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ORIGINAL RESEARCH

Stress distributions in internal resorption cavities restored with different materials at different root levels: A finite element analysis study

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Keywords
finite element analysis, gutta-percha, internal root resorption, mineral trioxide aggregate, stress distribution.

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Abstract

The aim of this study was to evaluate the stresses within simulated roots with internal resorption cavities at the apical, middle and coronal root levels, after obturation with gutta-percha and/or MTA utilising finite element analysis (FEA). Mandibular premolar teeth with internal resorption cavities at different root levels were modelled. Models were restored with gutta-percha and/or MTA. An oblique force of 300 N was applied and stress evaluations were carried out. In the MTA-filled resorption models, the stresses were distributed more homogeneously than the gutta-percha filled models, and the stress concentrations were lower in the remaining dentinal tissues. If the whole root is considered, the fully gutta-percha-filled models generated the highest stress values. Differences between the fully MTA-filled models and hybrid techniques were present only in the apical resorption models. Both the MTA and combination of MTA and gutta-percha can be suggested for use in clinical practice, in cases of internal root resorption cavity obturation.

Introduction

Internal root resorption (IRR) is the progressive damage of intracanal dentine due to the replacement of normal pulp tissue with granulomatous tissue and giant cells, which resorb dentine (1). One contributing factor is chronic inflammation of the coronal pulp caused by continuous bacterial stimulation, trauma, caries and restorative procedures (2,3). Internal resorptive lesions tend to expand from the central pulp space to the periodontal tissues, and continue to expand until either endodontic treatment is commenced or the pulp becomes necrotic. Subsequently, the resorptive cavity expands until it perforates the root canal walls and, the tooth structure weakens (4).

Root-filled teeth are more susceptible to fracture than vital teeth (5). In IRR cases, further destructive tissue losses are observed, and these teeth must be restored with a material capable of resisting occlusal loads. In such cases, mineral trioxide aggregate (MTA) is an ideal repair material that can provide an adequate seal. It exhibits good biocompatibility and bioactivity, and is well tolerated by the periradicular tissues (6). Gutta-percha is the most commonly used filling material in endodontic procedures (7), and the thermoplastic gutta-percha technique has been shown to produce excellent results (8). A hybrid technique can also be used to obturate the canals. In this case, the canal apical to the resorption defect is obturated with gutta-percha, and the resorption defect and associated perforation are sealed with MTA (9,10).

Finite element analysis (FEA) involves a series of computational procedures to predict specific outcomes, including mechanical behaviour, for a complex and specific geometric assembly. This is achieved by integrating the results obtained in smaller elements defined by a specific mesh. This analysis is extremely useful for indicating the mechanical aspects of biomaterials and human tissue that can be difficult to measure *in vivo* (11).

Maceri *et al.* stated that oblique loads are more hazardous than vertical loads in endodontically restored teeth (12). Oblique occlusal loads can create high lateral forces and increase the risk of fracture (13). Therefore, it has been widely used in FEA studies (11,14–16).

To the best of our knowledge, there have been no previous studies on the effects of the restoration techniques of

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IRR cavities on the stress distribution of root dentine. Therefore, the aim of this study was to evaluate the von Mises stresses (the value used to determine if a given material will yield or fracture) using FEA in simulated roots with internal resorption cavities at the apical, middle and coronal root levels, after obturation with gutta-percha and/or MTA.

Materials and Methods

The ANSYS software program (version 15.0; ANSYS Inc., Canonsburg, PA, USA) was used to model the mandibular premolar teeth with their supporting tissues and internal resorption cavities in the root canals. The average anatomic dimensions of the surrounding tissues and the geometry used for the tooth models were created in accordance with the literature (17,18) for this study. Nine different restored tooth models composed of enamel, dentine, composite filling, cortical bone, spongy bone, periodontal ligament, gutta-percha filling and MTA were created. The diameters of the internal resorption cavities in the apical, middle and coronal root regions were 1.8, 2.8 and 3.8 mm respectively. The distances between the centre of the resorption cavities and root apices were 3 mm in the apical region, 8 mm in the middle region and 13 mm in the coronal region. In all FEA models, the dentine tissue thickness surrounding the resorption cavity was 1 mm. All the materials were considered to be homogeneous, isotropic and linearly elastic. Young's modulus and Poisson's ratio were determined from the literature (14) and summarised in Table 1.

The tooth models for this study were created as follows (Fig. 1):

1. Model 1 (M1): The resorption cavity was in the apical part of the root. The entire root canal was filled with MTA.
2. Model 2 (M2): The resorption cavity was in the apical part of the root. The entire root canal was filled with gutta-percha.
3. Model 3 (M3): The resorption cavity was in the apical part of the root. The resorption cavity and the lumen below the canal were filled with MTA. The lumen above the canal was filled with gutta-percha (hybrid technique).
4. Model 4 (M4): The resorption cavity was in the middle part of the root. The entire root canal was filled with MTA.
5. Model 5 (M5): The resorption cavity was in the middle part of the root. The entire root canal filled with gutta-percha.
6. Model 6 (M6): The resorption cavity was in the middle part of the root. The root canal up to the resorption cavity was filled with gutta-percha. The resorption cavity and the lumen above the canal were filled with MTA (hybrid technique).
7. Model 7 (M7): The resorption cavity was in the coronal part of the root. The entire root canal was filled with MTA.
8. Model 8 (M8): The resorption cavity was in the coronal part of the root. The entire root canal was filled with gutta-percha.
9. Model 9 (M9): The resorption cavity was in the coronal part of the root. The root canal up to the resorption cavity was filled with gutta-percha. The resorption cavity and the lumen above the canal were filled with MTA (hybrid technique).

Table 1 Material properties used in the finite element models

Material	Young's modulus (*E*) (GPa)	Poisson's ratio (μ)
Dentin	18.6	0.31
Enamel	41	0.31
Gutta-percha	0.14	0.45
Mineral trioxide aggregate	20	0.314
Resin composite	12	0.30
Cortical bone	13.7	0.30
Spongy bone	1.37	0.30
Periodontal ligament	0.0000689	0.45

From Belli *et al*. (2016) (14).

Three-dimensional meshes were created through 10-node tetrahedral elements with quadratic displacement shape functions and three degrees of freedom per node, with a mesh-size mean value of approximately 0.5 mm, resulting from an optimization process based on convergence analysis. The models were created using approximately 414930 nodes and 271837 tetrahedral solid elements. An oblique force of 300 N was applied at the top of the tooth, angled at 30° with respect to the occlusal plane, and oriented towards the buccal side. The linear analyses were performed under defined loading conditions. The von Mises stress (equivalent stress) evaluations were carried out along the central XY planes of the resorption cavities (planes A, B and C) and the central XY planes of whole roots. To visualise the stress distributions in the FEA models more easily, calculated numeric data were converted into colour graphics.

Results

Stresses generated in resorption cavities (planes A, B and C)

In the apical, middle and coronal regions, IRR models at the maximum stresses in planes A, B and C were generated in the remaining dentine (1 mm thick) on the buccal sides of the roots. The gutta-percha filling models (M2, M5, M8) showed the highest stress concentrations

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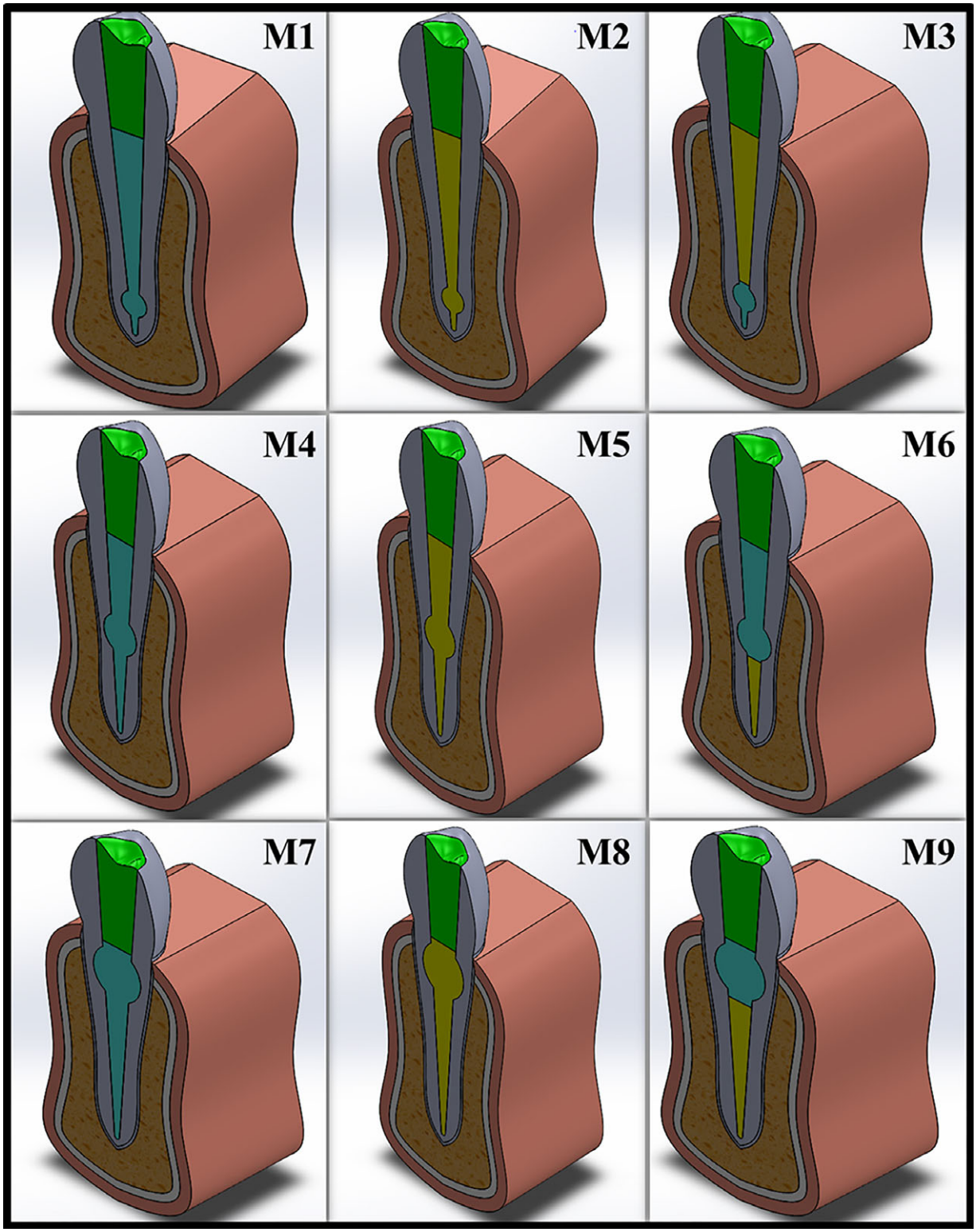


Figure 1 Finite element models of this study. M1: Apical IRR model filled with MTA, M2: Apical IRR model filled with gutta-percha, M3: Apical IRR model filled with MTA and gutta-percha, M4: Middle IRR model filled with MTA, M5: Middle IRR model filled with gutta-percha, M6: Middle IRR model filled with gutta-percha and MTA, M7: Coronal IRR model filled with MTA, M8: Coronal IRR model filled with gutta-percha, M9: Coronal IRR model filled with gutta-percha and MTA.

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in the remaining dentine tissues. In the MTA-filled resorption models (M1, M4, M7), the stresses were distributed more homogeneously than in the gutta-percha filled models, and the von Mises stress concentrations were lower in the remaining dentinal tissues. The hybrid techniques (M3, M6, M9) showed similar results to those of the fully MTA-filled techniques. Overall, the stresses generated on the buccal sides of the roots were greater than those on the lingual sides.

Figure 2 shows the von Mises stress values in the apical, middle and coronal regions. The maximum von Mises stress values recorded within the dentine are summarised in Table 2.

Stresses generated in whole root (XY plane)

In the apical, middle and coronal regions, the maximum stresses of the IRR models were generated on the buccal surfaces of the roots. The stresses generated on the buccal sides were greater than those on the lingual sides of the roots. The gutta-percha-filled models (M2, M5, M8) also exhibited a high concentration of von Mises stresses on the lingual root surface. In the apical IRR models (M1, M2, M3), the maximum stresses occurred on the buccal sides of middle and coronal thirds of the roots (Fig. 3). In the middle IRR models (M4, M5 and M6), the maximum stresses were distributed homogenously in M4 and M6 on the buccal sides of the middle and coronal thirds of the roots. However, in M5, the stresses were concentrated, especially in the remaining dentine of the resorption area (Fig. 4).

In the coronal IRR models (M7, M8 and M9), the maximum stresses were distributed homogenously in M7 and M9 on the buccal sides of the middle and coronal thirds of the roots. However, in M8, the stresses were concentrated, especially in the remaining dentine of the resorption area (Fig. 5). The maximum von Mises stress values recorded within the dentine are summarised in Table 2.

Discussion

For this study, the mechanical responses to the parafunctional loads of endodontically treated teeth with internal resorption, based on different root canal filling techniques, were investigated. A three-dimensional elastic FEA was used, which permitted the investigation of anatomical sites that are practically inaccessible *in vivo*. In addition to the low cost of this method, the high reliability of the results and need for only a few complementary tests were added benefits (19,20). The results of FEA analyses are usually expressed as stress distributed in the structures under investigation; however, von Mises stress depends on the entire stress field, and is a widely used indicator of the possibility of damage occurring (21). Therefore, the results have been presented considering the von Mises criteria.

All the materials were considered to be linear, isotropic and homogeneous, even though most dental materials and tooth tissues are anisotropic and non-homogeneous. In addition, the loading scenarios investigated lack the complexity that occurs during functional loading in a patient. This resulted in nonlinearity of the load application and its effects (22), and therefore is a limitation of this study - only one load condition was tested.

An oblique load was used to reflect the parafunctional load related to bruxism, and to limit the chewing conditions in the case of very tough foods. In all of the FEA models in this study, the stresses generated on the buccal sides of the roots were greater than those on the lingual sides. This could be related to the oblique force, which was applied to the occlusal plane and oriented towards the buccal side.

In this study, the filling material type affected the stress distributions in both the resorption cavities and whole root dentine. In all planes (A, B and C), the gutta-percha filling models showed the highest stress concentrations in the remaining dentinal tissues. In the MTA-filled resorption models, the stresses were distributed more homogeneously than in the gutta-percha filled models, and the von Mises stress concentrations were lower in the remaining dentinal tissues. Gutta-percha acts differently than dentine because of its elasticity; therefore, it could transfer the von Mises stress towards the root dentine. In contrast, MTA has a very similar elasticity to that of dentine, and acts as a dentine structure, thus keeping the stress within its own structure and sharing the stress with the dentine. More homogeneous stress means a lower fracture risk. It has been shown that MTA as a root canal filling material increases the fracture strength of roots (23).

In plane A, minimum stresses were observed in the fully MTA-filled model (M1), and the hybrid model (M3) showed lower stresses than the fully gutta-percha-filled model (M2). However, the maximum MPa values were similar in M1 and M3. In plane B, the fully MTA-filled model (M4) and hybrid model (M6) showed almost the same maximum MPa results. In addition, the fully gutta-percha-filled model (M5) generated higher von Mises stress than M4 and M6. In plane C, the fully gutta-percha-filled (M8) model showed higher stress than the fully MTA-filled model (M7) and the hybrid model (M9). Moreover, M7 and M9 exhibited the same MPa values. Based on these results, in planes B and C, the obturation of the resorption cavity with MTA was the most important step of the filling procedure. After obturation, the remaining unfilled root canal space can be filled with any of the experimental materials used in this study. This is

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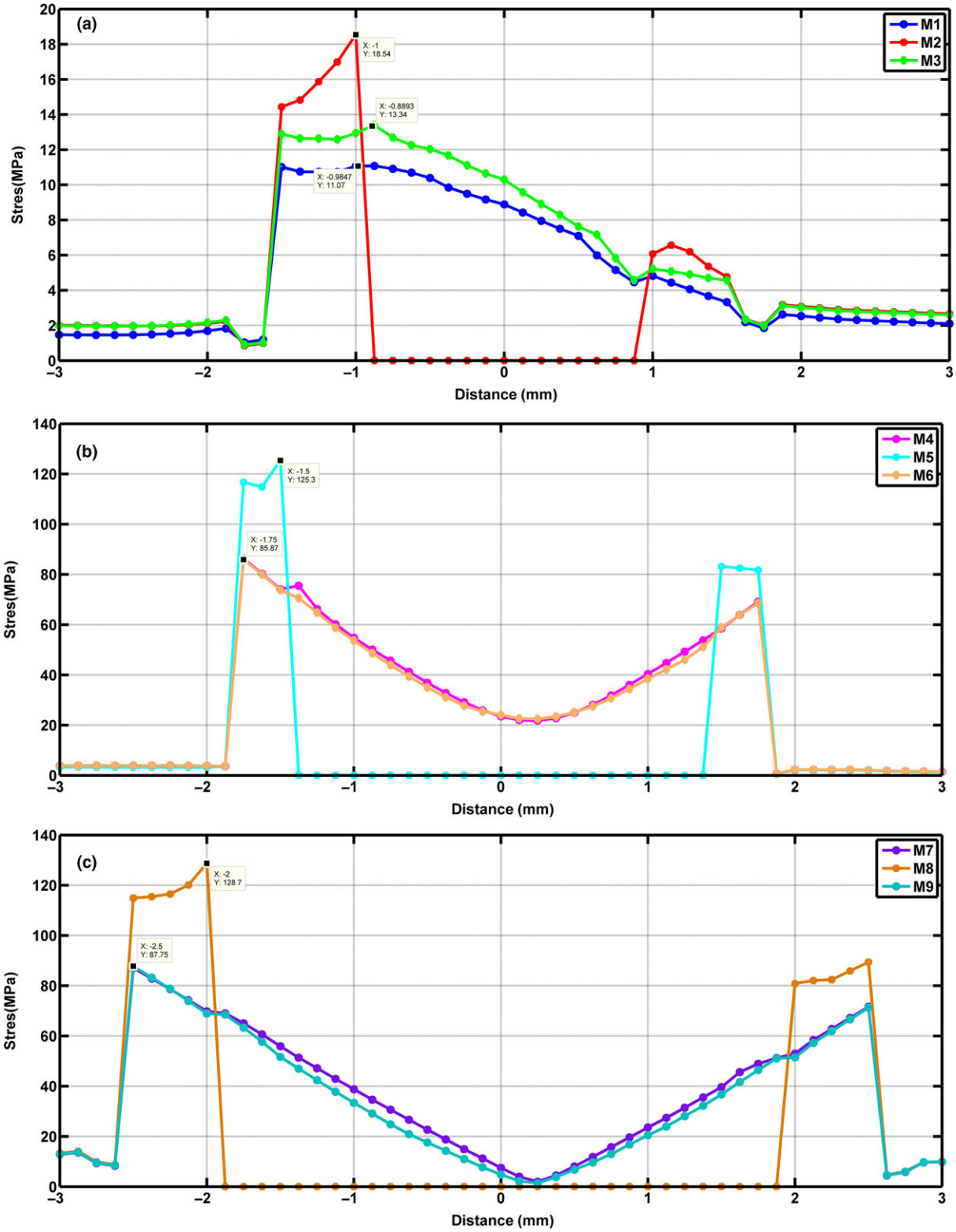


Figure 2 Stress distributions along planes a, b and c. A negative distance direction indicates the buccal side, whereas a positive direction indicates the lingual side of the root. The maximum stresses of the models are shown in the graphics.

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Table 2 Maximum von Mises stress values of the FEA models (MPa)

Obturation technique	Group	Maximum stress values (MPa) XY plane (Whole root)	Plane A (Apical)	Plane B (Middle)	Plane C (Coronal)
Full MTA	M1	74.32	11.06	–	–
	M4	107.96	–	85.87	–
	M7	102.79	–	–	87.75
Full Gutta-Percha	M2	106.84	18.54	–	–
	M5	381.15	–	125.30	–
	M8	150.50	–	–	128.70
Hybrid	M3	107.00	13.39	–	–
	M6	107.95	–	85.87	–
	M9	110.78	–	–	87.75

because the stresses were very similar, and were not affected by the type of obturation materials used. In the apical root region (plane A), although the fully MTA-filled obturation model reduced the stress a little more than the other techniques, it did not cause a remarkable difference (Fig. 2).

The central XY plane evaluations indicated that the fully gutta-percha-filled models (M2, M5 and M8) generated the highest MPa values. Among the apical resorption cavity models, M2 and M3 showed same maximum stresses; however, at the coronal and middle third levels, the fully gutta-percha-filled models (M5 and M8) showed the highest stresses. At the apical root level, the fully MTA-filled models (M1, M4 and M7) showed the lowest von Mises stresses. These results indicate that the use of MTA or gutta-percha in the obturation of apical internal resorption cavities did not affect the stress areas or maximum von Mises stress along the whole root structure. However, in the middle and coronal internal resorption models, the maximum stresses were observed in the thinnest dentin tissue of the cavities. Thus, it may be necessary to fill the resorption cavities with MTA. The restoration of root-filled teeth with materials having a similar elastic modulus to dentin can save the remaining tooth structure by creating a monoblock unit. More homogenous stress distribution was observed in the tooth models filled with MTA, confirming the primary monoblock concept (24).

When considering the location of the resorption cavity and the short length of the root, the canal can be completely filled with MTA. A combined treatment plan (hybrid technique) using bioactive materials along with thermoplasticized gutta-percha obturation will not only provide a three-dimensional obturation, but also induce remineralization and healing (25); thus, these kind of restorations is clinically relevant. In this study, different hybrid filling techniques were evaluated, in addition to the fully MTA or gutta-percha filling techniques. A common feature of all of the hybrid techniques was the presence of MTA in the resorption cavities. Therefore, the hybrid techniques showed results similar to those of the fully MTA-filled techniques in the resorption cavities. If

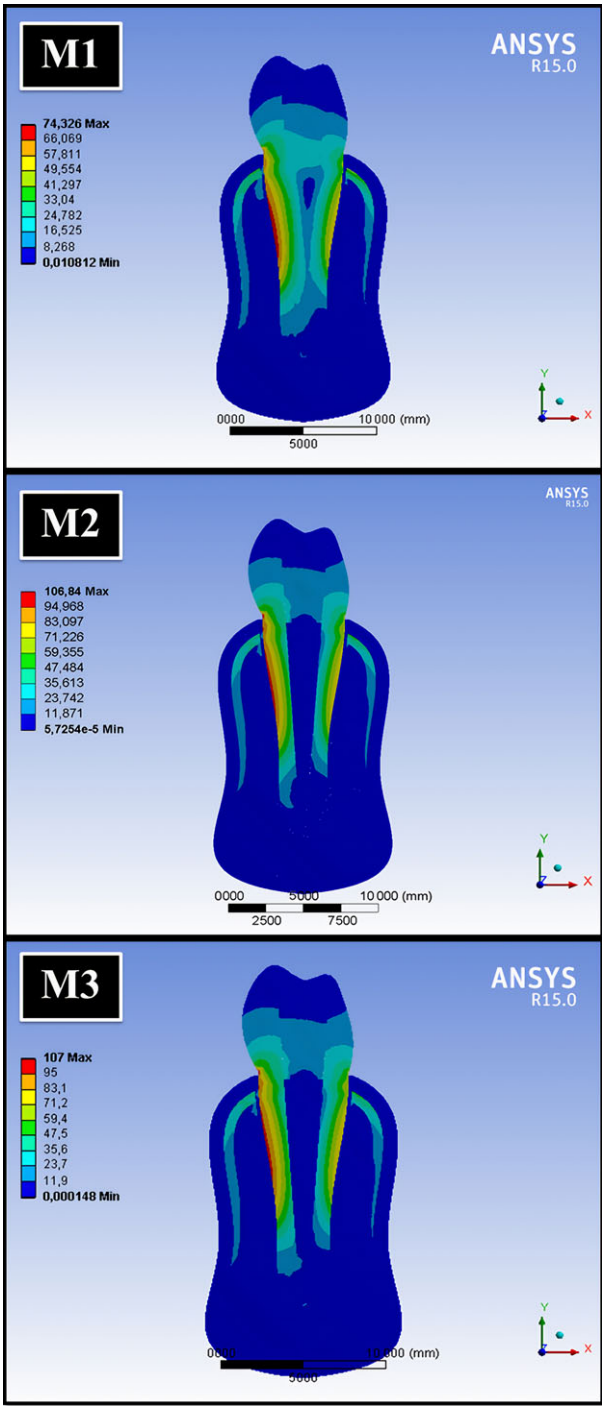


Figure 3 Stress distributions along the XY planes of the apical IRR models (M1, M2 and M3). The red colour shows the maximum stress, whereas the blue colour shows the minimum stress. Each model should be evaluated based on its own colour scale.

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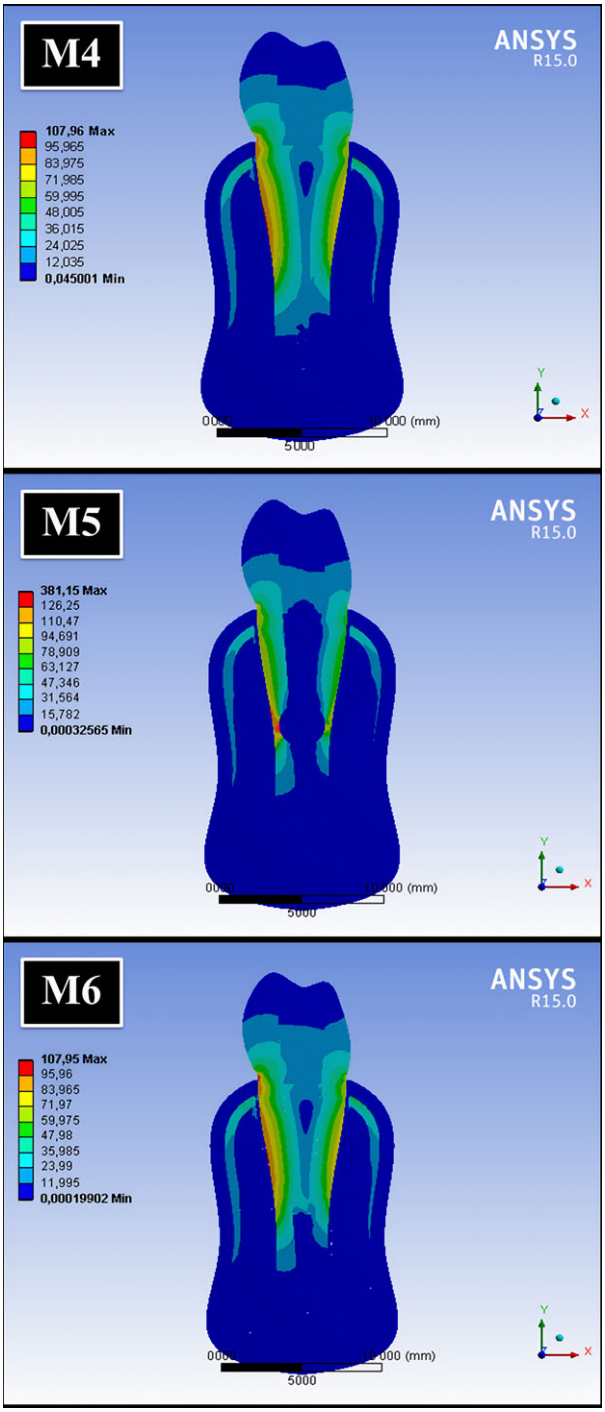


Figure 4 Stress distributions along the XY planes of the middle IRR models (M4, M5 and M6). The red colour shows the maximum stress, whereas the blue colour shows the minimum stress. Each model should be evaluated based on its own colour scale.

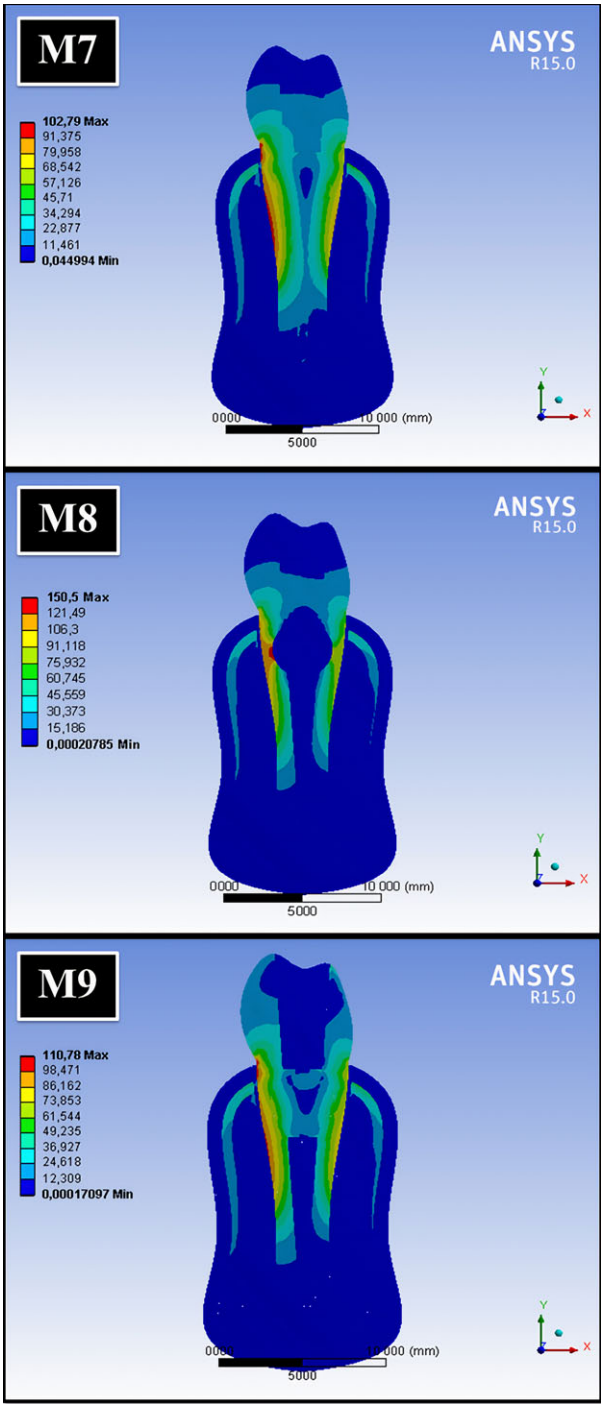


Figure 5 Stress distributions along the XY planes of the coronal IRR models (M7, M8 and M9). The red colour shows the maximum stress, whereas the blue colour shows the minimum stress. Each model should be evaluated based on its own colour scale.

the whole root is considered, the apparent difference between the fully MTA-filled models and hybrid techniques was present only in the apical resorption models. This could be related to the maximum stress areas, which were on the buccal root surface, coinciding with the gutta-percha filling. However, gutta-percha cannot act as a

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monoblock like MTA, due to its lower elasticity modulus than that of dentin, which could explain the results.

Conclusions

The results of the FEA showed that the use of MTA reduced the risk of stress concentration in the resorption sites. The gutta-percha root canal fillings seemed to transfer the stress to the dentin tissue, and therefore, increase the risk of fracture. According to the findings of this study, both the MTA and combination of MTA and gutta-percha can be suggested for use in clinical practice, in cases of internal root resorption cavity obturation.

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

Authorship Declaration

All authors have contributed significantly, and all authors are in agreement with the manuscript.

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