OSR
ORAL SCIENCES REPORTS

Original Article

Received: November 18, 2025
Revised: January 19, 2026
Accepted: February 6, 2026

Corresponding Author:
Galvin Sim Siang Lin, Department of Restorative Dentistry, Kulliyyah of Dentistry, International Islamic University Malaysia, Kuantan Campus, Kuantan 25200, Pahang, Malaysia
E-mail: galvin@iium.edu.my

Effect of Cavity Configuration on the Fracture Strength or Composite-Restored Root-Filled Maxillary Premolars: An *In Vitro* Study

Sulhi Abidin[1,2], Nicholas Martin[2], Galvin Sim Siang Lin[3]

[1]Department of Prosthodontics, Kulliyyah of Dentistry, International Islamic University Malaysia, Kuantan Campus, Pahang, Malaysia
[2]School of Clinical Dentistry, University of Sheffield, Sheffield, United Kingdom
[3]Department of Restorative Dentistry, Kulliyyah of Dentistry, International Islamic University Malaysia, Kuantan Campus, Pahang, Malaysia

Abstract

Objectives: To evaluate the fracture strength and fracture patterns of root-filled maxillary premolars restored with direct resin composite using three cavity configurations: occlusal, mesio-occlusal (MO), and mesio-occluso-distal (MOD).

Methods: Forty extracted maxillary premolars were randomly assigned to four groups (n=10): intact controls, occlusal, MO, and MOD restorations. Root canal treatment was performed for restored groups, followed by standardised cavity preparation and incremental restoration with nano-filled resin composite. Specimens were mounted with periodontal ligament simulation and loaded axially to fracture using a universal testing machine at 1 mm/min. Maximum fracture strength was recorded in Newtons. Fracture patterns were examined under 3× magnification and classified as favourable (Types 1-2) or unfavourable (Types 3-4). Differences among groups were analysed using one-way ANOVA with Games-Howell post-hoc tests at the significant level of 0.05.

Results: The control group showed the highest mean fracture strength (1265.7 N), followed by occlusal (846.1 N), MO (685.8 N), and MOD restorations (474.1 N). ANOVA revealed significant differences among all groups ($p<0.001$). Favourable fracture types predominated in intact and occlusal groups, whereas MO and MOD restorations showed substantially higher proportions of unfavourable Type 3 and Type 4 fractures. The MOD group exhibited the most catastrophic failures, with nearly half classified as a Type 4 failure.

Conclusions: Cavity configuration significantly influenced both fracture strength and fracture pattern of restored root-filled maxillary premolars. Preserving marginal ridges produced higher strength and more favourable fracture patterns. Further laboratory and clinical studies are warranted to optimise the management of structurally compromised premolars.

Keywords: composite resin, dental cavity preparation, dental restoration, endodontics, tooth fractures

Introduction

The long-term survival of root canal-treated or root-filled teeth is influenced by the quality of the definitive coronal restoration, which must restore structural integrity and withstand functional loading.(1) Although root-filled teeth were previously believed to be inherently weaker due to dentinal dehydration(2), altered mechanical properties(3), and the loss of pulpal tissue and proprioceptive responses(4), contemporary evidence suggests that the primary determinant of biomechanical compromise is not the root canal procedure itself but the loss of tooth structure associated with access cavity preparation, canal enlargement, and loss of peri-cervical dentine.(1,5) A recent study also reinforced that preservation of tooth structure, especially the marginal ridges and proximal walls, plays a more critical role in load resistance than previously understood.(6)

Of particular importance is the integrity of the marginal ridge, which contributes substantially to the structural bracing of posterior teeth.(7) Loss of a single marginal ridge reduces the fracture strength of posterior teeth by approximately 23%(8), whereas loss of both ridges in mesio-occluso-distal (MOD) preparations produces the greatest decrease in fracture strength of root-filled teeth.(9) Even when restored with composite resin, MOD cavities incorporating an endodontic access regain only limited fracture strength relative to intact teeth.(10) Moreover, experimental work on root-filled teeth restored with MOD cavities has demonstrated that reinforcement strategies, such as root canal posts, do not fully recover the load-bearing capacity of intact teeth.(11) Similarly, a previous work evaluating varying mesial marginal ridge thicknesses showed a stepwise decline in fracture strength of root-filled maxillary premolars as ridge thickness decreases, with complete loss of the ridge resulting in the weakest performance, even when fibre reinforcement is used.(12) These findings highlight that preservation of marginal ridges plays a more decisive role in the fracture strength of root-filled teeth than the choice of intracoronal reinforcement.

Maxillary premolars warrant special consideration, as vertical root fractures have been reported to occur frequently in both mandibular molars and maxillary premolars compared with other tooth types.(13) Recent finite element analysis has shown that greater dentine loss during access cavity preparation in maxillary premolars, particularly in designs that remove proximal walls, results in substantially higher stress concentrations across enamel, dentine, and the peri-cervical region compared with conservative designs.(14) Their anatomical form, characterised by thin cervical dentine, steep cusp inclines and a prominent mesial root concavity, renders them highly susceptible to cusp flexure and structural failure under both axial and lateral loading.(9) A recent systematic review and meta-analysis highlights that endodontically treated maxillary premolars are susceptible to fracture due to their anatomical and biomechanical characteristics, including thin cervical dentine and mesial root concavity. The review further indicates that, although fibre posts may increase fracture resistance compared with direct composite restoration without a post, fracture resistance generally remains inferior to that of sound premolars. Importantly, fracture behaviour of maxillary premolars appears to be strongly influenced by the amount and configuration of residual coronal structure, particularly marginal ridge preservation and the presence of MOD cavities, rather than being determined solely by the type of post system used.(9)

Despite the growing literature on minimally invasive access cavity designs and advancements in composite restorative materials(15,16), uncertainty remains regarding how progressive loss of marginal ridges, ranging from occlusal access to mesio-occlusal (MO) and MOD cavity configurations, affects fracture strength and failure patterns in root-filled maxillary premolars restored without cuspal coverage. Although previous in-vitro evidence showed that adding buccal and palatal cusp coverage can increase fracture strength of root-filled maxillary premolars by 45% as compared with conventional MOD composite restorations(17), such cuspal reduction is not universally practised among dentists.(18) In many cases, particularly in teeth with preserved cusp height or when indirect coverage is postponed, restoring root-filled upper premolars using intracoronal composite alone may be the restorative option. However, the independent biomechanical influence of cavity configuration under these conditions remains incompletely defined. Therefore, understanding how specific cavity designs influence the fracture behaviour of root-filled premolars is essential for evidence-based restorative decision-making. Accordingly, the present study aimed to evaluate the fracture strength and fracture patterns of root-filled maxillary premolars restored with direct resin-based composite using three cavity configurations: occlusal, MO, and MOD. The null hypothesis was that cavity configuration would have no significant effect on the fracture strength or fracture mode of restored root-filled premolars.

Materials and Method

Ethical approval

Ethical approval for the use of extracted human teeth was obtained from the National Health Service Research Ethics Committee. Ethics approval 16/WM/0236 (STH protocol number 18841). All procedures followed institutional laboratory safety standards and adhered to proper handling of biological specimens.

Sample size calculation

The sample size was calculated a priori using G*Power 3.1 (Heinrich-Heine University, Düsseldorf, Germany) for a one-way fixed-effects ANOVA (omnibus F-test). An effect size f=1.03 was derived from a previous similar study.[19] Using this effect size, with a significance level α=0.05, desired statistical power of 0.95, and four groups (three test groups and one control), the minimum total sample size required was 24 teeth, corresponding to 6 specimens per group. To compensate for potential exclusion of teeth due to undetected cracks, caries, or procedural errors during preparation and mounting, the calculated sample size was set at 40 teeth, yielding 10 specimens per group.

Sample selection and preparation

Forty freshly extracted maxillary permanent premolars were collected and stored in normal saline solution at room temperature and used within three months. Only single-rooted maxillary premolars were included. Root morphology was verified using pre-operative periapical radiographs taken in bucco-lingual (BL) and mesio-distal (MD) directions to confirm the absence of root bifurcation, external resorption, or severe curvature. Teeth with separated roots or marked anatomical variations were excluded to ensure standardisation. Canal configuration was not used as an exclusion criterion, as instrumentation was standardised across specimens. All teeth were then thoroughly debrided using a hand scaler to remove calculus, soft tissue remnants, and debris. Each sample was examined under an operating microscope (3.0× magnification) to verify the absence of cracks, structural defects, or previous restorations. Standardisation of size was achieved by measuring the BL and MD dimensions at the cemento-enamel junction (CEJ) level, and the occluso-gingival (OG) height from cusp tip to CEJ using a digital calliper (Mitutoyo Corp., Kawasaki, Japan) with 0.01 mm accuracy. The mean dimensions of the selected teeth were 9.15±0.12 mm (BL), 7.38±0.11 mm (MD), and 5.96±0.10 mm (OG). Teeth were included if they were maxillary permanent premolars, caries-free, unrestored, single-rooted, without visible fractures, and within the standardised dimensional range.

The samples were randomly allocated into four groups (n=10 per group): Group A (root-canal–treated teeth restored with occlusal composite), Group B (root-canal–treated teeth restored with MO composite), Group C (root-canal–treated teeth restored with MOD composite), and Group D (intact, untreated teeth serving as control).

Root canal treatment procedure

Root canal treatment (RCT) was performed on teeth assigned to Groups A–C. Access cavities were prepared using a cavity access bur set (Dentsply Maillefer, Ballaigues, Switzerland). Coronal flaring of the canal orifice was accomplished using Gates Glidden drills (sizes 4, 3, 2, and 1; Dentsply Maillefer, Ballaigues, Switzerland) sequentially with an X-smart™ contra-angle handpiece (Dentsply Maillefer, Ballaigues, Switzerland). Apical preparation was carried out using stainless steel K-files (size 30; Dentsply Maillefer, Ballaigues, Switzerland) to a working length 0.5 mm short of the radiographic apex, employing a step-back technique in 1-mm increments.

During instrumentation, canals were irrigated with 5.25% sodium hypochlorite solution (NaOCl, Vishal Dentocare Pvt. Ltd., Ahmedabad, India). A final rinse with 17% ethylenediaminetetraacetic acid (EDTA; Pulpdent Corporation, Watertown, MA, USA) for 1 minute was followed by a final rinse of 5.25% NaOCl for another 30 seconds before drying. Canals were then dried with sterile paper points (Dentsply Maillefer, Ballaigues, Switzerland). Obturation was carried out using a size 30 matched-taper gutta-percha master cone (Dentsply Maillefer, Ballaigues, Switzerland) in combination with a zinc oxide–eugenol–based sealer (Tubli-Seal™ EWT, Kerr Endodontics, Orange, CA, USA). Cold lateral condensation was performed using size A and size B finger spreaders (Dentsply Maillefer, Ballaigues, Switzerland) together with size A and B accessory gutta-percha points. Gutta-percha was vertically compacted 2 mm below the cemento-enamel junction (CEJ) using a heated hand instrument activated by an induction heater (Noflameplus, Micerium S.p.A., Avegno, Italy). After obturation, the pulp chamber and canal orifice were cleaned using alcohol-soaked cotton pellets to remove residual sealer and eugenol-containing materials. The teeth were kept at room temperature for 24 hours for the sealer to set.

Cavity preparation

Standardised cavity preparations were performed under water coolant using a high-speed handpiece (X-smart™, Dentsply Maillefer, Ballaigues, Switzerland) with tapered diamond burs (Komet Dental, Lemgo, Germany) under 3.0× magnification. The occlusal cavity (Group A) involved only the endodontic access cavity with a pulpal depth of 1 mm above the proximal CEJ. The average occlusal cavity depth measured from the central groove to the pulpal floor was standardised at 4±0.2 mm. The MO cavity (Group B) consisted of an access cavity plus a mesial box with a standardised 1/3 bucco-palatal width. The MOD cavity (Group C) incorporated both mesial and distal boxes, each also standardised to 1/3 bucco-palatal width. In the MO and MOD groups, proximal box depth extended to 1 mm above the CEJ to ensure uniform marginal ridge removal and wall thickness reduction. All cavity depths were standardised to 1 mm above the proximal CEJ. All preparations were verified for consistency using a periodontal probe (Hu-Friedy, Chicago, IL, USA).

Restorative procedure

Following RCT, gutta-percha was removed to 2 mm below the CEJ. A glass ionomer base (GC Fuji IX GP EXTRA, GC Corporation, Tokyo, Japan) was placed and allowed to set according to the manufacturer's instructions. Enamel and dentine were etched using 37% phosphoric acid for 20 seconds, rinsed thoroughly, and dried gently. A universal bonding agent (Scotchbond™ Universal Adhesive, 3M ESPE, St. Paul, MN, USA) was applied and light-cured for 15 seconds according to the manufacturer's instructions using an LED curing light (Henry Schein®, Gillingham, UK). The LED curing unit delivered a light intensity of 1000 mW/cm², verified using a radiometer prior to use. All cavities were restored incrementally (~ 2mm) using a nano-filled resin composite (Filtek™ Supreme XTE Universal Restorative, shade A2B; 3M ESPE, St. Paul, MN, USA). Each increment was polymerised for 20 seconds using the same LED curing light. Restorations were finished and polished using the Enhance® Finishing and Polishing System (Dentsply Caulk, Milford, DE, USA). Completed specimens were stored in normal saline at room temperature before further procedures.

Sample mounting and periodontal ligament simulation

To simulate the periodontal ligament (PDL), a two-stage mounting method was employed based on Brosh *et al.*[20] Each tooth was coated with a thin layer of die separator (Renfert GmbH, Hilzingen, Germany) to create uniform spacing. Teeth were positioned upside down, with the long axis perpendicular to the horizontal plane, and embedded in Dublisil® 15 A/B silicone material (Dreve Dentamid GmbH, Unna, Germany) using a dental surveyor to ensure alignment and standardisation (Figure 1a). The embedding height was limited to 2 mm apical to the CEJ. After the silicone had set, cylindrical copper rings (RS Components Ltd., Corby, UK) were centred around the exposed root surface (Figure 1b). A polyurethane resin (AlphaDie® MF, Schütz Dental GmbH, Rosbach, Germany) was mixed according to the manufacturer's specifications and poured into the ring to envelop the exposed root. Once polymerised, the tooth was removed from the resin block, and the resulting socket was filled with a light-body polyvinyl siloxane impression material (President Plus® Light Body, Coltene/Whaledent AG, Altstätten, Switzerland). The tooth was immediately reseated and held in place until the material set (Figure 2). Excess silicone was trimmed using a size 11 surgical blade (Swann-Morton, Sheffield, UK). Only specimens with mobility grade 0 were accepted for mechanical testing.

Mechanical testing (fracture strength assessment)

Fracture strength was evaluated using a universal testing machine (Lloyd Instruments LRX, Ametek Inc., Fareham, UK). Each mounted specimen was positioned on the machine platform such that its long axis was perpendicular to the loading direction. A stainless-steel spherical indenter with a diameter of 4.5 mm (Ametek

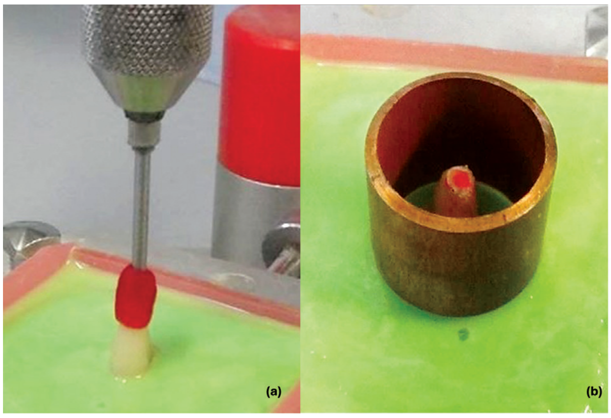

Figure 1: (a) The tooth sample was mounted upside down in the container containing silicone material with the aid of a dental surveyor; (b) The tooth sample was positioned in the centre of a cylindrical copper ring.

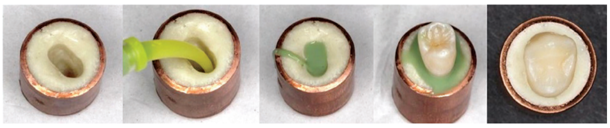

Figure 2: Composite image showing the injection of light-body silicone impression material into the tooth socket to simulate the periodontal ligament.

Inc., Fareham, UK) was attached to the crosshead, and a 1-mm-thick rubber dam sheet (Coltene Rubber Dam, Altstätten, Switzerland) was placed between the indenter and the occlusal surface to minimise stress concentration. A static compressive axial load was applied at a crosshead speed of 1 mm/min until catastrophic fracture occurred. The maximum load required to fracture each sample was automatically recorded in Newtons (N).[21]

Fracture pattern analysis

Fractured specimens were examined under 3.0× magnification using an operating microscope. Fracture patterns were classified into restorable (favourable) and non-restorable (non-favourable/catastrophic) fractures according to Soares's classification (Type 1 to Type 4).[10]

Type 1: fractures involving small tooth portions (coronal)

Type 2: fractures involving tooth portions (coronal) and cohesive failure of composite resin

Type 3: fractures involving tooth portions, with periodontal involvement and adhesive failure of composite resin

Type 4: vertical root/coronal fracture

For intact control teeth, Type 2 classification was assigned to fractures confined coronally without periodontal involvement, while Type 3 classification was assigned to fractures with periodontal involvement, consistent with the severity-based criteria of Soares *et al*.[10] In these specimens, cohesive composite failure was not applicable, and classification was based solely on fracture extent and restorability.

Statistical analysis

Data analysis was performed using SPSS software (Version 24.0; IBM SPSS Inc., Chicago, IL, USA). Normality of distribution was assessed using the Shapiro–Wilk test. One-way analysis of variance (ANOVA) was conducted to compare mean fracture strength across the four groups. The Games–Howell post-hoc test was selected for multiple pairwise comparisons due to heterogeneity of variances. Statistical significance was set at $\alpha=0.05$ for all analyses. In addition, the distribution of favourable (Types 1-2) and unfavourable (Types 3-4) fracture modes among groups was compared using Fisher's exact test, as several expected cell counts were below five. Statistical significance was set at $\alpha=0.05$.

Results

Fracture Strength

Normality testing using the Shapiro–Wilk test confirmed that the data were normally distributed for all groups ($p>0.05$). Fracture strength values are summarised in Table 1 and illustrated in Figure 3. The control group (intact premolars) recorded the highest mean fracture strength (1265.7 N), whereas the MOD group showed the lowest (474.1 N). Among restored teeth, occlusal restorations demonstrated the greatest fracture strength (846.1 N), followed by MO (685.8 N) and MOD (474.1 N). These results show a clear reduction in fracture strength with increasing cavity complexity and loss of marginal ridge support. A one-way ANOVA confirmed significant differences among the groups ($F(3,36) = 36.27$, $p<0.001$), indicating that cavity design significantly influenced fracture strength. Levene's test ($p<0.05$) and Welch's test both indicated unequal variances; therefore, the Games–Howell post-hoc test was used. Pairwise comparisons (Table 2) showed significant differences between all groups ($p<0.05$). The control group differed from all restored groups, and each restoration configuration differed significantly from the others. MOD restorations consistently showed the lowest fracture values. Overall, fracture strength decreased markedly with the loss of marginal ridges, with MOD cavities performing the poorest.

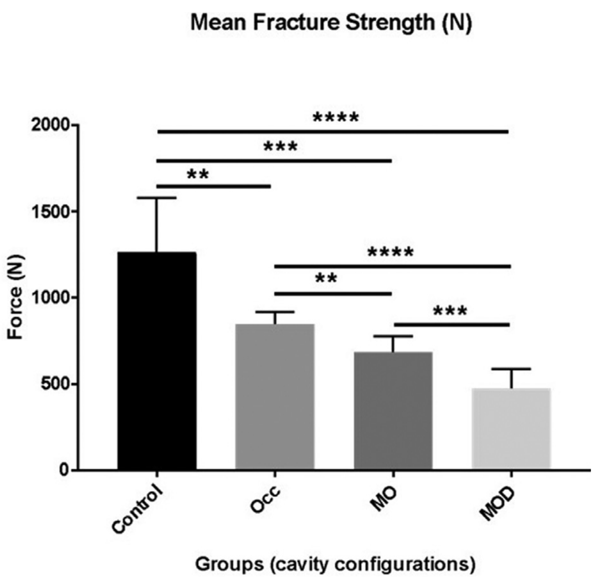

Figure 3: The mean fracture strength (N) of all groups.

Fracture pattern

The control group predominantly exhibited Type 1 fractures (6 out of 10), with no occurrence of Type 4 catastrophic fractures (Figure 4). In contrast, the occlusal group showed mostly Type 2 fractures (5 out of 10) and only one Type 4 fracture. The MO group displayed a higher proportion of severe fractures, with Type 3 fractures being the most frequent (7 out of 10) and 2 cases of Type 4 fractures. The MOD group demonstrated the most catastrophic outcomes, with nearly equal distribution of Type 3 (4 out of 10) and Type 4 fractures (5 out of 10). The frequency of unfavourable fractures (Types 3 and 4) increased with the complexity of the cavity design. MO and MOD restorations showed substantially more non-restorable, sub-CEJ fractures compared to the control and occlusal groups, which tended to exhibit more favourable, restorable fracture types. Fisher's exact test confirmed a statistically significant association between cavity configuration and fracture mode distribution ($p<0.001$), indicating that increasing marginal ridge loss significantly increased the likelihood of unfavourable fractures.

Table 1: Fracture strength (N) of all tested groups.

Group	n	Mean (N)	SD	SE	95% CI (Lower)	95% CI (Upper)	Min (N)	Max (N)
Control	10	1265.70	312.40	98.79	1042.22	1489.18	977	1890
Occlusal	10	846.10	72.62	22.96	794.15	898.05	720	960
MO	10	685.80	90.31	28.56	621.19	750.41	570	882
MOD	10	474.10	113.40	35.86	392.98	555.22	228	586
Total	40	817.93	339.10	53.62	709.47	926.38	228	1890

CI: confidence interval; SD: standard deviation; SE: standard error

Table 2: Games–Howell post-hoc pairwise comparisons.

Group Comparison	Mean Difference (N)	SE	Sig.	95% CI (Lower)	95% CI (Upper)
Control – Occlusal	419.60*	101.42	0.009	109.14	730.06
Control – MO	579.90*	102.84	0.001	267.96	891.84
Control – MOD	791.60*	105.10	<0.001	476.81	1106.39
Occlusal – MO	160.30*	36.65	0.002	56.26	264.34
Occlusal – MOD	372.00*	42.58	<0.001	249.57	494.43
MO – MOD	211.70*	45.84	0.001	81.50	341.90

*Significant at $p<0.05$

CI: confidence interval; MO: mesio-occlusal; MOD: mesio-occluso-distal; SE: standard error

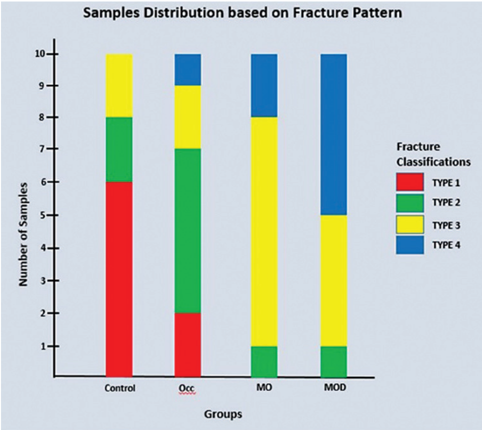

Figure 4: Distribution of samples according to fracture pattern across all groups.

Discussion

The present study investigated the effect of three cavity configurations, namely occlusal, MO, and MOD, on the fracture strength and fracture pattern of root-filled maxillary premolars restored with direct resin composite without cuspal coverage. The findings demonstrated that cavity configuration had a significant effect on the load-bearing capacity of restored teeth, with fracture strength decreasing substantially as cavity complexity increased. These results align with the well-established principle that the amount and configuration of remaining tooth structure are the primary determinants of biomechanical performance in root-filled teeth.(6,9) Intact premolars in the control group exhibited the highest fracture strength, consistent with previous research showing that sound teeth withstand high occlusal forces and fail in more favourable patterns due to their intact structural bracing and preserved enamel "compression dome".(10,17,19) In contrast, all restored groups exhibited significantly lower fracture strength, reinforcing earlier findings that neither root canal treatment nor composite restoration can fully restore the mechanical integrity of intact teeth, particularly when marginal ridge loss is involved.(6,22,23) The decline in fracture strength from occlusal to MO and finally MOD restorations reflects the increasingly detrimental effect of structural loss rather than the restorative material itself.

Among restored groups, occlusal restorations showed the highest fracture strength (846.1 N), approaching physiologic posterior occlusal loads and outperforming MO and MOD configurations. This supports the biomechanical principle that when both marginal ridges remain intact, the tooth retains substantial structural integrity.(24) Finite element analyses have suggested that loss of proximal walls may exert greater influence on stress distribution than moderate variations in canal shaping, supporting the present finding that coronal structural integrity plays a critical biomechanical role.(6) The significantly lower strength observed in MO preparations (685.8 N) demonstrates the importance of even a single marginal ridge, as its loss creates unilateral weakening and predisposes to flexure along the unsupported cusp. Notably, a recent comparative study suggested that conventional resin composite types may have a limited influence on fracture strength in extensive MOD cavities, although advanced fibre-reinforced materials may offer additional reinforcement potential.(25) These results further confirm that, although adhesive composites are excellent restorative materials for root-filled teeth, they cannot fully compensate for extensive structural loss when one or both marginal ridges are compromised.

Fracture pattern analysis reinforced the fracture strength findings. Intact teeth exhibited mostly Type 1 fractures, consistent with failures confined above the CEJ and considered restorable. Occlusal restorations showed predominantly Type 2 fractures, also largely favourable. In contrast, the MO and MOD groups demonstrated a much higher proportion of severe, non-restorable Type 3 and Type 4 fractures. MOD restorations, in particular, exhibited nearly half catastrophic Type 4 fractures extending below the CEJ, corroborating previous studies that correlate increased cavity size and marginal ridge loss with unfavourable fracture outcomes.(8,26) In the present study, the proximal box width was standardised to approximately one-third of the bucco-palatal dimension, which inevitably reduced the remaining wall thickness in the MO and especially the MOD configurations. Given the average MD dimension of the selected premolars, this preparation likely resulted in residual wall thickness approaching the biomechanical threshold previously reported to compromise fracture resistance. These findings highlight that cavity configuration not only influences fracture load but also directly affects the restorability and clinical prognosis of failed teeth. From a clinical perspective, this highlights the importance of preserving marginal ridges whenever possible and suggests that MOD-restored premolars may benefit from additional reinforcement or cuspal coverage to reduce the risk of catastrophic fracture.(17) Evidence from a previous study also indicates that when residual wall thickness falls below 2 mm, cuspal coverage becomes the preferred approach capable of achieving satisfactory fracture strength in maxillary premolars.[27]

Direct comparison with previous studies should be interpreted cautiously, as differences in load-testing protocols, such as indenter size, presence of an interface material, and crosshead speed, may influence fracture strength values. These methodological variations act as confounding factors that limit direct numerical comparison across studies. For instance, the present study used a 4.5-mm stainless-steel spherical indenter to simulate occlusal contact over functional cusp inclines and to distribute load over a broader area, and applied a static axial load at 1 mm/min. However, a previous similar study utilised a larger indenter diameter of 5.7 mm with a slower crosshead speed of 0.5 mm/min.[25] Chai *et al*.,[28] further highlighted that indenter geometry can substantially alter fracture initiation behaviour even in intact premolars, owing to changes in contact mechanics at the occlusal surface. Such findings reinforce that variability in testing configurations can shift fracture thresholds, complicating direct comparison across studies. Future investigations incorporating varying indenter geometries and angled loading protocols are recommended to better simulate functional occlusal contacts.

Several limitations must be considered in the present study. First, as with all *in vitro* studies, static loading cannot fully replicate complex intraoral conditions such as thermal fluctuations, cyclic fatigue, multidirectional forces, or long-term degradation of adhesive interfaces. The compressive or axial loading applied during the fracture strength test does not fully replicate intraoral conditions, where occlusal forces vary considerably in magnitude, direction, and dynamic loading patterns. Second, the present study evaluated only one composite resin material and did not assess alternative reinforcement strategies such as fibre-reinforced composite materials, bulk-fill composites, or cuspal coverage restorations. Future studies should incorporate cyclic fatigue testing, thermomechanical loading, and three-dimensional imaging of failure patterns to better simulate clinical function. Investigating cuspal coverage, indirect restorations, or novel composite reinforcement techniques for MOD preparations would also provide valuable insights. Ultimately, well-designed clinical trials are needed to validate these laboratory findings and guide evidence-based restorative decision-making for root-filled maxillary premolars.

Conclusions

Within the limitations of this *in vitro* study, cavity configuration significantly influenced both fracture strength and fracture mode of root-filled maxillary premolars restored with direct resin composite without cuspal coverage. Preservation of marginal ridges resulted in higher fracture resistance and more favourable fracture patterns, whereas loss of one or both ridges substantially increased the risk of catastrophic fracture. These findings highlight the critical biomechanical importance of coronal structural preservation in restorative decision-making.

Acknowledgments

This research forms part of the doctoral thesis work of the first author, completed as a requirement for the Doctor of Clinical Dentistry in Prosthodontics.

Funding

The study received no funding.

Conflict of Interest

The authors declare no conflicts of interest.

References

1. Mannocci F, Bitter K, Sauro S, Ferrari P, Austin R, Bhuva B. Present status and future directions: the restoration of root filled teeth. Int Endod J. 2022;55 Suppl 4(Suppl 4):1059-84.
2. Winter W, Karl M. Dehydration-induced shrinkage of dentin as a potential cause of vertical root fractures. J Mech Behav Biomed Mater. 2012;14:1-6.
3. Andreasen JO, Farik B, Munksgaard EC. Long-term calcium hydroxide as a root canal dressing may increase risk of root fracture. Dent Traumatol. 2002;18(3):134-7.
4. Awawdeh L, Hemaidat K, Al-Omari W. Higher maximal occlusal bite force in endodontically treated teeth versus vital contralateral counterparts. J Endod. 2017;43(6):871-5.
5. Haridoss S, Rajendran M, Swaminathan K, Anbarasi, Sharma A, Elumalai V. Impact of pericervical dentin on fracture resistance of endodontically treated posterior permanent teeth: a systematic review and meta-analysis. J Contemp Dent Pract. 2024;25(4):372-85.
6. Abdelfattah RA, Nawar NN, Kataia EM, Saber SM. How loss of tooth structure impacts the biomechanical behavior of a single-rooted maxillary premolar: FEA. Odontology. 2024;112(1):279-86.
7. Palamara JE, Palamara D, Messer HH. Strains in the mar-

ginal ridge during occlusal loading. Aust Dent J. 2002;47(3): 218-22.
8. Shirani F, Saatchi M, Shirani M, Jafari N. Evaluation of the fracture resistance of conservative and ultraconservative access cavity designs with different treatment modalities: an *in vitro* study. Biomed Res Int. 2023;2023:7247375.
9. Iaculli F, Rengo C, Lodato V, Patini R, Spagnuolo G, Rengo S. Fracture resistance of endodontically-treated maxillary premolars restored with different type of posts and direct composite reconstructions: a systematic review and meta-analysis of *in vitro* studies. Dent Mater. 2021;37(9):e455-e84.
10. Soares PV, Santos-Filho PCF, Queiroz EC, Araujo TC, Campos RE, Araujo CA, *et al*. Fracture resistance and stress distribution in endodontically treated maxillary premolars restored with composite resin. J Prosthodont. 2008;17(2):114-9.
11. da Rocha DM, Tribst JPM, Ausiello P, Dal Piva AMO, da Rocha MC, Di Nicolo R, *et al*. Effect of the restorative technique on load-bearing capacity, cusp deflection, and stress distribution of endodontically-treated premolars with MOD restoration. Restor Dent Endod. 2019;44(3):e33.
12. Kalburge V, Yakub SS, Kalburge J, Hiremath H, Chandurkar A. A comparative evaluation of fracture resistance of endodontically treated teeth, with variable marginal ridge thicknesses, restored with composite resin and composite resin reinforced with Ribbond: an *in vitro* study. Indian J Dent Res. 2013;24(2):193-8.
13. Cohen S, Berman LH, Blanco L, Bakland L, Kim JS. A demographic analysis of vertical root fractures. J Endod. 2006;32(12):1160-3.
14. Uslu G, Arican B, Gundogar M, Ozyurek T. How does endodontic access cavity design affect the biomechanics of a maxillary premolar?? a finite element analysis study. BMC Oral Health. 2025;25(1):1439.
15. Silva E, De-Deus G, Souza EM, Belladonna FG, Cavalcante DM, Simoes-Carvalho M, *et al*. Present status and future directions - minimal endodontic access cavities. Int Endod J. 2022;55 (Suppl 3):531-87.
16. Lin GSS, Cher CY, Cheah KK, Noorani TY, Ismail NH, Ghani N. Novel dental composite resin derived from rice husk natural biowaste: a systematic review and recommendation for future advancement. J Esthet Restor Dent. 2022;34(3):503-11.
17. Mincik J, Urban D, Timkova S, Urban R. Fracture resistance of endodontically treated maxillary premolars restored by various direct filling materials: an *in vitro* study. Int J Biomater. 2016;2016:9138945.
18. Abu-Awwad M. Dentists' decisions regarding the need for cuspal coverage for endodontically treated and vital posterior teeth. Clin Exp Dent Res. 2019;5(4):326-35.
19. Lin GSS, Ghani NRNA, Noorani TY, Ismail NH. Fracture resistance of the permanent restorations for endodontically treated premolars. Eur J Gen Dent. 2018;7(3):56-60.
20. Brosh T, Porat N, Vardimon AD, Pilo R. Appropriateness of viscoelastic soft materials as *in vitro* simulators of the periodontal ligament. J Oral Rehabil. 2011;38(12):929-39.
21. Lin GS, Ghani NR, Ismail NH, Singbal K, Murugeshappa DG, Mamat N. Fracture strength of endodontically treated lateral incisors restored with new zirconia reinforced rice husk nanohybrid composite. J Clin Exp Dent. 2020;12(8):e762-e70.
22. Shahrbaf S, Mirzakouchaki B, Oskoui SS, Kahnamoui MA. The effect of marginal ridge thickness on the fracture resistance of endodontically-treated, composite restored maxillary premolars. Oper Dent. 2007;32(3):285-90.
23. Gokturk H, Karaarslan ES, Tekin E, Hologlu B, Sarikaya I. The effect of the different restorations on fracture resistance of root-filled premolars. BMC Oral Health. 2018;18(1):196.
24. Patel SR, Youngson C, Jarad F. Principles guiding the restoration of the root-filled tooth. Br Dent J. 2025;238(7): 508-16.
25. Taha R, Ibrahim AH, Ibrahim SH. *In vitro* assessment of fracture resistance of premolar teeth restored with diatomite zirconia versus barium glass filled resin composite. Sci Rep. 2025;15(1):32438.
26. Daniel A, Saleh AR, Al-Jadaa A, Kheder W. Impact of access cavity design on fracture resistance of endodontically treated maxillary first premolar: *in vitro*. Braz Dent J. 2024;35:e245676.
27. Scotti N, Rota R, Scansetti M, Paolino DS, Chiandussi G, Pasqualini D, *et al*. Influence of adhesive techniques on fracture resistance of endodontically treated premolars with various residual wall thicknesses. J Prosthet Dent. 2013;110(5):376-82.
28. Chai H. On dental anatomy and the fracture resistance of maxillary premolar teeth. Int J Solids Struct. 2025;322: 113620.