tet4 elements are prone to volumetric locking and over-stiffness at stress concentrations, plausibly explaining the incomplete pericervical convergence; this is mitigated for between-group comparisons, since all five groups shared an identical mesh protocol and topology, but remains a concern for absolute magnitudes, discussed further below.

All materials were linear elastic and isotropic (Table 1). The gutta-percha modulus (69 MPa) reflects a corrected value following Ruse's documentation of a ten-fold error propagated through the FEA literature [7]. Native pulp was modeled as a soft elastic solid (2 MPa) rather than a fluid or poro-elastic medium with physiological hydrostatic pressure, a standard FEA simplification. The periodontal ligament was modeled as a distributed spring boundary condition along the root surface (0.20 mm assumed thickness) rather than an explicit three-dimensional layer; this was not separately validated here.

Coronal fill for each pulpotomy group used a two-layer scheme rather than a single uniform material, directly addressing the concern that a single stiff filling spanning the entire treated region could, by itself, mask a true depth-dependent effect. A thin (2 mm) plug of set MTA (11,000 MPa) was placed at the treatment interface, and the remaining coronal space (rest of the canal segment plus chamber) was filled with bulk composite resin (18,000 MPa, within the 10,000–26,000 MPa range used in dental FEA studies [13]). Stiff composite volume thus scaled with pulpotomy depth (~ 0, 4, and 8 mm in the coronal, partial radicular, and deep radicular groups), so a true depth effect should manifest as a graded difference between groups.

Apical nodes ($Z < -13.5$ mm) were rigidly fixed. A single static 100 N oblique load (45° to the long axis) was applied at the buccal cusp incline. No vertical, parafunctional, or cyclic/fatigue loading was modeled; results describe an instantaneous static stress state only and should not be extrapolated to fatigue behavior under repeated function.

Five scenarios were modeled (Table 2): the buccal (test) canal received coronal (2 mm), partial radicular (6 mm), or deep radicular (10 mm) pulpotomy, or full RCT; the palatal canal was a fixed comparator (full RCT) in Groups 1–4. Group 4 was full RCT of both canals (no preservation); Group 5 was bilateral coronal

pulpotomy (maximal preservation). The shared pulp chamber received the bulk composite modulus whenever either canal retained vital pulp, and gutta-percha only when both underwent full RCT.

Maximum principal stress (reflecting dentin's tension-sensitive, semi-brittle behavior) was the primary outcome. Three buccal-side dentin regions of interest (ROIs) were defined: pericervical (−2.0 to + 0.3 mm), furcation (−7.5 to − 6.5 mm), and apical third (−12.0 to − 10.0 mm; relocated from a non-convergent − 13.5 to − 10.5 mm window adjacent to the apical boundary). The 95th percentile of element-wise stress was reported per ROI, reducing sensitivity to single-element mesh artifacts. Peak stresses were compared against reported dentin ultimate tensile strength (UTS), which varies from approximately 44.4 MPa near the pulp to 97.8 MPa near the dentino-enamel junction [12].

Table 1
Linear elastic material properties.

Material / Tissue	Elastic Modulus (MPa)	Poisson's Ratio
Enamel	84,100	0.30
Dentin	18,600	0.31
Native (vital) pulp	2.0	0.45
Gutta-percha	69.0	0.45
MTA cap (thin plug, 2 mm)	11,000	0.33
Composite resin build-up (bulk)	18,000	0.24
Periodontal ligament (spring analog)	68.9	—

Table 2
Experimental group definitions.

Group	Buccal canal (test canal)	Palatal canal (fixed comparator)
G1	Coronal pulpotomy (2 mm treated depth: 2 mm MTA cap, no composite within the canal)	Full RCT (gutta-percha)
G2	Partial radicular pulpotomy (6 mm: 2 mm MTA cap + 4 mm bulk composite)	Full RCT (gutta-percha)
G3	Deep radicular pulpotomy (10 mm: 2 mm MTA cap + 8 mm bulk composite)	Full RCT (gutta-percha)
G4	Full RCT (gutta-percha)	Full RCT (gutta-percha)
G5	Coronal pulpotomy (as G1)	Coronal pulpotomy (as G1)

RESULTS

Following relocation of the apical-third ROI, the furcation and apical third converged within 5% for all five groups; the pericervical ROI converged strictly for G1/G4 and approximately (5.1–5.6%) for G2/G3/G5 (Fig. 3). Absolute stress fell with mesh refinement, as expected for Tet4, but the relative between-group difference remained stable across refinements, supporting between-group comparisons at the finest mesh.

At the finest mesh, pericervical stress was consistently lower in every group retaining vital pulp (G1 4.224, G2 4.194, G3 4.196, G5 4.202 MPa) than with full RCT of both canals (G4 4.712 MPa) – 11.6–12.4% lower depending on comparator (Table 3, Fig. 3A). This pattern was essentially unchanged from a preliminary analysis using a single uniform capping material instead of the two-layer MTA/composite scheme, arguing against a materials-modeling artifact. Across the three pulpotomy depths (G1–G3), pericervical stress varied by < 1%, smaller than residual mesh-to-mesh scatter. Neither the furcation nor apical third showed a consistent pattern, despite the material immediately adjacent to the canal differing substantially at the furcation level (native pulp for G1, bulk composite for G3); all five groups fell within a narrow band at both regions (furcation 3.22–3.26 MPa; apical third 2.29–2.34 MPa), suggesting the canal cross-section is too small, relative to surrounding dentin, to govern bulk regional stress at these levels. Representative whole-tooth stress fields for G1 and G4 are shown in Fig. 3B.

Table 3
Regional dentin stress by treatment group (fine mesh, 95th percentile maximum principal stress, MPa).

Group	Pericervical dentin (MPa, 95th pct.)	Furcation (MPa, 95th pct.)	Apical third (MPa, 95th pct.)
G1 – Coronal pulpotomy	4.224	3.239	2.317
G2 – Partial radicular	4.194	3.219	2.325
G3 – Deep radicular	4.196	3.223	2.293
G4 – Full RCT (both canals)	4.712	3.259	2.336
G5 – Coronal (both canals)	4.202	3.240	2.318

The highest simulated pericervical stress (G4, 4.71 MPa) corresponded to approximately 10.6% of the lowest reported dentin UTS near the pulp (44.4 MPa) [12], and a smaller fraction of the value near the dentino-enamel junction (97.8 MPa); G1 (4.22 MPa) corresponded to approximately 9.5% of the same conservative threshold. Under this single static load, all simulated stresses remained 9.4- to 10.5-fold below the margin against dentin fracture, regardless of treatment group.

DISCUSSION

The principal finding is that the pericervical biomechanical benefit of selective RCT derived from retaining any vital pulp, rather than from pulpotomy depth. This held after two checks prompted by

anticipated methodological concerns. First, replacing a uniform capping-material assumption with a clinically layered thin-MTA-plus-bulk-composite fill — in which stiff composite volume explicitly scaled with depth — did not produce a depth-dependent pericervical gradient, arguing against the possibility that the original flat result was a materials-modeling artifact. Second, at the furcation, where canal material genuinely differed in composition between shallow and deep groups (native pulp versus bulk composite immediately adjacent to the ROI), no corresponding bulk-dentin difference was detected, consistent with the canal cross-section being mechanically small relative to surrounding dentin at that level.

This is consistent with the pericervical zone, rather than the mid-root or apical canal space, being the principal site of stress concentration in root canal-treated teeth [2, 3, 6], and with recent finite element work showing that coronal restorative material choice, more than treatment depth per se, governs cervical dentin stress after pulpotomy [10, 11]. Once the coronal chamber and orifice region are conservatively managed and sealed, further apical extension of the pulpotomy appeared to carry no additional pericervical penalty here.

Two boundaries on this conclusion, raised directly during internal review of this manuscript, deserve explicit emphasis. First, this study fixed access-cavity and canal geometry to isolate pulpotomy depth as a single variable; it therefore cannot address whether a conservatively accessed full RCT might outperform a widely accessed partial pulpotomy — access-cavity design and pulpotomy depth are independent, interacting variables, and Reeh et al. found access-related stiffness loss to exceed instrumentation-related loss [1], making this a question for a dedicated factorial study, not this one. Second, the ~ 9–12% pericervical difference reported here occurred within a stress range (4.2–4.7 MPa) approximately 9- to 10-fold below conservative dentin failure thresholds under this single static load. Every stress value reported in this study describes an instantaneous, single-cycle elastic stress state, not a fracture event or a fatigue-life prediction, and the reported between-group differences should not be extrapolated to cumulative fracture risk under repeated masticatory loading over years of function. The absence of a detectable pattern at the furcation and apical third likewise reflects this model's sensitivity at the resolution studied, not proof that pulpotomy depth has no biological consequence at those levels; radicular pulp preserved deep within the canal remains vital tissue subject to its own risk of persistent inflammation or necrosis, a decision governed by histological and clinical factors rather than by root dentin biomechanics.

This study has several further limitations. Linear Tet4 elements are prone to volumetric locking and artificial over-stiffness at stress concentrations, plausibly explaining the incomplete pericervical convergence; this concern is substantially mitigated for the between-group comparisons underlying this study's conclusions, since all five groups were meshed identically, but it remains a direct concern for absolute stress magnitudes, and replication with quadratic (Tet10) elements is planned. The periodontal ligament was approximated as distributed springs rather than an explicit three-dimensional layer, not separately validated here. Native pulp was modeled as a linear elastic solid rather than a fluid or poro-elastic medium with physiological hydrostatic pressure, a simplification standard in the FEA literature. A

single anatomical model was used, without inter-patient variability in root or canal morphology. Finally, a small, disclosed increase in minimum enamel thickness at the CEJ scallop (~ 0.15 mm) was required for stable meshing and slightly reduces enamel volume relative to the idealized target anatomy.

In conclusion, within a fixed access-cavity design, linear tetrahedral elements, and a single static oblique load, retaining any depth of vital pulp reduced simulated pericervical dentin stress by approximately 9–12% relative to conventional, fully instrumented root canal treatment; this pattern persisted after replacing a uniform capping-material assumption with a depth-scaled two-layer MTA/composite fill, arguing against a materials-modeling artifact. Extending pulpotomy depth from a shallow coronal to a deep radicular level conferred no additional, mesh-convergent pericervical benefit, and no consistent effect was detected at the furcation or apical third. All simulated stresses remained approximately an order of magnitude below reported dentin failure thresholds under this instantaneous static loading condition. These findings suggest that the clinically decisive variable in selective root canal treatment may be whether vital pulp is preserved at all, rather than precisely how much — a conclusion that describes a single static stress state and should be tested against variation in access-cavity design and against cyclic/fatigue loading before any clinical extrapolation is made.

Declarations

Ethics approval and consent to participate: This is a purely computational (in silico) finite element analysis study; no human or animal subjects, tissues, or data were involved, and this work therefore does not fall under Institutional Review Board (IRB) purview.

Consent for publication: Not applicable.

Availability of data and materials: The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Competing interests: The authors declare no competing interests.

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Authors' contributions: AA: Conceptualization, Methodology, Software, Formal analysis, Investigation, Data curation, Validation, Visualization, Writing - original draft, Writing - review & editing. AHM: Conceptualization, Methodology, Supervision, Validation, Writing - review & editing. KMT: Investigation, Writing - review & editing. All authors read and approved the final manuscript.

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Figures

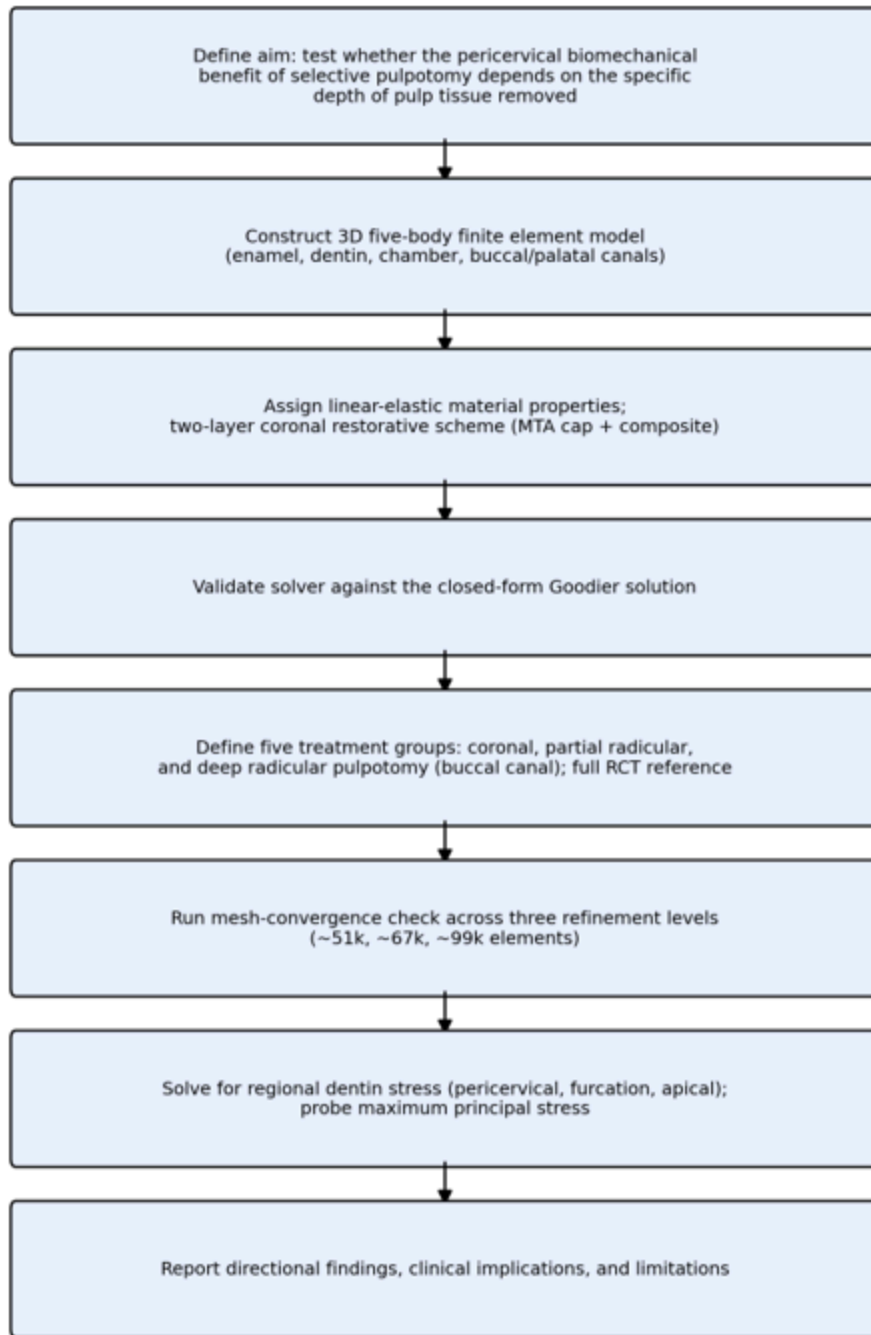


Figure 1

PRILE 2021 flowchart summarizing the study design and workflow of this computational finite element analysis.

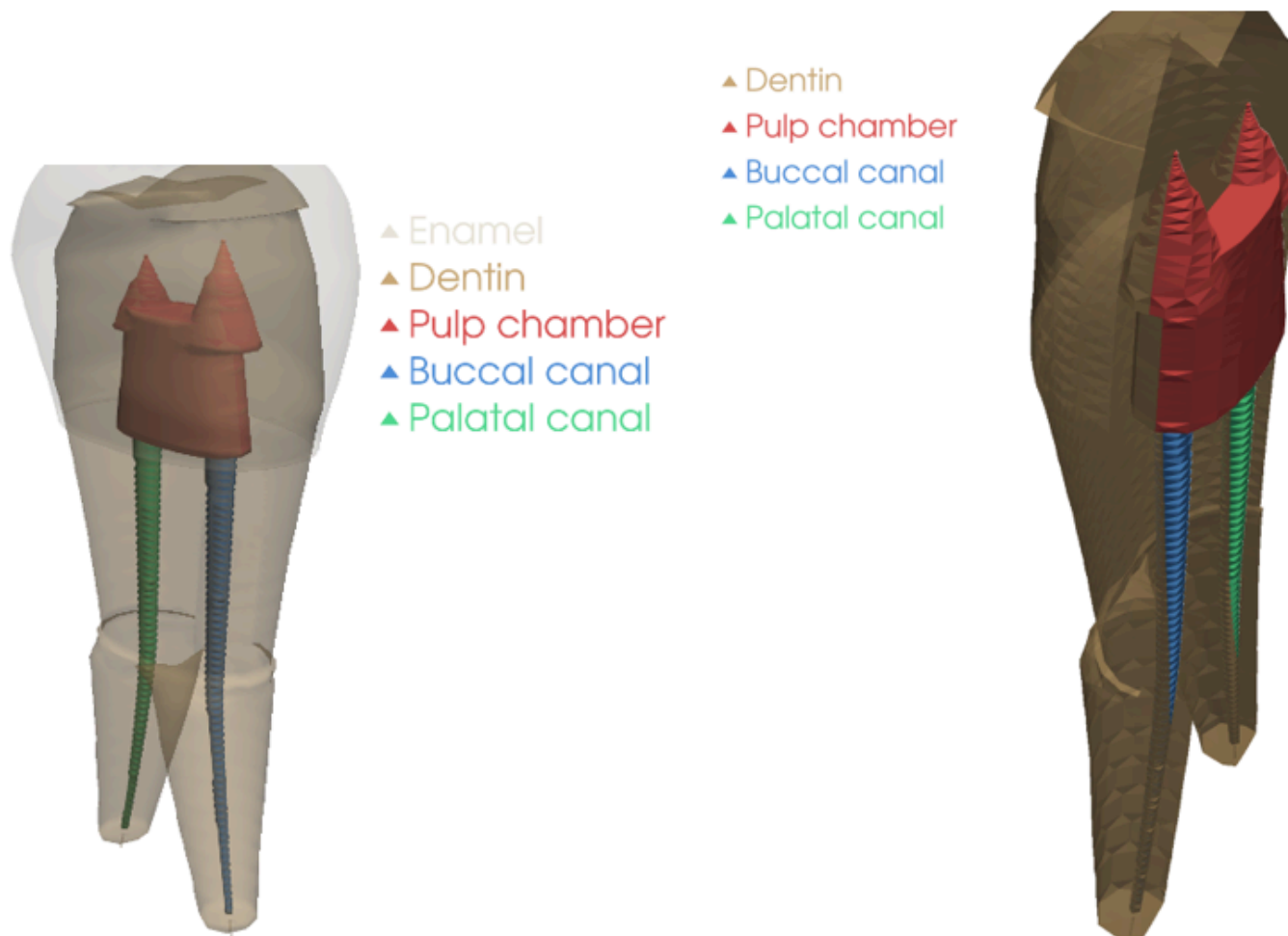


Figure 2

(A) Rendered assembly of the five modeled solid bodies. (B) Sagittal cutaway of the dentin body showing the internal pulp chamber and canal anatomy.

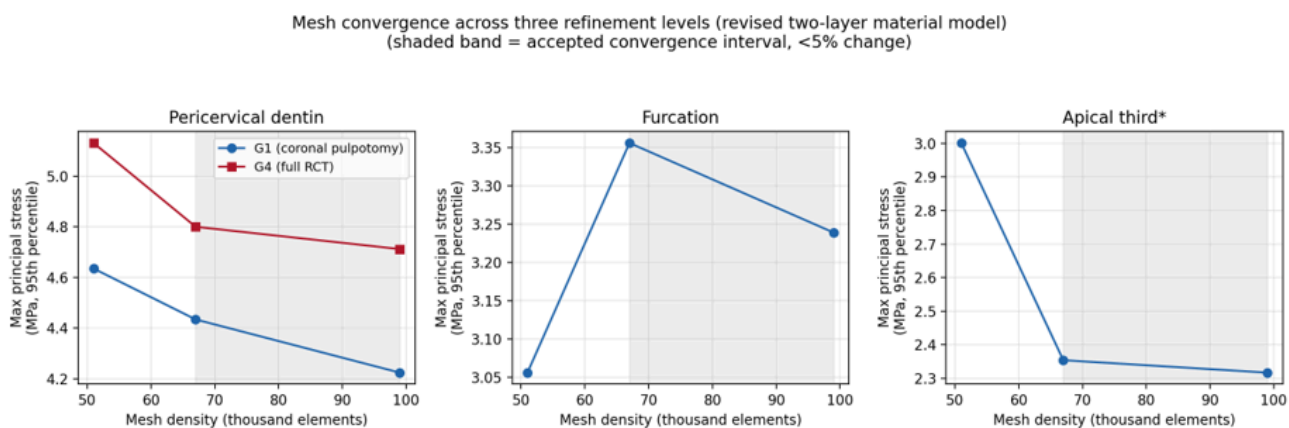


Figure 3

Mesh convergence across three refinement levels (~51k, ~67k, and ~99k elements). Shaded band marks the interval used to assess convergence (<5% change).

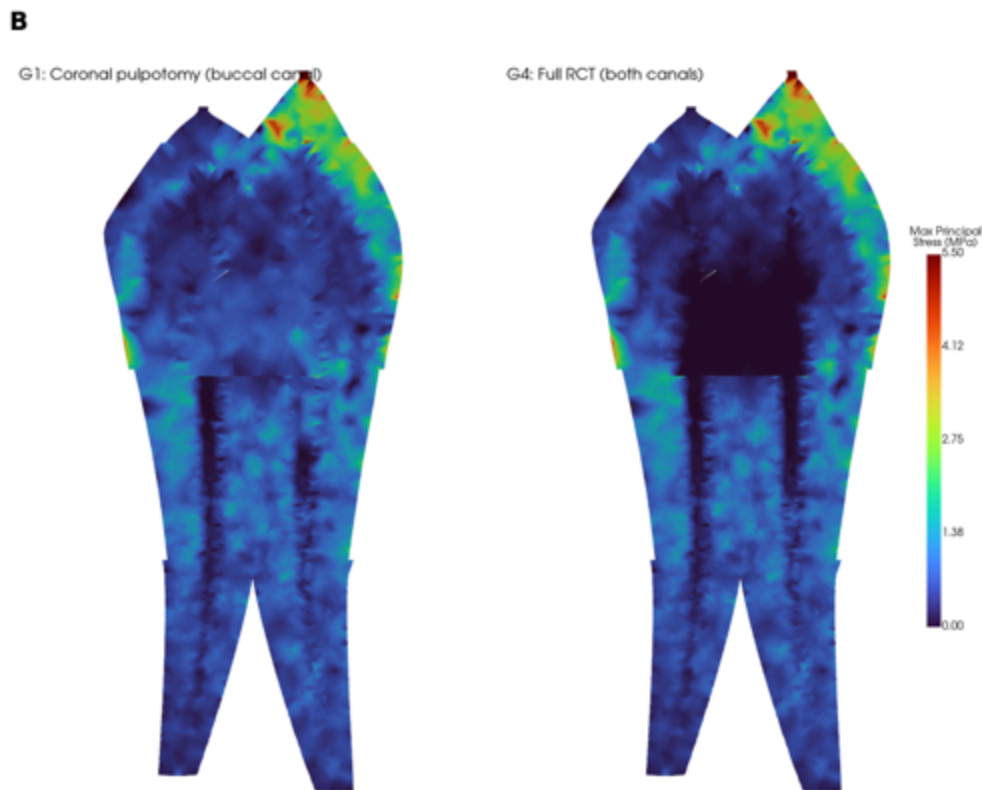
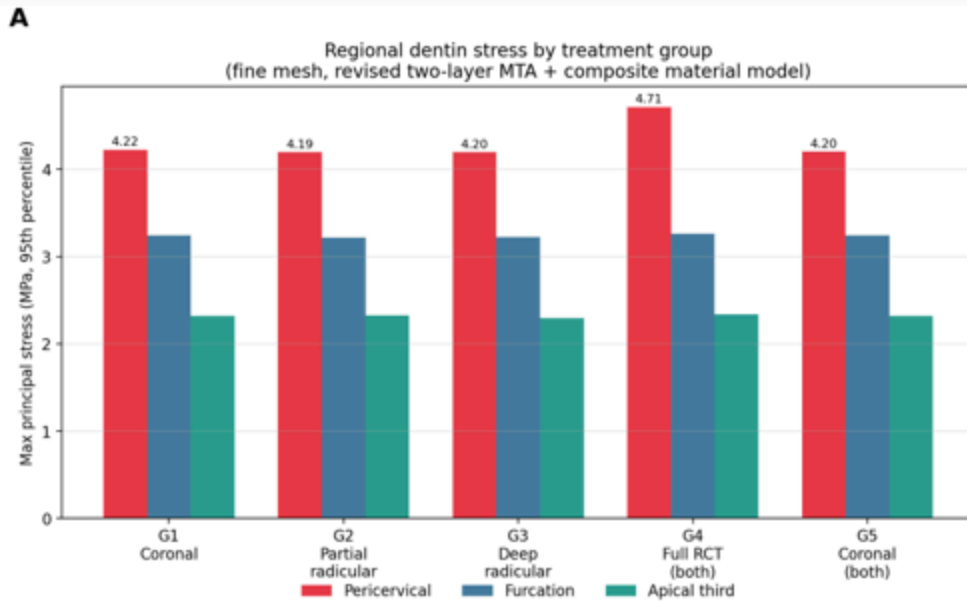


Figure 4

(A) Regional dentin stress by treatment group; pericervical stress is elevated only in G4 (full RCT, both canals). (B) Buccal-palatal sagittal slice through the whole-tooth maximum principal stress field under 100 N oblique loading, comparing G1 (coronal pulpotomy) and G4 (full RCT of both canals).