Original Article

DOI: 10.7860/JCDR/2026/90932.24529

Dentistry Section

Fracture Resistance of Mandibular Second Primary Molars after Rotary Instrumentation and Adhesive Bulk-Fill Composite Restoration: An In-vitro Study

SELVAKUMAR HARIDOSS[1], R MATHAN RAJAN[2], ANBARASI[3], KAVITHA SWAMINATHAN[4], E VIJAYARAGAVAN[5]

ABSTRACT

Introduction: Endodontic access and canal preparation can compromise the structural integrity of primary teeth. Standardised adhesive coronal reinforcement may mitigate fracture susceptibility after pulpectomy in primary molars. Comparative evidence on paediatric rotary instrumentation systems combined with standardised adhesive restoration of primary molars is limited.

Aim: To compare the fracture resistance of mandibular second primary molars in five groups: an intact reference, an unrestored access-only group, and three rotary-instrumented groups restored with the same adhesive bulk-fill composite.

Materials and Methods: This laboratory-based in-vitro study, reported in accordance with the Preferred Reporting Items for Laboratory studies in Endodontology (PRILE) 2021 guidelines, was conducted in the Department of Paediatric and Preventive Dentistry at Sri Ramachandra Dental College and Hospital between December 2023 and June 2024. A total of 125 extracted mandibular second primary molars were allocated to five groups (n=25): Group I (intact, no access cavity preparation), Group II (access cavity preparation only; no instrumentation, obturation, or restoration, unrestored), Group III (XP-endo Shaper), Group IV (NeoEndo PedoFlex), and Group V (Kedo SG). Groups III-V underwent instrumentation, obturation with Metapex (calcium hydroxide–iodoform paste), and coronal restoration using etch-and-rinse adhesive with bulk-fill resin composite. The specimens were mounted with periodontal ligament simulation (light-body polyvinyl siloxane) and loaded in compression (30°; 0.5 mm/min) until fracture. The outcomes assessed were maximum force, compressive stress at maximum force, compressive displacement at break, and compressive stress at break. One-way Analysis of Variance (ANOVA) with Tukey's post-hoc test was performed. A p-value<0.05 was considered statistically significant.

Results: Group I (intact) had the highest mean maximum force (933.59±383.55 N), while group II had the lowest (325.82±128.45 N). Groups III, IV, and V showed comparable intermediate values. The maximum force and compressive stress at maximum force differed significantly across the groups (p<0.001), and the compressive stress at break also differed significantly (p=0.027), whereas the displacement at break did not differ significantly (p=0.243). Group II showed significantly lower values than all other groups for maximum force and compressive stress at maximum force, and group I showed significantly higher values than groups II, III, IV, and V for these parameters. No significant differences were detected among groups III, IV, and V. For compressive stress at break, group V (Kedo SG) was significantly higher than group I (intact), and no other pairwise differences reached significance.

Conclusion: An unrestored access cavity markedly compromises the fracture resistance of mandibular primary second molars. Endodontic instrumentation, followed by a standardised adhesive bulk-fill composite restoration, substantially improved fracture resistance relative to the unrestored condition, approaching the intact reference. The three rotary systems did not differ significantly from one another. Kedo SG exhibited a significantly higher compressive stress at break than the intact reference, with no other pairwise differences observed for this parameter.

Keywords: Composite resins, Deciduous tooth, Pulpectomy, Root canal preparation

INTRODUCTION

Pericervical Dentin (PCD), the dentin surrounding the tooth in the cervical region around the Cementoenamel Junction (CEJ), is increasingly regarded as a key biomechanical determinant of the structural integrity of endodontically treated teeth [1-3]. PCD is often described as the dentin within approximately 4 mm coronal and 4 mm apical to the CEJ/crestal bone level, where functional stress concentrates during mastication and parafunction [1,4]. Loss of dentin in this zone increases the stress concentration and reduces the fracture resistance, particularly when combined with extensive access preparation and canal flaring [5-7].

From a paediatric perspective, the PCD concept is clinically relevant because primary molars have comparatively thinner dentin walls, larger pulp chambers, and pronounced cervical anatomy, which may predispose them to structural compromise after endodontic access and shaping [8-10]. Consequently, minimally invasive endodontic approaches emphasising directed dentin conservation during access and shaping have been advocated to preserve the PCD and improve the long-term survival of teeth [2,3,11].

The fracture resistance of endodontically treated teeth is not dictated by dentin preservation alone; it is also influenced by the extent and quality of coronal reinforcement. Adhesively bonded restorations can partially recover stiffness by coupling the cusps and redistributing functional loads, thereby reducing cuspal deflection and the risk of catastrophic fracture [12,13]. In primary teeth, adhesive performance and restorative selection have been evaluated in laboratory and clinical studies, including evidence supporting contemporary adhesive systems and bulk-fill composites in appropriately selected posterior primary teeth [14,15]. Nevertheless, the reinforcing effect of adhesive restorations remains dependent on the remaining dentin scaffold, particularly the PCD, and cannot fully compensate for extensive cervical dentin loss [6,13].

Systematic reviews, ex-vivo studies, and finite element analyses have consistently demonstrated that access cavity design and canal taper/enlargement influence the remaining dentin thickness, stress distribution, and fracture resistance [5,16-18]. The Cone Beam Computed Tomography (CBCT) -based investigations have further confirmed that access design and instrumentation strategies can alter PCD thickness [19-22]. In primary molars, access cavity geometry has been shown to influence instrumentation efficacy and fracture strength, underscoring the need for tooth- and age-specific evidence [23].

Contemporary paediatric NiTi systems (including the file systems evaluated in the present study) differ in taper, metallurgy, and mechanical behaviour, which may result in differences in dentin removal patterns and biomechanical responses during and after canal preparation [24-26]. However, comparative data on the influence of rotary preparation strategies on the fracture resistance of mandibular second primary molars when coronal restoration is standardised using an adhesive bulk-fill composite protocol are limited.

Finite Element Analysis (FEA) is valuable for visualising stress distribution, but laboratory mechanical testing provides direct empirical validation of fracture resistance under controlled loading. In a primary molar FEA study, conservative access designs improved stress patterns compared with conventional access designs [27]. This laboratory-based investigation constitutes the third and final phase of a three-phase doctoral research project. Phase I involved the quantification of PCD in mandibular second primary molars, while Phase II assessed the biomechanical impact of various instrumentation techniques and adhesive restorations on PCD using FEA. The current phase offers direct empirical validation of fracture resistance through laboratory-based experiments following actual instrumentation and restoration with these systems. By controlling the adhesive restorative variable, the present study sought to clarify the combined mechanical effect of endodontic instrumentation, obturation and standardised adhesive coronal restoration following access preparation and to inform evidence-based minimally invasive paediatric endodontic protocols. Hence, the present study aimed to compare the fracture resistance of mandibular second primary molars across an intact control, unrestored access cavity, and three rotary-instrumented and adhesively restored groups, and to determine whether the three instrumentation systems differed from one another once coronal restoration was standardised. The primary objective of the present study was to compare the fracture resistance across all five groups. The secondary objective was to determine whether the three rotary instrumentation systems differed from one another once the coronal restoration was standardised.

Null hypothesis (H0): There is no significant difference in fracture resistance among the intact, access-only, and three rotary-instrumented and adhesively restored groups.

Alternative hypothesis (H1): There is a significant difference in fracture resistance among the intact, access-only, and rotary-instrumented and adhesively restored groups.

MATERIALS AND METHODS

This laboratory-based in-vitro study was conducted in the Department of Paediatric and Preventive Dentistry, Sri Ramachandra Dental College and Hospital, Sri Ramachandra Institute of Higher Education and Research, Chennai, India, from December 2023 to June 2024, as Phase III of a three-phase doctoral research project. The study protocol was approved by the Institutional Ethics Committee of the Sri Ramachandra Institute of Higher Education and Research (Approval No. IECNI/21/Aug/79/111).

The study evaluated the fracture resistance of mandibular second primary molars following access preparation and rotary instrumentation with standardised obturation and adhesive bulk-fill composite coronal restoration in the instrumented group. The experimental methods were reported according to the PRILE 2021 checklist for laboratory studies in endodontology [28], and the completed PRILE checklist is provided as a supplementary file.

Inclusion criteria: Mandibular second primary molars were obtained following extraction by the treating clinicians for indications unrelated to the present study, including orthodontic treatment, submerged teeth, and ankylosis; no extractions were performed specifically for research purposes. The extracted teeth were subjected to radiographic screening, and only specimens with at least two-thirds of the root length intact were included.

Exclusion criteria: Teeth with fractures, caries extending into the root, or structural anomalies were excluded. Teeth extracted surgically because of submergence or ankylosis were additionally subjected to radiographic and visual examination before inclusion. Specimens exhibiting gross structural distortion attributable to the extraction procedure were excluded.

Teeth were collected from the Department of Paediatric and Preventive Dentistry, Sri Ramachandra Institute of Higher Education and Research, as well as from external dental clinics and Outpatient Departments (OPD) of the university. Before collection, written informed consent was obtained from the parents or legal guardians for the research use of the already extracted teeth (not for the extraction procedure itself) in their preferred language (English or Tamil), in accordance with the principles of the Declaration of Helsinki [29]. The guardians who provided consent were informed of the study objectives, procedures, potential risks, and possible benefits in simple and comprehensible language. They were explicitly informed that the extracted teeth would be used solely for laboratory research purposes, that participation was entirely voluntary, that no payment would be provided, and that refusal or withdrawal at any stage would not affect the clinical care provided to their children. Confidentiality was strictly maintained, and no personal or identifying information was recorded or linked to any collected specimen. All teeth were handled, stored, and disposed of in accordance with Institutional biosafety guidelines.

Sample size calculation: The sample size was estimated using G*Power (One-way ANOVA, fixed effects, omnibus) with α=0.05, power (1-β)=0.80, five groups, and an assumed effect size (Cohen's f=0.32, a medium-to-large effect by convention [30]), yielding a minimum total sample size of 125 specimens (25 specimens per group). No additional attrition or replacement allowance was incorporated into this calculation. As this was a non clinical, single-timepoint laboratory protocol in which every screened specimen meeting the inclusion criteria underwent testing with no follow-up period, dropout/attrition was not anticipated and was therefore not included in the sample size calculations. Accordingly, 125 extracted human mandibular second primary molars were randomly allocated to five groups (n=25/group) using a computer-generated random sequence, with allocation concealment maintained from whoever assigned the specimens to the groups. No specimen was excluded or replaced after allocation because fracture or visible distortion under load is the defined outcome measure of this destructive, single-load-to-failure test rather than an adverse event; every allocated specimen was tested once, its failure load recorded, and the specimen then disposed of in accordance with institutional biosafety guidelines.

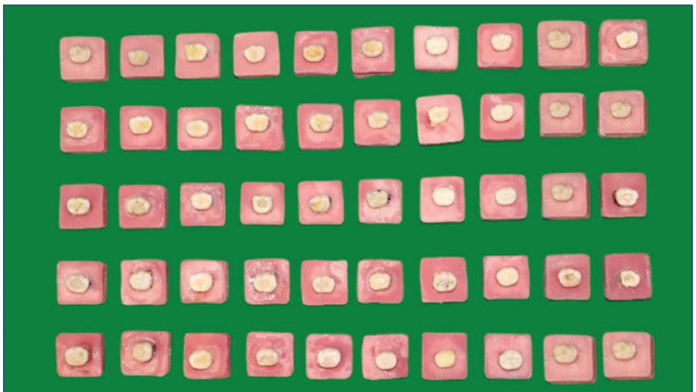
Study Procedure

Specimen selection, screening, and storage: After debridement of soft tissue remnants, the specimens were stored in 0.1% thymol at 4±2°C (temperature-monitored refrigerator, 2-8 °C) for not more than one month before testing, ISO/TS 11405:2015 was referred to only for specimen storage/handling conditions and was not used as the protocol for fracture-resistance testing [31]. The solution was renewed weekly, and the containers were shielded from light. Prior to adhesive procedures and mechanical testing, the teeth were rinsed, soaked in fresh distilled water for 24 hours (one water change), and brought to room temperature.

Specimen mounting (periodontal ligament simulation): Each tooth was embedded in acrylic resin blocks up to the CEJ to simulate the alveolar support. To simulate periodontal ligament behaviour, a thin layer of light-body polyvinyl siloxane was applied around the root surfaces prior to embedding [32].

Access cavity preparation: Access cavities were prepared following the conventional cavity design described by Easwaran HN et al., (2023) [27]. Standardisation was aided by radiographic assessment and maintaining a curvature consistent with the canal anatomy at its maximum curvatures. A single operator performed all access preparations to minimise inter-operator variability. Preparations were performed using a sterile medium-sized round bur and a non-end-cutting bur (Mani Inc., Utsunomiya, Japan) with a high-speed handpiece under continuous water cooling.

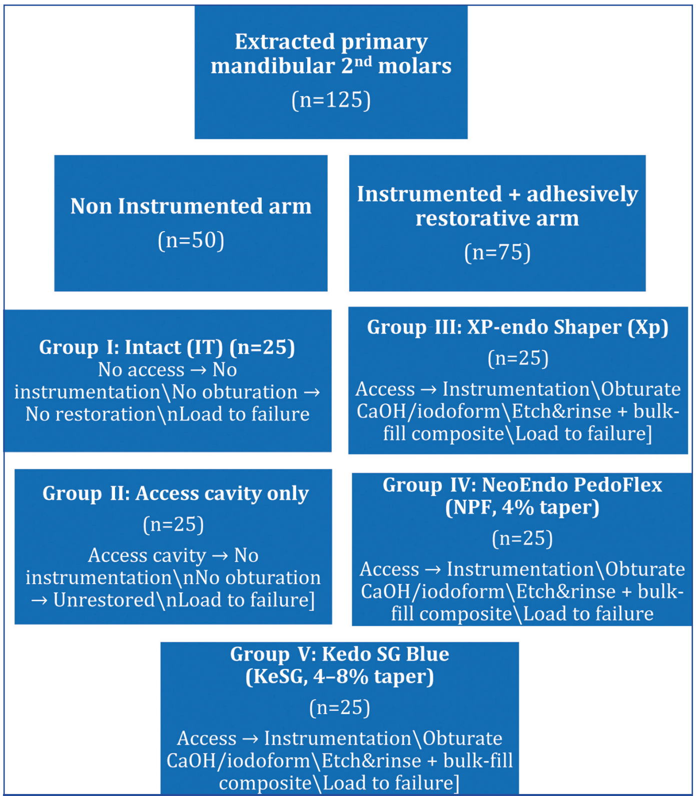
Group allocation and instrumentation: After access preparation, the specimens were allocated into five groups (n=25/group): 50 received no instrumentation (25 intact and 25 access cavity only), and 75 received full instrumentation, obturation, and restoration (25 each for groups III, IV, and V) [Table/Fig-1].



[Table/Fig-1]: Photographs showing representative specimens from each group mounted in resin blocks after group allocation, prior to instrumentation and fracture resistance testing.

- **Group I (Intact control):** Following specimen screening and preparation of the access cavity in the designated specimens, the specimens were allocated to five groups
- **Group II {Access Cavity Preparation; (ACP)}:** Conventional access prepared; no instrumentation or obturation; specimens were left unrestored to represent coronal dentin loss without reinforcement.
- **Group III (XP-endo shaper; Xp):** Instrumentation with XP-endo shaper (M phase below 35°C and change to austenitic at above 35°C along with taper of 0.02-0.08 and tip size of #30–#90), obturation, access restoration using a standardised etch-and-rinse protocol, and bulk-fill resin composite.
- **Group IV (NeoEndo PedoFlex; NPF):** Instrumentation with NeoEndo PedoFlex rotary files (sequential sizes 20 and 25, both 4% constant taper), obturation, standardised etch-and-rinse, and bulk-fill composite restoration.
- **Group V (Kedo SG; KeSG):** Instrumentation with Kedo SG D1 and E1 files (variable taper 4-8%); obturation; standardised etch-and-rinse + bulk-fill composite restoration [Table/Fig-2].

Instrumentation in the experimental groups (III-V) was performed using an endodontic motor, following the manufacturer's torque and speed recommendations. The working length was determined using a size 10 K-file and radiographically verified. Blinding was not performed at any stage: the single operator who performed instrumentation and restoration was aware of group allocation,



[Table/Fig-2]: Flowchart summarising specimen allocation, instrumentation, and restorative protocol across the five study groups (Group I: intact control; Group II: access cavity preparation, unrestored (ACP); Group III: XP-endo Shaper (Xp); Group IV: NeoEndo PedoFlex (NPF); and Group V: Kedo SG (KeSG)).

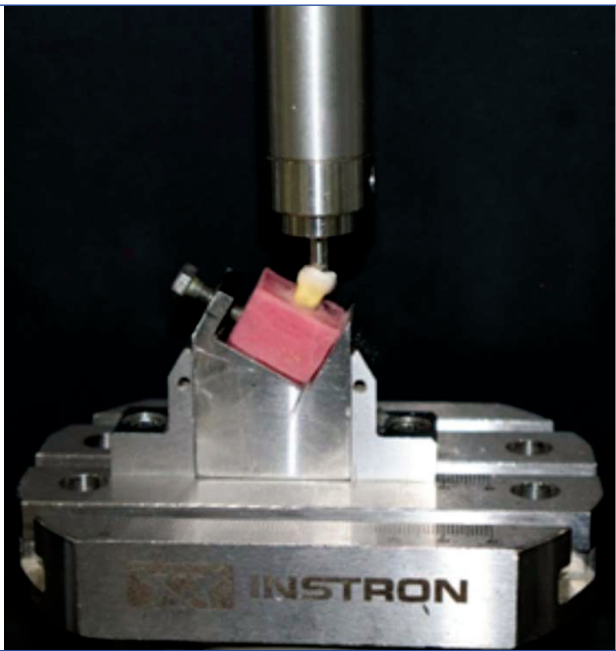
and the outcome assessor during fracture testing was not blinded to group-Identity. This is acknowledged as a potential source of performance and detection biases.

Irrigation protocol: During and after instrumentation, the canals were irrigated using a standardised protocol with a side-vented needle to optimise debris removal and minimise apical extrusion. The sequence included 0.9% normal saline, followed by 1% sodium hypochlorite (Prime Dental Products Pvt., Ltd., Mumbai, India). A SuperEndo Sonic Flush Irrigator was used between each instrument to enhance debris removal. After final shaping, a final rinse was performed using 17% EDTA, followed by 0.9% normal saline to remove the smear.

Obturation and adhesive restorative protocol: After irrigation, the canals were dried with sterile paper points. In groups III, IV, and V, the canals were obturated with Metapex (calcium hydroxide and iodoform paste) delivered using a preloaded syringe system to achieve complete canal filling.

For coronal restoration in groups III-V, the access cavity was restored using a standardised adhesive composite protocol: conditioning with 37% phosphoric acid for 15 seconds, followed by the application of a bonding agent. A light-cured bulk-fill resin composite (Filtek Bulk Fill Posterior; 3M ESPE, St. Paul, MN, USA) was placed and light cured (Woodpecker LED curing unit, 20 s per layer). Final finishing and polishing were performed to achieve the desired occlusal adaptation of the restoration. A periapical radiograph was obtained after restoration to verify the obturation quality.

Fracture resistance testing and failure definition: Fracture resistance testing was performed using an ElectroPuls E3000 (Instron, USA), a linear all-electric dynamic test instrument with a ±3000 N dynamic load capacity. A continuous compressive load was applied to the central fossa using a spherical crosshead at an inclination of 30° to the long axis of the tooth at a crosshead speed of 0.5 mm/min until fracture occurred [23]. The maximum force required to induce failure was recorded in newtons (N) for each specimen. Fracture failure was defined as the first audible crack and the appearance of a visible structural fracture [Table/Fig-3]. The compressive displacement at break was defined as the crosshead



[Table/Fig-3]: Representative picture illustrating the failure endpoint used in the fracture resistance testing: the first audible crack accompanied by a visible structural fracture line at the site of load application.

displacement (mm) recorded at the point of specimen fracture, and the compressive stress at break was defined as the load per unit contact area (MPa) recorded at the same point.

STATISTICAL ANALYSIS

Data were analysed using Statistical Package for Social Sciences (IBM SPSS) version 29.0 (IBM Corp., Armonk, NY, USA). The mean fracture resistance values across the five groups were compared using one-way ANOVA. When ANOVA indicated statistical significance ($p<0.05$), Tukey's post-hoc test was used for multiple comparisons. Formal normality testing was not performed; given the equal group sizes (n=25/group), one-way ANOVA was used because of its robustness to moderate deviations from normality. A single examiner performed all fracture assessments; formal inter- or intra-examiner calibration was not conducted, which is acknowledged as a limitation of the present study.

RESULTS

Fracture resistance was assessed using the maximum force, compressive stress at the maximum force, compressive displacement at fracture, and compressive stress at fracture.

Descriptive outcomes: Group I (intact) demonstrated the highest fracture resistance, with a mean maximum force of 933.59±383.55 N and mean compressive stress at the maximum force of 10.37±4.26 MPa. Group II (access cavity only; unrestored) showed the lowest values (325.82±128.45 N and 3.62±1.43 MPa, respectively), indicating a substantial structural compromise in the absence of coronal reinforcement. Group III (XP-endo Shaper), IV (NeoEndo PedoFlex), and V (Kedo SG) showed comparable intermediate performance that did not differ significantly from one another: Group III recorded 679.59±309.40 N and 7.55±3.44 MPa, group IV recorded 712.51±215.58 N and 7.92±2.39 MPa, and group V recorded 712.73±228.65 N and 7.99±2.53 MPa. The compressive displacement at break was broadly similar across groups (2.80-3.60 mm), with no clear separation by group. The compressive stress at break was more variable, with group V (Kedo SG) showing the highest mean value (2.40±3.72 MPa) and group I (intact) showing the lowest (0.49±0.67 MPa) [Table/Fig-4].

Inferential statistics: One-way ANOVA demonstrated statistically significant differences among the five groups in terms of maximum force ($F=16.723$, $p<0.001$, partial $\eta2=0.358$) and compressive stress at the maximum force ($F=16.796$, $p<0.001$, partial $\eta2=0.359$). The

Parameters	Groups	N	Mean±SD	95% CI Lower	95% CI Upper
Maximum Force (N)	Group I	25	933.59±383.55	775.27	1091.91
Maximum Force (N)	Group II	25	325.82±128.45	272.80	378.85
Maximum Force (N)	Group III	25	679.59±309.40	551.88	807.31
Maximum Force (N)	Group IV	25	712.51±215.58	623.53	801.50
Maximum Force (N)	Group V	25	712.73±228.65	618.35	807.12
Compressive Stress at Maximum Force (MPa)	Group I	25	10.37±4.26	8.61	12.13
Compressive Stress at Maximum Force (MPa)	Group II	25	3.62±1.43	3.03	4.21
Compressive Stress at Maximum Force (MPa)	Group III	25	7.55±3.44	6.13	8.97
Compressive Stress at Maximum Force (MPa)	Group IV	25	7.92±2.39	6.93	8.90
Compressive Stress at Maximum Force (MPa)	Group V	25	7.99±2.53	6.95	9.03
Compressive Displacement at Break (mm)	Group I	25	3.37±1.13	2.90	3.83
Compressive Displacement at Break (mm)	Group II	25	2.80±1.32	2.25	3.34
Compressive Displacement at Break (mm)	Group III	25	3.49±1.12	3.03	3.95
Compressive Displacement at Break (mm)	Group IV	25	3.60±1.38	3.03	4.17
Compressive Displacement at Break (mm)	Group V	25	2.98±2.12	2.10	3.85
Compressive Stress at Break (MPa)	Group I	25	0.49±0.67	0.21	0.77
Compressive Stress at Break (MPa)	Group II	25	1.15±1.57	0.50	1.80
Compressive Stress at Break (MPa)	Group III	25	1.14±1.45	0.54	1.74
Compressive Stress at Break (MPa)	Group IV	25	1.16±1.55	0.52	1.80
Compressive Stress at Break (MPa)	Group V	25	2.40±3.72	0.87	3.94

[Table/Fig-4]: Descriptive statistics for fracture resistance parameters across groups.
Group I=Intact control; Group II=Access cavity only (ACP); Group III=XP-endo Shaper (Xp); Group IV=NeoEndo PedoFlex (NPF); Group V=Kedo SG (KeSG)

compressive stress at break differed significantly among the groups ($F=2.846$, $p=0.027$, partial $\eta2=0.087$). No statistically significant difference was observed in the compressive displacement at break ($F=1.386$, $p=0.243$, partial $\eta2=0.044$) [Table/Fig-5].

Parameters	F-value	p-value	Partial $\eta2$	Interpretation
Maximum force (N)	16.723	<0.001*	0.358	Significant
Compressive stress at maximum force (MPa)	16.796	<0.001*	0.359	Significant
Compressive displacement at break (mm)	1.386	0.243	0.044	Not significant
Compressive stress at break (MPa)	2.846	0.027*	0.087	Significant

[Table/Fig-5]: Intergroup comparison for fracture resistance parameters.
*One-way ANOVA; p<0.05 was considered statistically significant. Partial η^2=partial eta squared (effect size)

Tukey's post-hoc analysis showed that group II differed significantly from all other groups for both maximum force and compressive stress at maximum force ($p<0.05$ throughout), confirming substantially reduced fracture resistance in the unrestored access-only condition [Table/Fig-6]. For maximum force, the mean difference between group I and II was 607.77 N ($p<0.001$). Group II also differed significantly from the restored instrumented groups, with mean differences of -353.77 N versus group III (p<0.001), –386.69 N versus group IV (p<0.001), and –386.91 N versus group V (p<0.001). Group I (intact control) also recorded significantly higher maximum force than groups III (XP-endo Shaper) (-253.99 N, p=0.0092), IV (NeoEndo PedoFlex) (-221.08 N, p=0.0333), and V (Kedo SG) (-220.86 N, p=0.0336), and groups III, IV, and V did not differ significantly from one another (p ≥ 0.992). For compressive stress at maximum force, the mean difference between group I and II was 6.751 MPa (p<0.001), and group II was also significantly lower than groups III–V (p<0.001). Group I also recorded significantly higher compressive stress at maximum force than group III (2.819 MPa, p=0.0092), IV (2.455 MPa, p=0.0332), and V (2.383 MPa, p=0.0419). No statistically significant differences were detected among groups III, IV, and V for either maximum force or compressive stress at maximum force (p ≥ 0.985). For compressive stress at break, group V (Kedo SG) was significantly higher than group I (intact) (mean difference -1.91 MPa, p=0.0117); no other pairwise comparisons for this parameter reached significance [Table/Fig-6]. Overall, group I (intact) exhibited the highest fracture resistance, with the three instrumented groups performing comparably to each other, while group II remained a clear outlier, with the lowest fracture resistance across all groups.

Parameters	Groups	Groups compared	Mean Difference	p-value
Maximum Force (N)	Group I	Group II	607.76920*	<0.001*
Maximum Force (N)	Group I	Group III	253.99960*	0.0092*
Maximum Force (N)	Group I	Group IV	221.07960*	0.0333*
Maximum Force (N)	Group I	Group V	220.85840*	0.0336*
Maximum Force (N)	Group II	Group I	-607.76920*	<0.001*
Maximum Force (N)	Group II	Group III	-353.76960*	<0.001*
Maximum Force (N)	Group II	Group IV	-386.68960*	<0.001*
Maximum Force (N)	Group II	Group V	-386.91080*	<0.001*
Maximum Force (N)	Group III	Group I	-253.99960*	0.0092*
Maximum Force (N)	Group III	Group II	353.76960*	<0.001*
Maximum Force (N)	Group III	Group IV	-32.92000	0.9925
Maximum Force (N)	Group III	Group V	-33.14120	0.9923
Maximum Force (N)	Group IV	Group I	-221.07960*	0.0333*
Maximum Force (N)	Group IV	Group II	386.68960*	<0.001*
Maximum Force (N)	Group IV	Group III	32.92000	0.9925
Maximum Force (N)	Group IV	Group V	-0.22	1.000
Maximum Force (N)	Group V	Group I	-220.85840*	0.0336*
Maximum Force (N)	Group V	Group II	386.91080*	<0.001*
Maximum Force (N)	Group V	Group III	33.14120	0.9923
Maximum Force (N)	Group V	Group IV	0.22120	1.000
Compressive Stress at Maximum Force (MPa)	Group I	Group II	6.75120*	<0.001*
Compressive Stress at Maximum Force (MPa)	Group I	Group III	2.81920*	0.0092*
Compressive Stress at Maximum Force (MPa)	Group I	Group IV	2.45520*	0.0332*
Compressive Stress at Maximum Force (MPa)	Group I	Group V	2.38320*	0.0419*
Compressive Stress at Maximum Force (MPa)	Group II	Group I	-6.75120*	<0.001*
Compressive Stress at Maximum Force (MPa)	Group II	Group III	-3.93200*	<0.001*
Compressive Stress at Maximum Force (MPa)	Group II	Group IV	-4.29600*	<0.001*
Compressive Stress at Maximum Force (MPa)	Group II	Group V	-4.36800*	<0.001*
Compressive Stress at Maximum Force (MPa)	Group III	Group I	-2.81920*	0.0092*
Compressive Stress at Maximum Force (MPa)	Group III	Group II	3.93200*	<0.001*
Compressive Stress at Maximum Force (MPa)	Group III	Group IV	-0.36400	0.9926
Compressive Stress at Maximum Force (MPa)	Group III	Group V	-0.43600	0.9853
Compressive Stress at Maximum Force (MPa)	Group IV	Group I	-2.45520*	0.0332*
Compressive Stress at Maximum Force (MPa)	Group IV	Group II	4.29600*	<0.001*
Compressive Stress at Maximum Force (MPa)	Group IV	Group III	0.36400	0.9926
Compressive Stress at Maximum Force (MPa)	Group IV	Group V	-0.07200	1.000
Compressive Stress at Maximum Force (MPa)	Group V	Group I	-2.38320*	0.0419*
Compressive Stress at Maximum Force (MPa)	Group V	Group II	4.36800*	<0.001*
Compressive Stress at Maximum Force (MPa)	Group V	Group III	0.43600	0.9853
Compressive Stress at Maximum Force (MPa)	Group V	Group IV	0.07200	1.000
Compressive Stress at Break (MPa)	Group I	Group II	-0.65880	0.7905
Compressive Stress at Break (MPa)	Group I	Group III	-0.65000	0.7986
Compressive Stress at Break (MPa)	Group I	Group IV	-0.66840	0.7816
Compressive Stress at Break (MPa)	Group I	Group V	-1.91280*	0.0117*
Compressive Stress at Break (MPa)	Group II	Group I	0.65880	0.7905
Compressive Stress at Break (MPa)	Group II	Group III	0.00880	1.000
Compressive Stress at Break (MPa)	Group II	Group IV	-0.00960	1.000
Compressive Stress at Break (MPa)	Group II	Group V	-1.25400	0.2060
Compressive Stress at Break (MPa)	Group III	Group I	0.65000	0.7986
Compressive Stress at Break (MPa)	Group III	Group II	-0.00880	1.000
Compressive Stress at Break (MPa)	Group III	Group IV	-0.01840	1.000
Compressive Stress at Break (MPa)	Group III	Group V	-1.26280	0.2001
Compressive Stress at Break (MPa)	Group IV	Group I	0.66840	0.7816
Compressive Stress at Break (MPa)	Group IV	Group II	0.00960	1.000
Compressive Stress at Break (MPa)	Group IV	Group III	0.01840	1.000
Compressive Stress at Break (MPa)	Group IV	Group V	-1.24440	0.2127
Compressive Stress at Break (MPa)	Group V	Group I	1.91280*	0.0117*
Compressive Stress at Break (MPa)	Group V	Group II	1.25400	0.2060
Compressive Stress at Break (MPa)	Group V	Group III	1.26280	0.2001
Compressive Stress at Break (MPa)	Group V	Group IV	1.24440	0.2127

[Table/Fig-6]: Tukey's post-hoc test for pairwise comparisons of maximum force, compressive stress at maximum force, and compressive stress at break.
Group I: Intact control; Group II: Access cavity only (ACP); Group III: XP-endo Shaper (Xp); Group IV: NeoEndo PedoFlex (NPF); and Group V: Kedo SG (KeSG). * p<0.05; statistically significant.

DISCUSSION

The present in-vitro study was designed to isolate the structural consequences of access preparation, canal preparation, and standardised adhesive coronal reinforcement on the fracture resistance of mandibular primary second molars. Group I (intact) served as a structural reference. Group II (access cavity only, left unfilled/unrestored) was intentionally included as a boundary condition to quantify the worst-case mechanical penalty of cervical/tooth-structure loss without restorative reinforcement- an approach consistent with biomechanical studies evaluating the contribution of remaining tooth structure to fracture resistance [5-7,16,17].

All instrumented groups (III-V) were obturated and restored using the same adhesive bulk-fill resin composite protocol, thereby controlling the restorative variable and allowing the discussion to focus on whether instrumentation-related dentin removal meaningfully altered fracture resistance once adhesive reinforcement was provided. A universal testing machine with controlled compressive loading provides repeatable failure endpoints that are suitable for between-group comparisons in laboratory studies of endodontic biomechanics.

The substantially lower fracture resistance in group II (unrestored access) is consistent with the broader endodontic biomechanics literature showing that loss of coronal/cervical tooth structure- especially around the cervical region- reduces stiffness and increases fracture susceptibility [2,3,5-7,16,17].

In contrast, all instrumented groups that received adhesively bonded composite restorations demonstrated significantly higher fracture resistance than group II and did not differ significantly from one another, although all three groups recorded significantly lower maximum force and compressive stress at maximum force than the intact reference group. This finding agrees with evidence that adhesive restorations can partially restore mechanical performance by coupling cusps and redistributing functional loads, although reinforcement depends on the remaining dentin scaffold and restoration configuration [12,13]. In primary teeth, clinical and laboratory literature supports adhesive restorative approaches in selected posterior cases where technique control and case selection are appropriate [14,15].

For compressive stress at break, group V (Kedo SG) showed significantly higher values than group I (intact), whereas no other pairwise comparisons reached significance for this parameter. Because the compressive stress at break reflects specimen behaviour just beyond the point of initial fracture rather than the load required to initiate failure, this isolated difference may relate to specimen-level variability at fracture rather than to a systematic effect of instrumentation, particularly since it did not distinguish any of the three instrumented groups from one another or from the intact reference. Given that the omnibus effect size for this parameter was modest (partial $\eta 2=0.087$) and only one of the ten possible pairwise comparisons reached significance, this finding should be interpreted with caution and confirmed in future studies.

Therefore, the null hypothesis of no significant difference in fracture resistance among the five groups was rejected for maximum force, compressive stress at maximum force, and compressive stress at break (omnibus one-way ANOVA, $p<0.05$ for all three), but not for compressive displacement at break ($p=0.243$). Post-hoc pairwise comparisons showed that Group II differed significantly from all other groups, and Group I (intact) differed significantly from Groups II, III, IV, and V for both maximum force and compressive stress at maximum force; Groups III, IV, and V did not differ significantly from one another for either parameter. For compressive stress at break, group V (Kedo SG) differed significantly from group I (intact), and no other pairwise comparisons reached significance for any parameter.

The strengths of this Phase III include the use of both an intact reference group and a purposeful worst-case boundary condition, which provides clinically interpretable anchors for fracture behaviour [16,17]. In addition, the restorative protocol was standardised across all instrumented groups, reducing confounding factors and strengthening the inference regarding the role of tooth structure preservation and adhesive reinforcement in determining fracture resistance [12,13].

Limitation(s)

The present study has several limitations that must be acknowledged. Static fracture testing does not replicate thermomechanical ageing, cyclic fatigue, moisture, and thermal fluctuations, or complex loading trajectories. Moreover, extracted primary molars inherently vary in their anatomy and pre-extraction history despite strict screening. Blinding was not performed, which may have introduced performance or assessment bias, which is typical of laboratory workflows. Finally, only one coronal restorative strategy (adhesive bulk-fill composite) was evaluated; therefore, extrapolation to full-coverage restorations commonly used in paediatric endodontics requires further direct comparative studies. Specific additional limitations include the following: no cyclic fatigue testing, no thermocycling, restoration durability under simulated clinical aging was not assessed, only mandibular second primary molars were studied, only a single loading angle (30°) was tested, whereas clinical occlusal forces act from multiple directions, only one crosshead speed (0.5 mm/min) was used, which does not reflect the variable loading rates encountered clinically, and formal examiner calibration was not performed.

Future research should incorporate cyclic fatigue and thermocycling to evaluate the durability of reinforcements under simulated clinical aging conditions. Comparative testing of adhesive composite restorations against full-coverage restorations (e.g., stainless steel or zirconia crowns) under standardised remaining tooth structure scenarios would better inform restorative choices after pulpectomy in primary teeth. Failure mode analysis should be performed to distinguish restorable cusp fractures from catastrophic cervical fractures and root fractures. Finally, integrating objective structural metrics, such as remaining dentin thickness or volume (e.g., CBCT-based quantification), with mechanical outcomes would strengthen the structure–function inferences.

CONCLUSION(S)

Within the limitations of this laboratory model, the present study demonstrated that an unrestored access cavity condition markedly compromised fracture resistance; in contrast, endodontically treated primary molars restored with a standardised adhesive bulk-fill composite protocol showed substantially improved fracture resistance relative to the unrestored condition and showed improved fracture-related mechanical performance relative to the unrestored condition, although maximum force and compressive stress at maximum force remained significantly lower than those of the intact reference. No statistically significant differences were observed among groups III, IV and V for any of the measured parameters. Collectively, the findings provide laboratory-based support for preserving cervical/pericervical tooth structure where possible and for standardised adhesive coronal reinforcement when a composite restoration is selected.

Acknowledgement

The authors thank the parents, guardians, and clinical staff at Sri Ramachandra Institute of Higher Education and Research and the participating external sites for facilitating specimen collection.

Authors' contribution: SH, RMR, A: Conceptualisation; SH, RMR, KS: Methodology; SH, A, KS: Formal analysis and investigation; SH, RMR: Writing – original draft preparation; A, KS, EV: Writing – review and editing; SH, RMR, EV: Resources; SH, EV: Supervision.

Data availability statement: The data supporting the findings of the present study are available from the corresponding author upon reasonable request.

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PARTICULARS OF CONTRIBUTORS:

1. Associate Professor, Department of Paediatric and Preventive Dentistry, Sri Ramachandra Institute of Higher Education and Research, Chennai, Tamil Nadu, India.
2. Professor and Head, Department of Conservative Dentistry and Endodontics, Sri Ramachandra Institute of Higher Education and Research, Chennai, Tamil Nadu, India.
3. Professor, Department of Oral Medicine and Radiology, Sri Ramachandra Institute of Higher Education and Research, Chennai, Tamil Nadu, India.
4. Professor and Head, Department of Paediatric and Preventive Dentistry, Sri Ramachandra Institute of Higher Education and Research, Chennai, Tamil Nadu, India.
5. Assistant Professor, Department of Mechanical Engineering, SRM Institute of Science and Technology, Potheri, Tamil Nadu, India.

NAME, ADDRESS, E-MAIL ID OF THE CORRESPONDING AUTHOR:
Dr. R Mathan Rajan,
Professor and Head, Department of Conservative Dentistry and Endodontics, Sri Ramachandra Dental College and Hospital, Sri Ramachandra Institute of Higher Education and Research, Chennai-600116, Tamil Nadu, India.
E-mail: mathanrajanr@sriramachandra.edu.in

PLAGIARISM CHECKING METHODS: [Jain H et al.]

- Plagiarism X-checker: Jun 13, 2026
- Manual Googling: Aug 03, 2026
- iThenticate Software: Aug 05, 2026 (7%)

ETYMOLOGY: Author Origin

EMENDATIONS: 7

AUTHOR DECLARATION:

- Financial or Other Competing Interests: None
- Was Ethics Committee Approval obtained for this study? Yes
- Was informed consent obtained from the subjects involved in the study? Yes
- For any images presented appropriate consent has been obtained from the subjects. No

Date of Submission: **Jun 01, 2026**
Date of Peer Review: **Jun 19, 2026**
Date of Acceptance: **Aug 07, 2026**
Date of Publishing: **Oct 01, 2026**