



# Analysis of the Impact of the Minimally Invasive Access Preparation on the Fracture Resistance in Endodontics, Systematic Review of Vitro Study

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## Abstract

**Purpose of Review** The accurate execution of endodontic access is crucial for the success of therapy, influencing various phases of canal treatment. Traditional approaches prioritize a convenient form and broad endodontic opening to facilitate subsequent procedures. Minimally invasive dentistry, which prioritizes dentin preservation, is increasingly being embraced. Nonetheless, the scientific evidence supporting this approach remains limited, and concerns have been raised regarding its influence on the various phases of root canal treatment.

**Recent findings** Clinical studies explore the risk of dental fractures during endodontic treatment, considering the removal of dental tissue. Traditional openings may increase fracture risk due to reduced resistance to masticatory loads. This review aims to compare the fracture resistance of teeth prepared with minimally invasive access preparation to those treated with traditional endodontic access cavities. The review protocol was developed in accordance with the Cochrane Handbook guidelines and was registered in INPLASY, while the manuscript was drafted following the PRISMA statement; after the study identification and selection process, included a total of 5 studies. We pooled fracture-load data using the standardised mean difference (SMD) because studies used different scales.  $SMD > 0$  favours minimally invasive access cavities (NAC) (i.e., teeth with NAC sustained a greater load than teeth with traditional endodontic access (TEC); the magnitude expresses the difference in standard deviations). Given the expected variability between studies, a random-effects model was applied alongside the fixed-effects model: 0.97 [0.65, 1.29];  $Chi^2$  36.88,  $df=9$  ( $P < 0.0001$ ),  $I^2 = 76\%$ .

**Summary** The data derived from the meta-analyses may offer valuable insights for clinicians performing endodontic treatments using specific access cavity designs. The minimally invasive approach to endodontics with an ultraconservative or minimally invasive access preparation may be a viable solution in cases where the fracture resistance of a tooth is crucial. Future studies should focus primarily on aspects related to the increased difficulty in localizing orifices and the presence of debris that could affect the advantages obtained on fracture resistance with NAC. Ultraconservative techniques are characterized by cavity designs that show superior fracture resistance, suggesting enhanced resilience to masticatory loads when compared to traditional endodontic access cavities.

**Keywords** Endodontic · Access cavity · Minimally invasive access preparation · Ultraconservative access · Dental · Endodontic failure

## Introduction

In recent years, novel endodontic access techniques have emerged with the aim of enhancing the precision, quality, and effectiveness of treatment while preserving maximal dental tissue for subsequent prosthetic rehabilitation [1].

The accurate execution of endodontic access has been demonstrated to be pivotal for the success of this therapy, influencing all subsequent phases of canal treatment. These phases encompass the localization of canal orifices, shaping, cleansing, and disinfection of the canal, as well as achieving an apical and coronal seal. Moreover, appropriate endodontic access is essential to prevent fractures that could compromise subsequent prosthetic rehabilitation [2].

Traditional endodontic accesses (TEC) are founded on the application of two key principles: the creation of a convenient form and the implementation of a broad endodontic opening, aimed at preventing complications during the phases of localization, probing, and shaping of the root canals [3]. The “convenience form” principle suggests creating access as direct as possible to the orifice of the root canal by extending the walls of the cavity. A broad access renders all subsequent phases of endodontic treatment more efficient, contributing to the prevention of complications during the procedure. Consequently, the principles of traditional access preparation operationally translate into the following three points: removal of the roof of the pulp chamber; creation of an easy and unobstructed path to the canal orifices; preservation of healthy dental structure [4].

We acknowledge that minimally invasive dentistry is gaining approval in endodontics, emphasizing the maximum preservation of dentin. Indeed, the goal is to conserve dental structures by retaining part of the pulp chamber roof, which would reduce cusp deflection caused by occlusal forces once the dental element has been prosthetically restored. Teeth undergoing endodontic treatment, in fact, exhibit a lower long-term survival rate compared to intact teeth, precisely due to reduced fracture resistance [5].

A recent systematic review by Rahbani Nobar et al. (2023) identified 20 *in vitro/ex vivo* studies on minimally invasive access cavities and the load capacity of root-canal-treated teeth. These experiments primarily assess how access design influences fracture resistance, although definitions vary and direct NAC–TEC comparisons are limited [6]. This risk stems from the need to remove dental tissue for caries removal, especially during the preparation of endodontic access. Similarly, the influence of shaping in the subsequent stages of canal treatment has been examined [7].

While it is true that the concept of minimally invasive endodontics has gained increasing approval in clinical dentistry in recent years, it is important to emphasize that scientific evidence supporting this perspective is still limited.

Only recently has the scientific community begun to raise doubts about such minimally invasive access cavities. This is because they could represent a limitation in the phases of canal orifice identification, irrigation, shaping, and root canal filling, thus influencing the entire endodontic treatment [8].

It is also relevant to consider that access cavities of insufficient size could increase the risk of incidents and complications during endodontic treatment.

On the contrary, traditional access cavities may increase the risk of tooth fracture due to reduced resistance to masticatory loads, primarily resulting from the loss of coronal mineralized tissue. The most recent systematic review on the fracture resistance of various endodontic access methods, conducted in 2021 [9], compared different opening techniques in a network meta-analysis. It identified only two studies for minimally invasive access preparation, generally classified as ultraconservative according to Silva et al.’s 2020 categorization [10], and compared them with traditional openings. The meta-analysis, while not providing definitive data except within the context of a network meta-analysis, could see an enhancement in statistical significance with the release of additional studies in 2022 and 2023. This enhancement would allow for a more meaningful direct comparison of the fracture resistance between minimally invasive access preparation and TEC.

In this review we use a consistent terminology to avoid conflating conservative designs; for this classification we relied on the nomenclature proposed by Silva et al. [10].

TEC indicates the conventional outline with complete removal of the chamber roof and a wide convenience form to achieve straight-line access to all canal orifices. Marginal ridges are usually sacrificed in molars and most of the pericervical dentine is removed to gain visibility and instrument freedom [11].

Conservative access cavity (CAC) refers to a single occlusal cavity that is smaller than TEC and aims to preserve coronal dentine (often at least one marginal ridge). The chamber roof may be partially preserved, but the design still targets a reasonably direct access to orifices through a single opening.

Truss access cavity (TRAC) (also called “trussed” or “bridged” access) denotes two or more small occlusal windows oriented towards separate canal clusters (e.g., MB-complex vs. distal). A dentine “truss” is intentionally left between windows to protect marginal ridges and pericervical dentine. Visibility is window-specific and straight-line trajectories are segmental rather than through a single common opening [12].

Minimally invasive (or ultraconservative) access cavity (NAC) is the most restrictive design. It generally uses a single, small-diameter orifice directed to the pulpal chamber

with maximal preservation of the chamber roof and marginal ridges. NAC prioritises dentine conservation over straight-line access, relying on magnification, angulated approaches and flexible NiTi/glide-path instruments. By concept and execution, NAC is not a synonym of CAC/TRAC: compared with CAC it further reduces the occlusal outline and chamber unroofing; compared with TRAC it avoids multiple windows and preserves the central dentine bridge by using one micro-orifice [6].

As previously reported, a recent systematic review and meta-analysis by Rahbani Nobar et al. (2023) synthesised the effect of minimally invasive access cavities on the load capacity of root-canal-treated teeth. The authors screened broadly and included 25 *in vitro/ex vivo* studies, of which 20 were eligible for quantitative synthesis, grouping designs as conservative, ultra-conservative, and truss access cavities. Using a maximum-likelihood random-effects model, they reported tooth-type-specific advantages for conservative/truss designs but highlighted heterogeneous definitions, variable experimental protocols, and the predominance of laboratory evidence, calling for higher-level clinical studies [6].

Building on this foundation, the present review provides a direct, pairwise comparison between NAC and TEC based on harmonised operational definitions that distinguish NAC from CAC/TRAC. We synthesised effects using the standardised mean difference (SMD) under random- and fixed-effects models to account for between-study variability. We further quantified small-study effects via Egger's regression and, where feasible, conducted sensitivity analyses and tooth-type subgroup analyses. In doing so, we address key limitations highlighted by previous syntheses—namely the paucity of direct NAC–TEC contrasts—thereby offering a clearer estimate of the comparative effect on fracture load while maintaining appropriately cautious interpretation regarding clinical translation.

To achieve this objective, we have chosen to delve into pulp chamber opening techniques, with a specific focus on ultraconservative approaches, such as minimally invasive access preparation. The aim of this systematic review is to compare the fracture resistance of teeth subjected to a minimally invasive access preparation with those undergoing a TEC.

## Materials and Methods

### Protocol

The planning of the systematic review was implemented following the guidelines described in the Cochrane Handbook for Systematic Reviews of Interventions. The drafting

of the review manuscript followed the recommendations of PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis), and the protocol was registered on INPLASY (International Platform of Registered Systematic Review and Meta-analysis Protocols) before carrying out the selection of articles and was registered with number INPLASY202410026 and number DOI is <https://doi.org/10.37766/inplasy2024.1.0026>.

### Eligibility Criteria

The study aimed to identify *in vitro* research on ultraconservative endodontic access cavities, with a specific focus on those reporting data regarding the fracture resistance of endodontically treated teeth, particularly those connected to the minimally invasive access preparation.

The exclusion criteria were the exclusion of all clinical studies, and in *in vitro* studies that did not report fracture toughness data performed with ultra-conservative access methods and to exclude studies that did not have an abstract in English.

To enhance clarity when specifying inclusion and exclusion criteria, we define a minimally invasive access (NAC, ultraconservative access) as an access cavity designed to maximise preservation of coronal dentine—particularly the chamber roof and pericervical dentine—while accepting a less straight-line trajectory to canal orifices and relying on magnification and flexible NiTi instruments.

To ensure consistent study classification despite methodological heterogeneity, we adopted a set of a-priori operational definitions for access designs. These served as reference standards for data extraction and were applied uniformly across studies:

- Traditional endodontic cavity (TEC). Complete unroofing of the pulp chamber with a wide convenience form that provides straight-line access to all canal orifices; in molars, marginal ridges are typically sacrificed.
- Minimally invasive / ultraconservative access (NAC). A single micro-orifice occlusal entry with maximal preservation of the chamber roof (guide:  $\geq 50\%$  retained), preserved marginal ridges, and a reduced outline (guide: maximum diameter  $\leq \sim 3\text{--}4$  mm or area  $\leq \sim 10$  mm<sup>2</sup> when measurable from figures). NAC prioritises dentine preservation over straight-line access, relying on magnification/angulated trajectories and flexible NiTi instruments.

In detail the exclusion criteria have been better explained in Table 1.

All studies reporting data on the fracture resistance of teeth endodontic treatments were considered potentially eligible.

**Table 1** Exclusion criteria

Exclusion criterion	Operational rule (how we judged it)	Rationale
Not an <i>in vitro/ex vivo</i> experiment (e.g., clinical, animal, finite-element analysis, artificial/3D-printed teeth)	Study design not meeting <i>in vitro/ex vivo</i> specification	Out of scope for the laboratory fracture-load question
No fracture-load outcome	Fracture load (N) not measured/reported	Primary outcome unavailable
Insufficient quantitative data	n, mean and SD per arm not reported and not derivable; authors not responsive	Effect size (SMD) cannot be computed
Unclear access classification	Text/figures insufficient to classify as NAC/CAC/TRAC/TEC under operational rules; author clarification unavailable	Avoids misclassification bias
Specimens not eligible	Pre-existing vertical root fractures; extensive structural loss beyond planned access; non-human teeth	Threat to internal validity/applicability
No eligible pairwise contrast	Study does not include a NAC vs. TEC comparison (e.g., only CAC vs. TRAC)	Not informative for the primary comparison
Duplicate/overlapping data	Same cohort reported multiple times: retain the most complete dataset and exclude the duplicate(s)	Prevents double-counting
Incompatible reporting unit	Outcome expressed only as stiffness, strain, or non-convertible units	Not comparable with fracture load meta-analysis

*NAC* minimally invasive/ultraconservative access cavity; *CAC* conservative access cavity; *TRAC* truss access cavity; *TEC* traditional endodontic cavity; *SD* standard deviation; *SMD* standardised mean difference. Units: *N* newton (unit of force)

The systematic review was performed by 3 reviewers (M.D., F.E. and A.B.) and followed the following steps:

1. The selection of reviewers (M.D. and F.E.) was established, with a third reviewer (A.B.) designated as a supervisor to resolve any disagreements. Responsibilities included the selection of studies for inclusion, identification of relevant outcomes, choice of databases and keywords, definition of eligibility criteria, selection of data to be extracted, methods of data synthesis, and registration of the review protocol on INPLASY;
2. Search and selection of studies through the use of databases with manual elimination or through the use of software (EndNote 8.0). This process was conducted independently, followed by comparing the selections made and deciding which studies to include;
3. Data extraction on tables performed independently (M.D. and F.E.), followed by data comparison to minimize the risk of errors in reporting information.

## Sources of Information, Research, and Selection

The keywords used were: (ultraconservative OR access cavity OR truss OR Nija Access) AND endodontic.

The literature search was performed across three databases—ScienceDirect, SCOPUS, and PubMed—and one registry, the Cochrane Library. In addition, Google Scholar (using the keywords ‘minimally invasive access preparation’), gray literature sources such as OpenGrey (same keywords), and the reference lists of previous systematic reviews on access cavity designs were also consulted. Specifically, the following keywords were used in the PubMed search: Search (ultraconservative OR access cavity OR truss OR Nija Access) AND endodontic Sort by: Most Recent:

(“ultraconservative“[All Fields] OR (“access“[All Fields] OR “accessed“[All Fields] OR “accesses“[All Fields] OR “accessibilities“[All Fields] OR “accessibility“[All Fields] OR “accessible“[All Fields] OR “accessing“[All Fields]) AND (“cavity s“[All Fields] OR “dental caries“[MeSH Terms] OR (“dental“[All Fields] AND “caries“[All Fields]) OR “dental caries“[All Fields] OR “cavities“[All Fields] OR “cavity“[All Fields])) OR (“trusses“[MeSH Terms] OR “trusses“[All Fields] OR “truss“[All Fields] OR (“Ninja“[All Fields] AND (“access“[All Fields] OR “accessed“[All Fields] OR “accesses“[All Fields] OR “accessibilities“[All Fields] OR “accessibility“[All Fields] OR “accessible“[All Fields] OR “accessing“[All Fields]))) AND (“endodontal“[All Fields] OR “endodontic“[All Fields] OR “endodontical“[All Fields] OR “endodontically“[All Fields] OR “endodontics“[MeSH Terms] OR “endodontics“[All Fields]). Translations:

access: “access“[All Fields] OR “accessed“[All Fields] OR “accesses“[All Fields] OR “accessibilities“[All Fields] OR “accessibility“[All Fields] OR “accessible“[All Fields] OR “accessing“[All Fields];

cavity: “cavity’s“[All Fields] OR “dental caries“[MeSH Terms] OR (“dental“[All Fields] AND “caries“[All Fields]) OR “dental caries“[All Fields] OR “cavities“[All Fields] OR “cavity“[All Fields];

truss: “trusses“[MeSH Terms] OR “trusses“[All Fields] OR “truss“[All Fields].

Access: “access“[All Fields] OR “accessed“[All Fields] OR “accesses“[All Fields] OR “accessibilities“[All Fields] OR “accessibility“[All Fields] OR “accessible“[All Fields] OR “accessing“[All Fields];

endodontic: “endodontal”[All Fields] OR “endodontic”[All Fields] OR “endodontical”[All Fields] OR “endodontically”[All Fields] OR “endodontics”[MeSH Terms] OR “endodontics”[All Fields].

The literature search was completed on 24 December 2023.

For accuracy, some studies and authors refer to the minimally invasive access preparation as the ‘ninja access cavity’; however, this terminology has been discouraged by the authors, and reference is made solely to the minimally invasive access preparation (NAC).

The data to be extracted included the first author of the study, the date of publication, the country in which the research was conducted, the type of access cavity performed, the number of teeth involved in the study, the type of machine used for the test, the type of teeth, type of restoration and load at fracture expressed in newtons.

### Risk of Bias, Publication bias, Summary Measures and Summary of Results

The risk of bias was evaluated using the Checklist for Reporting In *vitro* Studies (CRIS) guidelines, proposed for the assessment of in *vitro* dental studies. Publication bias will be assessed through visual analysis of the asymmetry in the funnel plot of the studies included in the meta-analysis.

The extracted results were tabulated, and data concerning fracture resistance were also illustrated through figures, including forest plots showing the corresponding mean and standard deviation values. These data were compared with those of the control groups to calculate the mean difference and assess heterogeneity indices, such as Higgins’  $I^2$  statistic.

The risk of bias among studies was visually assessed by analyzing the overlap of confidence intervals (CI.) on the forest plot and through the inconsistency index  $I^2$  represented in a funnel plot. If the meta-analysis exhibited high heterogeneity indices ( $I^2$  exceeding 75%), a sensitivity analysis was performed by excluding studies with low C.I. overlap or those identified graphically in the funnel plot. A subgroup analysis was also performed based on the type of tooth (molar or premolar) undergoing the intervention. For the meta-analysis, and specifically for calculating the standardized mean difference, Reviewer Manager 5.4 software (RevMan, Cochrane Collaboration, Copenhagen, Denmark) was employed.

We assessed funnel-plot asymmetry using Egger’s regression, fitting the standard normal deviate (effect/SE) on precision (1/SE):  $Z_i = \beta_0 + \beta_1 \cdot (1/SE_i) + \epsilon_i$   $Z_i = \beta_0 + \beta_1 \cdot (1/SE_i) + \epsilon_i$ . Evidence of small-study effects was inferred from a

non-zero intercept ( $\beta_0$ ) with a two-sided t-test ( $df = k - 2$ ).

Software and implementation. Egger’s regression were run with a custom Python script (funnel plot 09\_09\_2025.py) in Python 3.10, using NumPy 1.26 (numerics), Pandas 2.2 (data handling), SciPy 1.11 (statistical functions, including the t distribution), and Matplotlib 3.8 (figure generation). Figures were exported as PNG at 300 dpi. Study-level effects were computed as Hedges’ standardised mean difference (g) with the small-sample J correction; within-study variances and standard errors followed standard formulae. Fixed-effects pooling used inverse-variance weights; random-effects used the DerSimonian–Laird estimator, reporting  $I^2$  and  $\tau^2$ . Funnel plots were centred on the fixed-effects pooled estimate and displayed with pseudo-95% confidence limits.

The input dataset (NAC\_vs\_TEC\_Egger\_Funnel.csv) and the Python script (funnel plot 09\_09\_2025.py) are provided in the Supplementary Material to enable full reproducibility.

To enhance transparency and reproducibility, we organised the extracted study-level data into a lightweight “data space” with explicit schema, provenance, and versioning, enabling machine-readable updates and re-analysis. The design principles (interoperability, governance, incremental integration) were adapted from cross-domain data-space architectures used in digital-twin platforms, and applied here to meta-analytic datasets and scripts [13].

## Results

The study selection was guided by the following research question: Do endodontically treated teeth with an ultraconservative access cavity demonstrate greater fracture resistance under masticatory loads compared to those prepared with a traditional endodontic access?

During the search phase, bibliographic references were retrieved from three databases—SCOPUS ( $n = 962$ ), ScienceDirect ( $n = 1,283$ ), and PubMed ( $n = 1,514$ )—as well as from a registry in the Cochrane Library ( $n = 274$ ), yielding a total of 4,033 records.

No filters were applied to Scopus and PubMed to selectively exclude studies prior to a specific date or within a specific area of interest. Subsequently, bibliographic references from Scopus and PubMed were imported into EndNote X8, and duplicates were removed both programmatically and manually. The selected studies were determined through the review of abstracts and titles. This phase was also conducted for Science Direct and Cochrane Library, with studies selected from these sources added to those chosen from PubMed and Scopus, resulting in 32 potentially eligible records.

An additional search in the gray literature (Google Scholar and Open Gray) and previous systematic reviews did not identify further manuscripts for inclusion in the present systematic review (Fig. 1). The records were independently screened by two authors (M.D. and E.F.), while ambiguous situations were addressed at the end of the selection process, involving a third author (A.B.) to resolve potential conflicts.

## Data Characteristics and Data Extraction

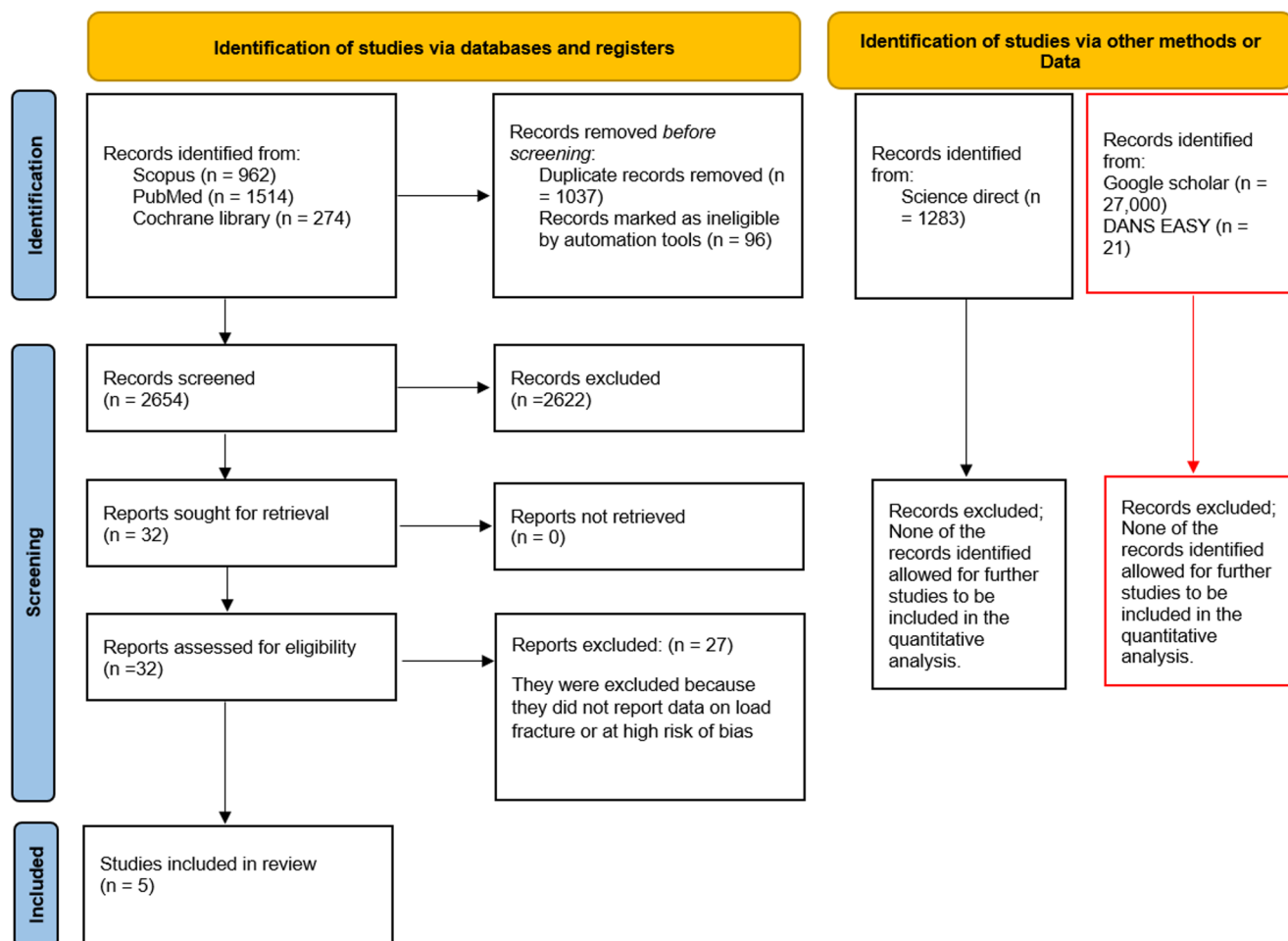
The articles included in the review are as follows: Silva et al. [14], Divyasree et al. [15], Plotino et al. [16], Patil et al. [17] and Augusto et al. [18].

A study conducted by Espino and Iberico [19], was considered at high risk of bias because data on the number of teeth in each group were not clearly reported, and for some groups, the standard deviation was not provided. It was decided to exclude this study from the included studies, not

reporting it in the results and meta-analysis. However, the extracted data are presented in Table 2.

The extracted data are presented in a table, including the first author, the study's country, the total number of teeth tested, the type of teeth, the investigated cavity access methods compared with ultraconservative methods, the type of testing machine, and fracture resistance expressed in Newtons with standard deviation.

The study types were homogeneous: three studies were conducted only on mandibular molars, one on maxillary premolars, and one included both molars and premolars from both dental arches. The total number of teeth included in the review was 352, with 212 mandibular molars, 60 maxillary premolars, 40 mandibular premolars, and 40 maxillary molars. Out of these, 106 teeth underwent ultraconservative access, and an equal number underwent traditional access. Intact teeth were investigated in only three studies, totaling 40 teeth.



**Fig. 1** Entire selection and screening procedures are described in the PRISMA flowchart. The red boxes show the results of the research conducted in the gray literature (Google Scholar and Open Gray: DANS EASY archive)

**Table 2** Data extracted from the 5 studies included, (in addition to the Data from the study excluded from the results of: Espino and Iberico, 2023); Newtons (N), Standard Deviations (SD), Ultraconservative Endodontic Cavity (UEC), Minimally Invasive Access Preparation (NAC), Tradizional Endodontic Access Cavity (TEC), C (Intact teeth or control group), Conservative Access Cavity (CAC), Truss Access Cavity (TRAC), Short Fiber-reinforced Composite (SFC), GIC (Glass ionomer Cement), Upper Premolars (UP), Lower Premolars (LP), Upper Molars (UM), Lower Molars (LM), TEC or UEC with 0.3 or 0.5 (canals shaped with 3% or 5% taper instruments), DR Definitive Restoration, PR Provisional Restoration, ? Data not explicitly indicated in study, \ Data not reported; the ultraconservative endodontic cavity (UEC) and the minimally invasive access Preparation (NAC) are synonymous, in this table they are however reported as they were defined by the authors of the manuscripts; the Espino and Iberico study fails to report Data such as standard deviation on many groups tested

First Autor, Data	Country	Type Teeth	Numbers Teeth	Machine	Access Cavity	Numbers Teeth	Fracture load, N, SD
Silva et al. [14]	Brazil	Maxillary premolars	20	Universal testing machine (EMIC DL2000; EMIC, São José dos Pinhais, Brazil)	UEC	10	556±154
					TEC	10	600±281
Divyasree et al. [15]	India	Mandibular molar	90	Universal testing machine	C	10	1564±54.9
					TEC	SFC+10	887±29
						GIC+10	703±96.2
					CAC	SFC+10	1117±96
						GIC+10	956±153.1
					NAC	SFC+10	1159±82
						GIC+10	989±103.2
					TRAC	SFC+10	1075±96.02
						GIC+10	879±154.8
					Plotino et al. [16]	Italy	maxillary and mandibular premolars and molars
LP 10	1006±313						
TEC	UM 10	1172±598					
	LM 10	1572±639					
	UP 10	498±250					
	LP 10	704±310					
CAC	UM 10	810±425					
	LM 10	923±393					
	UP 10	821±324					
	LP 10	929±384					
NAC	UM 10	1143±506					
	LM 10	1401±495					
	UP 10	805±204					
	LP 10	945±267					
Patil et al. [17]	India	Mandibular molar	50	load testing machine	C	UP 10	2116.4±1570.6339
						LM 10	1459±278
					TEC	UP 10	702±308.6835
						LM 10	944.6±520.4871
					CAC	UP 10	1805.8±981.2641
						LM 10	1712.2±827.2144
Augusto et al. [18]	Brazil	Mandibular molar	32	Universal testing machine (EMIC DL2000; EMIC, São José dos Pinhais, Brazil)	TEC	8 TEC 0.3	1103±369
						8 TEC 0.5	1393±165
					UEC	8 UEC 0.3	1289±446
						8 UEC 0.5	1357±328

**Table 2** (continued)

First Autor, Data	Country	Type Teeth	Numbers Teeth	Machine	Access Cavity	Numbers Teeth	Fracture load, <i>N</i> , SD
Espino and Iberico [19]	Perù	Maxillary premolars	42	Universal testing machine (LG CMT-5 L)	C	6?	597.64
					TAC	6? DR	414.15
						6? PR	391.71
					CAC	6? DR	425.75
						6? PR	380.48 ± 82.15
					NAC	6? DR	638.13 ± 189.59
	6? PR	513.45					

Newtons (N), Standard deviations (SD), Ultraconservative endodontic cavity (UEC), minimally invasive access preparation (NAC), Traditional endodontic Access cavity (TEC), C (Intact teeth or control group), Conservative access cavity (CAC), Truss access cavity (TRAC), Short fiber-reinforced composite (SFC), GIC (Glass Ionomer Cement), Upper premolars (UP), Lower premolars (LP), Upper molars (UM), Lower molars (LM), TEC or UEC with 0.3 or 0.5 (canals shaped with 3% or 5% taper instruments), DR definitive restoration, PR provisional restoration, ? data not explicitly indicated in study, \ data not reported; The Ultraconservative endodontic cavity (UEC) and the minimally invasive access preparation (NAC) are synonymous, in this table they are however reported as they were defined by the authors of the manuscripts;

### Risk of Bias

The risk of bias was assessed using the Checklist for Reporting In *Vitro* Studies (CRIS) guidelines [20], developed to evaluate methodological quality in *vitro* dental research. The results are presented in Table 3. For each item in the risk of bias assessment, a score from one to five was assigned (with one indicating high risk and five indicating low risk). The items evaluated by the reviewers included the following:

1. For the sample size calculation, “Is the sample size adequate for obtaining statistically significant results?”
2. For meaningful difference between groups, “Has the ‘meaningful difference’ measurement been set correctly in the groups taking into account the sample size and the type of measurement?”
3. Sample Preparation and Handling: “Does the study provide detailed information regarding the preparation and handling of the samples to be tested?”
4. Allocation Sequence, Randomization, and Blinding: “Did each sample have an equal and independent chance of being allocated to any experimental group?”
5. Statistical Analysis: “Are the statistical methods clearly described and appropriately applied?”

Studies assessed as having a high risk of bias were excluded from both the systematic review and the meta-analysis, with some being eliminated during the inclusion phase and others during data extraction (Table 3) (Fig. 2). The risk of bias evaluation for the five included studies was independently conducted by M.D. and A.B.

The following scale was adopted in the evaluation (CRIS scale):

- 5 = Excellent: criteria fully met; methods complete and reproducible.

- 4 = Good (minor limitations): adequate, with small, non-substantive omissions.
- 3 = Partial: present but incomplete or with methodological gaps.
- 2 = Weak: inadequate by current standards.
- 1 = Not reported/unclear.

Across five in *vitro* studies, CRIS appraisal highlighted recurrent limitations: absence of a priori clinically meaningful thresholds, incomplete reporting of randomization, blinding, and non-uniform periodontal-ligament simulation. Only two studies reported a priori power calculations. These issues likely contribute to the observed heterogeneity and small-study effects; therefore, pooled estimates are interpreted cautiously and complemented with sensitivity analyses.

### Meta-Analysis, Subgroup analysis, Sensitivity analysis, Publication Bias

The meta-analysis of the data was conducted using Reviewer Manager 5.4 software (Cochrane Collaboration, Copenhagen, Denmark).

The initial meta-analysis focused on fracture resistance between the group subjected to an ultraconservative endodontic access (NAC) and the one with a traditional endodontic access (TEC). Specifically, the aggregated Standard Mean Difference (SMD) between the two groups was calculated, applying fixed-effects models. The mean difference value was found to be 0.97, with a confidence interval (C.I.) of (0.65, 1.29). The SMD value was unfavorable for Traditional Endodontic Access Cavity, as the central diamond, indicating the effect size, did not intersect the line of no effect (Fig. 3).

Furthermore, a subgroup analysis was conducted based on tooth type (molars or premolars). The subgroup analysis reveals, for the molar subgroup, an aggregated SMD of

**Table 3** Assessment of the risk of bias within the studies, with scores 7 to 12=low quality, 13 to 20=intermediate quality, and 21 to 25=high quality

First Author, Data	Sample size calculation	Meaningful difference between groups	Sample preparation and handling	Allocation sequence, randomization and blinding	Statistical analysis	Score
Silva et al. [14]	5 A-priori power analysis (G*Power) reported with $\alpha$ and $1-\beta$ ; calculated n achieved/exceeded.	3 No pre-specified clinically meaningful fracture-load threshold; effect size for power drawn from prior literature rather than a defined $\Delta$ .	5 Detailed, reproducible protocols (tooth selection and matching, storage/mounting, access/shaping/irrigation/obturation/restoration, PDL simulation, ageing/loading settings).	4 Clear random allocation (pair-matched specimens assigned to groups); blinding of operator/assessor not reported	4 Normality checked; arm-level n/mean/SD provided; appropriate two-group comparison. Homoscedasticity test or paired analysis not explicitly stated despite matching (minor limitation)	21
Divyasree et al. [15]	1 No a-priori power or sample-size justification reported (despite large total n); only group sizes stated.	2 Outcome defined (fracture load) and significance tested, but no pre-specified clinically meaningful $\Delta$ to guide interpretation.	4 Clear inclusion/handling, random allocation to five groups, full endo+restoration protocols, embedding, and standardised loading; no periodontal-ligament simulation reported (embedded in acrylic), hence one minor limitation	4 Randomly divided into groups; all procedures by the same operator (reduces operator variability) but blinding not stated	4 Shapiro–Wilk, two-way ANOVA+Tukey, arm-level mean±SD reported for every group; assumptions beyond normality (e.g., homoscedasticity) not detailed; units labelled “N/mm <sup>2</sup> ” in the table though text describes Newtons.	15
Plo-tino et al. [16]	1 No a-priori power/sample-size calculation reported; only fixed group sizes (10 per arm per tooth type).	3 Outcome clearly defined (fracture load) and compared, but no pre-specified clinically meaningful threshold ( $\Delta$ ) to guide interpretation.	4 Transparent specimen selection/storage, CBCT-guided access planning, full endo/restorative protocols, standardised loading. Limitation: no periodontal-ligament simulation (roots embedded in acrylic)	2 Teeth assigned to groups based on matched dimensions; randomisation/blinding not stated. Same operator performed procedures.	5 Normality (Kolmogorov–Smirnov) and homogeneity (Levene) tested; ANOVA+SNK post-hoc; arm-level means±SD reported by tooth type;	15
Patil et al. [17]	1 No a-priori power or sample-size calculation; fixed n=10 per group reported without justification	2 Outcome (fracture load) defined, but no pre-specified clinically meaningful threshold to guide interpretation.	4 Clear inclusion/exclusion; storage in 0.1% thymol; CBCT-guided access outlines; full endo+ bonded composite restoration; standardised loading. Limitation: no PDL simulation (roots embedded in acrylic)	2 Teeth allocated to five groups of ten; randomisation/blinding not stated; procedures performed by the same operator.	4 Kolmogorov–Smirnov and Levene reported; ANOVA+Student–Newman–Keuls; arm-level means±SD provided. Minor issues: SNK is relatively liberal; effect sizes not reported	13
Augusto et al. [18]	5 A-priori G*Power ( $\alpha=0.05$ , power=95%, effect size=0.81) → 32 specimens (8/group).	3 Outcome defined (fracture load), but no pre-specified clinically meaningful threshold to aid interpretation.	5 Micro-CT matching; mannequin setup; detailed access/shaping/restoration; PDL simulation; standardised loading protocol.	4 Random assignment to UEC/TEC and taper subgroups; blinding not reported.	4 Normality (Shapiro–Wilk); one-way ANOVA+Tukey; paired t for size 25 vs. 40; arm-level mean±SD reported. Homoscedasticity not explicitly stated.	21

$\alpha$  significance level;  $1-\beta$  statistical power;  $\Delta$  pre-specified clinically meaningful difference (delta); N newton (unit of force); N/mm<sup>2</sup> newton per square millimetre (stress unit; equivalent to MPa); SD standard deviation; df degrees of freedom; PDL periodontal ligament; CBCT cone-beam computed tomography; micro-CT micro-computed tomography; ANOVA analysis of variance; SNK Student–Newman–Keuls (post-hoc test); Tukey (HSD) honestly significant difference; UEC ultraconservative endodontic cavity (synonym of NAC); NAC minimally invasive/ultraconservative access cavity; TEC/TAC traditional endodontic cavity; CAC conservative access cavity; TRAC truss access cavity; G\*Power sample-size/power software; ISO size 25/40 endodontic instrument tip sizes; taper 0.03/0.05 nominal shaping taper (3%/5%)

1.19 (0.79, 1.60), favoring the minimally invasive access preparation over the traditional endodontic cavity. However, for the premolar subgroup, despite reporting a mean difference favoring TEC openings, the central diamond touches

the line of no effect. It’s important to note that the diameter of the effect is determined by confidence intervals, with an SMD of 0.58 (0.05, 1.11). Heterogeneity is high for both subgroups, with an  $I^2$  of 79% for molars and moderate for

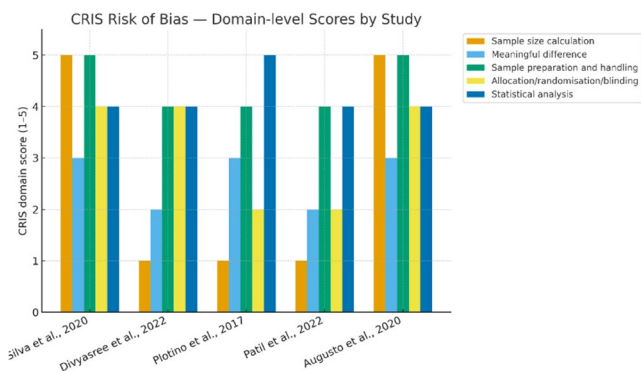


Fig. 2 CRIS risk of bias — domain-level scores

premolars with an  $I^2$  of 61%. The heterogeneity between the two subgroups is 69.1%. It is likely that the source of heterogeneity is the study by Divyasree et al. [15], which, among other things, shows little overlap in confidence intervals with other studies (Fig. 4).

Given the high heterogeneity indicated by the inconsistency index ( $I^2 \approx 76\%$ ), we conducted a random-effects meta-analysis. Substantial heterogeneity ( $I^2 \approx 76\%$ ;) reflects genuine methodological diversity across experiments (tooth type, access definitions, shaping taper, restorative materials, and cavity dimensions). Because the true effects are unlikely to be identical, we complemented the prespecified fixed-effects analysis with a DerSimonian–Laird random-effects model to estimate the mean of a distribution of true effects and to incorporate between-study variance into the confidence intervals. Across 10 contrasts from 5 studies, NAC outperformed TEC: SMD=1.18 (95% CI 0.51–1.84),  $I^2 = 76\%$ ,  $\tau^2 = 0.85$ ;  $Z=3.47$ ,  $p<0.001$ . Nevertheless, heterogeneity remained high (Fig. 5).

A second meta-analysis was also conducted, comparing the fracture resistance expressed in newtons of teeth with NAC to intact teeth. The SMD was calculated, and the results significantly favored intact teeth, with a value of Heterogeneity was high, indicated by an inconsistency index ( $I^2$ ) of 88% and a  $\text{Chi}^2$  value of 48.12 with 6 degrees of freedom ( $P<0.0001$ ). Once again, the source of heterogeneity appears to be the study by Divyasree et al. [15], as there is visually limited overlap of confidence intervals with data from other studies (Fig. 6).

Conducting a sensitivity analysis and excluding data from the study by Divyasree et al. [15], heterogeneity decreases for both meta-analyses. Specifically, for the first meta-analysis (NAC vs. TEC), the inconsistency index drops to 48%, and to 0% for the difference between the two subgroups (Molar, Premolar,  $I^2=0\%$ ). In the second meta-analysis (NAC vs. Control), heterogeneity decreases from  $I^2=88\%$  to  $I^2=0\%$  (Fig. 7).

A publication bias assessment was conducted through the graphical analysis of funnel plot symmetry, which appears to exhibit some asymmetry (Fig. 8). To minimize bias, a search for unpublished material in gray literature was also carried out, encompassing conference proceedings and material that may not have been published due to the lack of significance in results.

Egger’s regression indicated small-study effects: intercept ( $\beta_0$ \beta\_0)=11.10,  $t=5.06$ ,  $df=8$ ,  $p=0.002$  (approximate 95% CI~6.0 to 16.2). The fitted slope was  $\beta_1=-4.67$ \beta\_1=-4.67. This quantitative finding is consistent with the visual asymmetry of the funnel plot (larger effects in less precise studies) (Fig. 9).

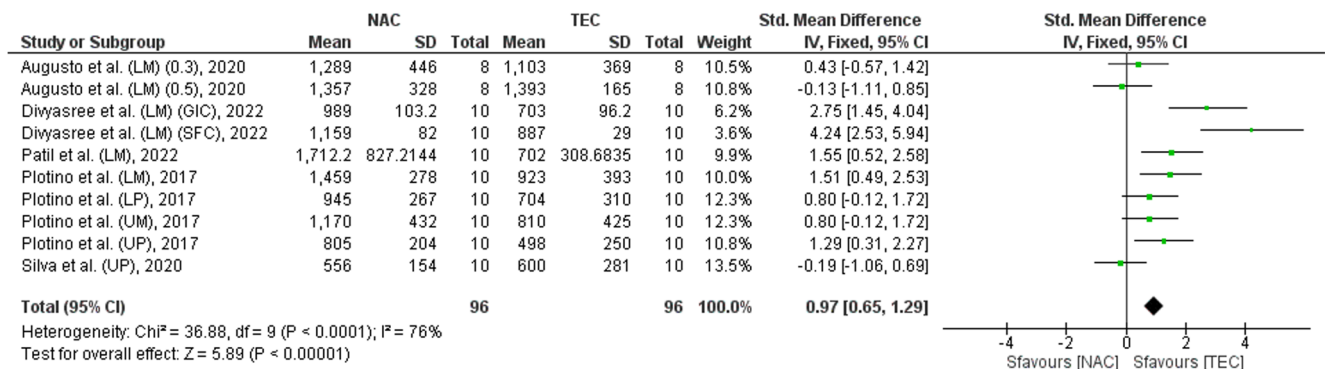
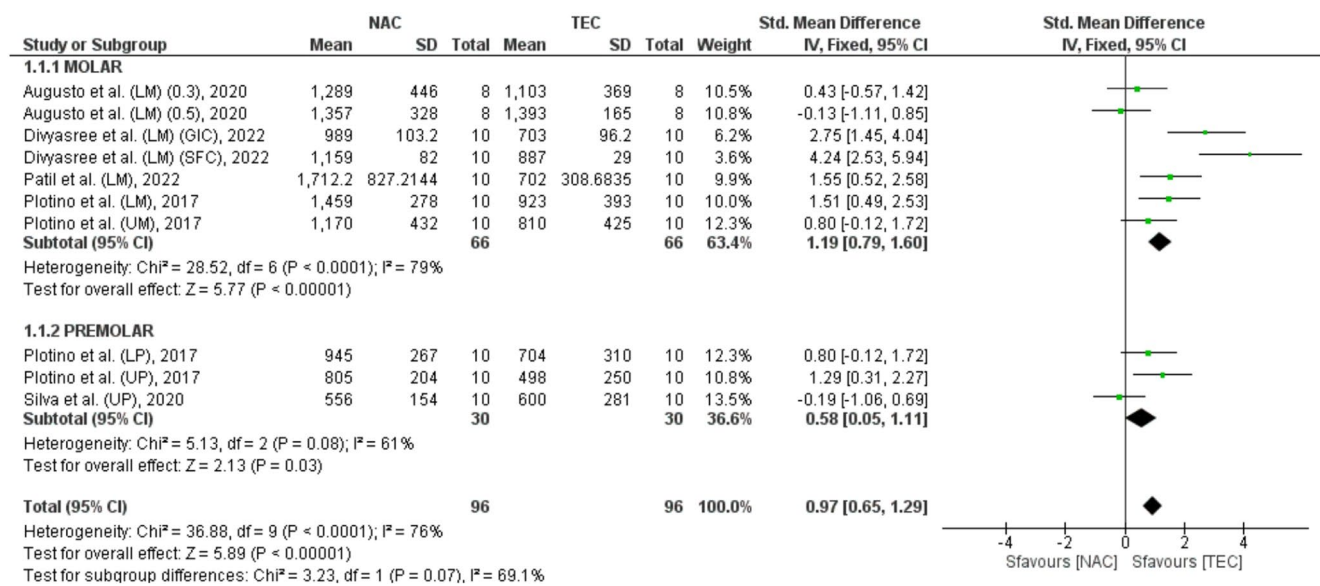
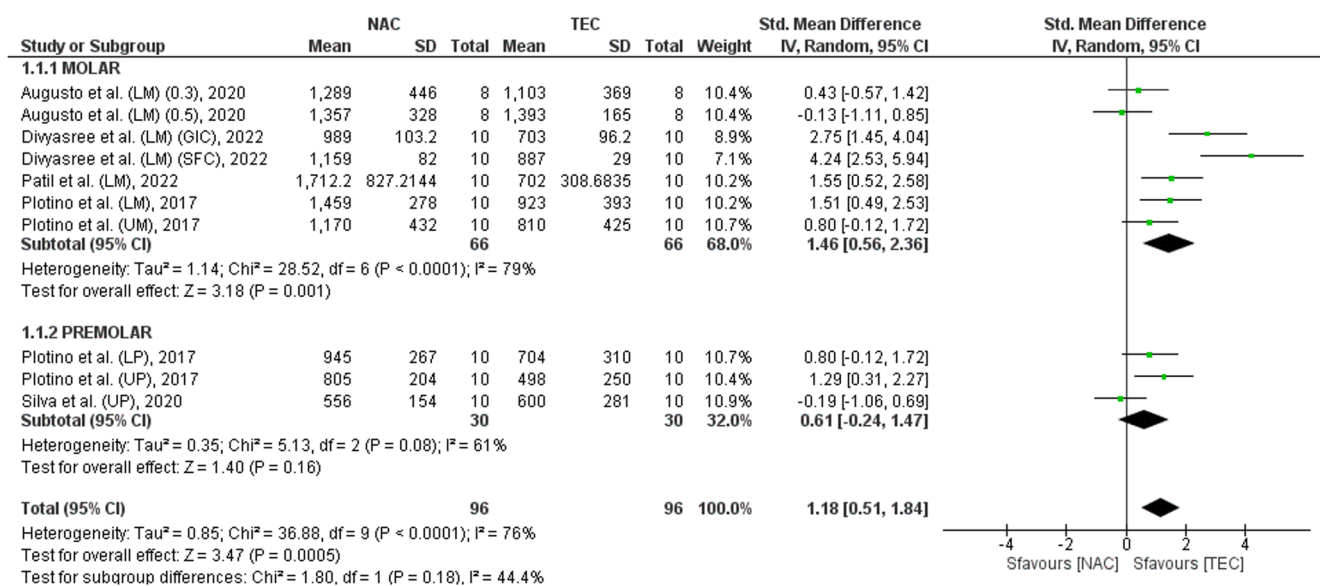


Fig. 3 Forest plot of the fixed-effects model of the meta-analysis, NAC vs. TEC, Std. Mean difference: 0.97 C.I.: [0.65, 1.29].  $\text{Chi}^2 36.88$ ,  $df=9$  ( $P<0.0001$ ),  $I^2=76\%$  The graph for each study shows the first author and the date of publication, Mean, standard deviation the number of teeth, the Std, Mean Differences for each report with confidence intervals, and the final aggregate value of the SMD. The final value was expressed in bold with the relative confidence intervals, the green squares in the center of the confidence intervals represent the average value of the study in the meta-analysis and its size represents the weight of the study. The black line shows the position of the average value, and the rhombus in light black shows the measure of the average effect.  $df$ =degrees of freedom;  $I^2$ =Higgins heterogeneity index,  $I^2<50\%$ , heterogeneity irrelevant;  $I^2>75\%$ , significant heterogeneity; C.I. = confidence intervals;  $P$ =p-value; Short fiber-reinforced composite (SFC), GIC (Glass Ionomer Cement), Upper premolars (UP), Lower premolars (LP), Upper molars (UM), Lower molars (LM), TEC or NAC with 0.3 or 0.5 (canals shaped with 3% or 5% taper instruments)



**Fig. 4** Subgroup analysis; Subgroup Molar: Chi<sup>2</sup> 36.88 df=6 (P<0.00001); I<sup>2</sup>=79% Z=5.77 (p<0.00001), Std. Mean Difference aggregate: 1.19 [0.79, 1.60]; Subgroup Premolar: Chi<sup>2</sup> 5.13, df=2 (P<0.00001); I<sup>2</sup>=61% Z=2.13 (P=0.03), 0.58 [0.05, 1.11], test for subgroup difference: Chi<sup>2</sup>=3.23 df=1 (P=0.07) I<sup>2</sup>=69.1%



**Fig. 5** Forest plot for NAC vs. TEC under random-effects (primary) pooling (SMD). Squares show study effects (size  $\propto$  weight); the diamond shows the pooled effect. We report I<sup>2</sup>,  $\tau^2$ , and 95% CI. SMD=1.18 (95% CI 0.51–1.84), I<sup>2</sup> = 76%,  $\tau^2$  = 0.85; Z=3.47, p<0.001

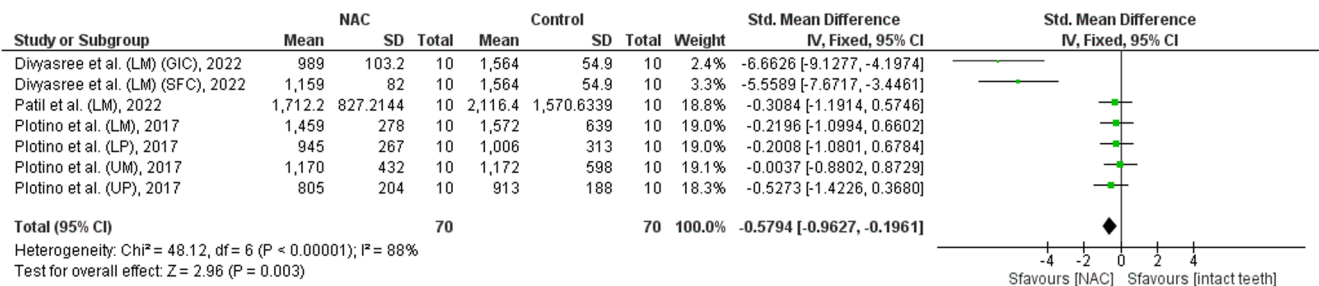
### Discussion

The authors conducted a systematic literature review to ascertain whether there were significant differences in fracture resistance between ultraconservative endodontic accesses and traditional endodontic accesses, and how this might impact the strength of teeth undergoing endodontic treatment.

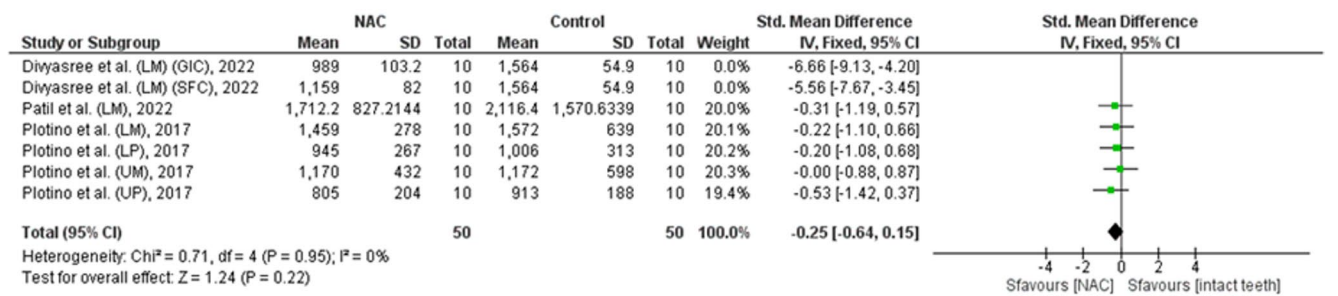
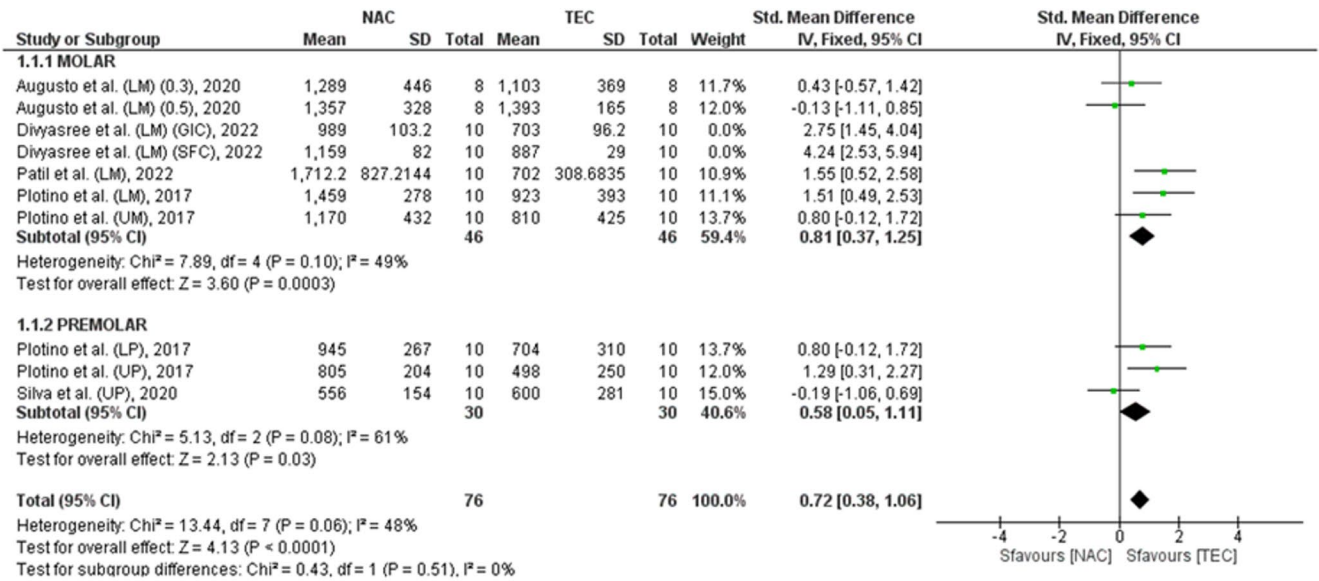
This review is currently the first systematic review with meta-analysis that specifically evaluated the fracture

resistance of teeth treated with ultraconservative access cavities compared to traditional accesses and intact teeth. It was possible to aggregate the data because in the last three years, four studies on ultraconservative endodontic openings investigating fracture resistance have been published (Table 2), data not available to those who conducted previous systematic reviews [6, 9, 21].

The review included five studies, and the total number of teeth included in this review was 352, of which 96 underwent an ultraconservative access cavity (NAC).



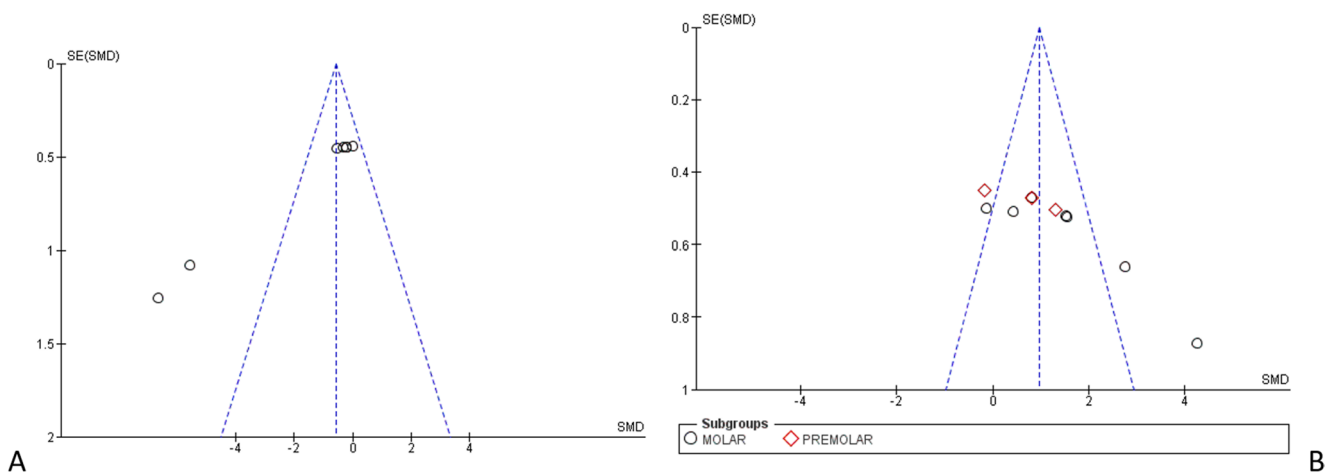
**Fig. 6** NAC vs. control (intact teeth) resistance fracture load, SMD, -0.5794 [-0.9627, -0.1961] Chi<sup>2</sup> = 48.12, df, = 6, P < 0.00001, I<sup>2</sup> = 88%, Z = 2.96, P = 0.003



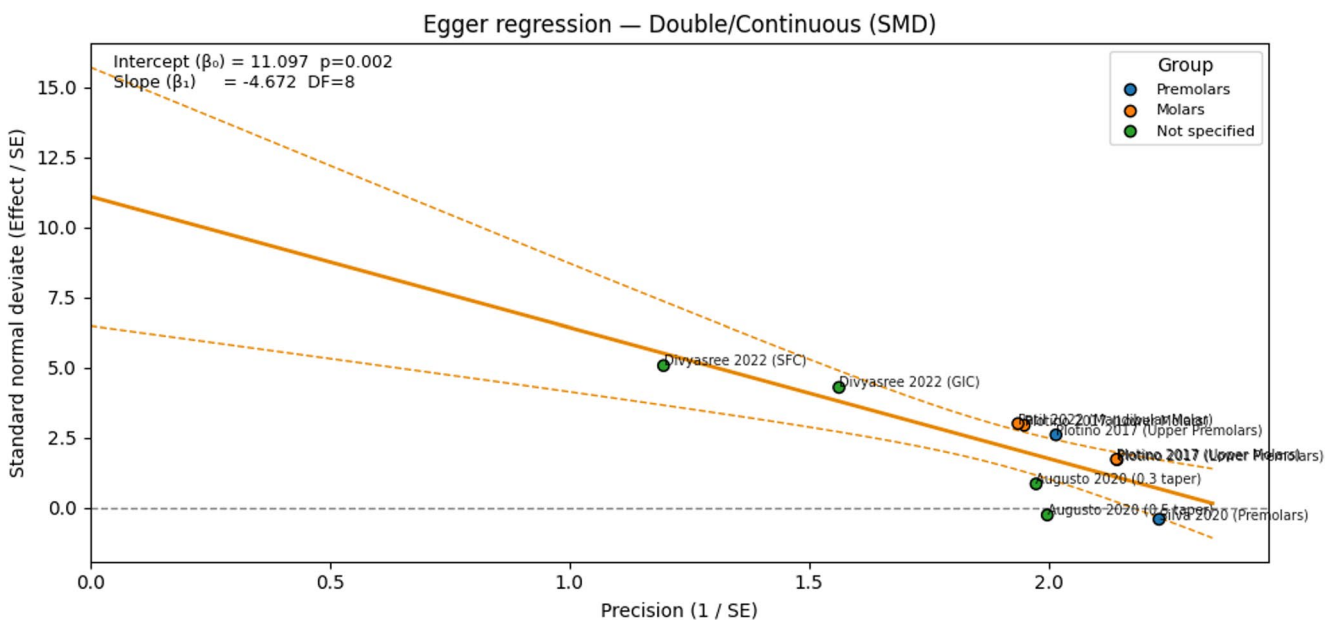
**Fig. 7** Sensitivity analysis: by excluding the study Divyasree et al., 2022, the heterogeneity drops (I<sup>2</sup>=48%) NAC vs. TEC and 0% for NAC vs. Control (intact teeth)

Endodontic treatment aims to preserve teeth affected by pulpitis or compromised by carious processes that would otherwise be destined for loss or extraction. The loss of mineralized hard tissue represents one of the primary factors contributing to the fragility and susceptibility to fractures of endodontically treated teeth. A proper design of the endodontic access cavity can minimize the removal of healthy dentin, thus promoting the deformability of the tooth [22].

The main causes of fractures in endodontically treated teeth may lie in the loss of coronal mineralized tissue following pathological or iatrogenic processes (endodontic access cavities) and during the canal shaping phase. Minimally invasive endodontics, as conceptualized by Clark & Khademi in 2010 [5], suggests eliminating the least amount of healthy mineralized tissue.



**Fig. 8** Funnel plots; **A**, (NAC vs. Control); **B**, (NAC vs. TEC); SMD, standardized Mean difference; SE, standard error. Graphically, there are sources of heterogeneity



**Fig. 9** Egger’s regression (SMD). Scatter of standard normal deviate (effect/SE) against precision (1/SE). The solid line is the fitted regression; dashed lines show the 95% confidence band. Intercept ( $\beta_0$ / $\beta_0$ )=11.10;  $p=0.002$ ;  $df=8$ . Point colours denote subgroups

Among the initial reports of the adoption of NAC as an ultraconservative endodontic access and the first to investigate its fracture resistance was Plotino et al. in 2017 [16], indicating how this technique can enhance the fracture resistance of endodontically treated teeth.

NAC involves a small opening on the occlusal surface of the tooth, designed to allow the dentist to locate and access all canal orifices using small burs to maximize the preservation of the pulp chamber roofs. It differs from TRAC, which involves direct access from the occlusal surface to each canal orifice, preserving the roof of the pulp chamber. NAC would result in the incomplete removal of infected pulp tissue and make canal shaping more challenging and less secure.

The aspects related to the localization of canal orifices represent a crucial phase of endodontic treatment, and conservative and ultraconservative accesses, such as NAC, can influence their proper identification, especially when dealing with upper and lower molars that may have additional canals like MB2 or MMC.

In the study conducted by Saygili et al. [23], performed on 60 maxillary first molars extracted for periodontal reasons, three successive methods were employed, referred to by the authors as Point Endodontic Access Cavity (PEAC), similar to ultraconservative access and partly to minimally invasive access preparation, Conservative Endodontic Access Cavity (CAC), and Traditional Endodontic Access Cavity (TEC).

Opening techniques using conservative and traditional methods were equally effective in identifying MB2 (mesial buccal canal 2) compared to ultraconservative methods, which produced inferior results. It is known from the literature that the non-identification of MB2 can be a cause of endodontic failure, and in this regard, ultraconservative access cavities like minimally invasive access preparation do not facilitate the identification of orifices, which is closely related to the operator's experience [24]. Similar results between Conservative Access Cavities and TEC were found in Mendes' [25] study, which identified no difference between the two methods in locating middle mesial canals (MMC) in lower first molars.

Regarding the residues left in the pulp chamber, histological examinations in the study by Neelakantan et al. [26], on mandibular first molars, identified a greater quantity of organic residues derived from the pulp in the forms of openings identified by the authors as orifice-directed dentin conservation (DDC), which should be part of conservative approaches to access cavities compared to traditional access openings. Similarly, more hard tissue debris would result in upper premolars in the study by Silva et al. [14].

Specifically on fracture resistance, a previous literature review of *in vitro* studies with network meta-analysis [9] reported that CAC had a more favorable access cavity design compared to TRAC, TEC, and ultraconservative cavities, showing that TEC was the least favorable for fracture resistance, in line with our results. However, for NAC, only two studies were included, and the comparison was made indirectly through network meta-analysis. Moreover, they found no evidence supporting that an ultraconservative access was associated with improved fracture resistance.

The results of our meta-analysis clearly show that NAC has a favorable design for fracture resistance compared to traditional accesses (TEC) with a SMD of 0.97 CI [0.65, 1.29], unfavorable to TEC (Fig. 2). When a subgroup analysis was conducted, differentiating between openings on molars and premolars to reduce data heterogeneity, the aggregated data still showed unfavorable results for fracture resistance on teeth with a traditional access design, with a SMD of 1.19 CI [0.79, 1.60]. The aggregated data for the premolar subgroup were still unfavorable for TEC (Fig. 3), but the black central diamond indicating the size of the effect intersected the central line of no effect. In fact, the confidence intervals were: StdMD 0.58 CI [0.05, 1.11], indicating no significant differences in fractures between the two cavity designs in premolars.

The second meta-analysis confirms that teeth subjected to ultraconservative access have lower fracture resistance than intact teeth, with a significant SMD of 0.5794 CI [-0.9627, -0.1961].

Among the included studies, there are results that slightly contradict the overall trend. For instance, Silva et al. [14] reported slightly favorable fracture resistance results for TEC (600  $N \pm 281$ ) compared to UEC (556  $N \pm 154$ ) in upper premolars, and Augusto et al. [18] showed slightly higher fracture resistance for TEC (1393  $N \pm 165$ ) compared to NAC (1357  $N \pm 328$ ) in lower molars.

The data obtained from the meta-analyses can provide positive indications to clinicians dealing with endodontic treatment with a specific cavity design. The minimally invasive approach to endodontics with an ultraconservative or minimally invasive access preparation may be a viable solution in cases where the fracture resistance of a tooth is crucial, such as in situations of partial edentulism where it is impossible to rehabilitate the patient with implant prosthetics, or when masticatory load on a tooth is particularly significant. In such cases, where intervention on that specific tooth is necessary and redistributing masticatory loads across multiple teeth is not feasible, NAC can be a correct approach to increase the resistance of a tooth undergoing endodontic therapy.

However, these results should be treated with caution because the dataset is limited: only five *in vitro* studies with modest sample sizes (total  $n=352$ ; NAC  $n=96$ ). This limited scale compromises the statistical power and precision of the pooled estimates, increasing susceptibility to small study effects. Therefore, the results should be interpreted with caution.

Egger's test suggests small-study effects, which may include publication bias. However, with approximately 10 data sets and substantial heterogeneity, asymmetry may also arise from differences between studies (tooth type, variations in chamber opening design, measurement methods). Therefore, the results shown should be considered more of a warning than definitive evidence of publication bias.

These results are derived exclusively from *in vitro* experiments and should not be directly extrapolated to clinical practice. Fracture load is a laboratory surrogate and does not capture patient-level outcomes (e.g., disinfection and apical seal efficacy, restoration longevity, occlusion). Therefore, clinical recommendations cannot be made based on this alone, and translation to clinical outcomes is inherently uncertain. Therefore, the results should be considered hypothesis-generating rather than clear indications of treatment plans and therapeutic choices.

Future studies should focus primarily on aspects related to the increased difficulty in localizing orifices and the presence of debris that could affect the advantages obtained on fracture resistance with NAC.

The limitations of this review include the low number of studies included in the meta-analysis and the high heterogeneity of the provided data, addressed through subgroup and

sensitivity analysis and the assessment of publication bias. The cumulative sample is limited ( $n=352$ ; NAC  $n=96$ ), and heterogeneity remains high despite subgrouping and random-effects modelling, warranting cautious interpretation. Differences in tooth type, access definitions, instrumentation taper, restorative protocols, and measurement methodologies likely contribute to the observed variability. The average effect favours NAC, but the range of plausible effects for future, similar experiments remains wide. These findings are in *vitro* and not directly generalisable to clinical outcomes; well-designed in *vivo* randomised controlled trials are needed.

Moreover, potential confounders—such as tooth type and the variable definition and execution of access cavities within the same nominal category, together with non-standardised measurement protocols across studies (as noted above)—may have influenced fracture-load estimates. Laboratory-measured fracture resistance should not be over-interpreted as a comprehensive indicator of endodontic success between techniques; clinical success over time depends on a combination of factors, including canal shaping, disinfection, the quality of the apical and coronal seal, and the definitive restoration, which collectively determine long-term survival.

The fracture resistance data related to NAC (96 teeth in total in the literature) at our disposal are still limited, but they outline a trend that mainly affects molars and less so premolars.

## Conclusions

The ultraconservative techniques exhibit a cavity design that demonstrates may improve fracture resistance, implying greater resilience to masticatory loads compared to traditional endodontic accesses.

However, between-study variability remained substantial and small-study effects were detected, so the pooled estimate should be interpreted cautiously.

A balanced appraisal also requires recognising potential downsides of NAC, including reduced straight-line access with possible difficulty in canal location, more challenging instrumentation and irrigation, and a potential increase in iatrogenic events or operator time in less experienced hands. Any gain in in *vitro* fracture load must therefore be weighed against these practical considerations.

These findings are laboratory results and cannot be directly translated to patient outcomes.

Future research should prioritise well-designed in *vivo* studies and randomised clinical trials using harmonised, operational definitions of NAC versus TEC.

## Key References

### important(•) or very important(••) recent references.

- Prado HS, Petean IBF, Franco NJS, Camargo RV, Carvalho KKT, Mazzi-Chaves JF, et al. Impact of access cavities on root canal preparation, restorative protocol quality, and fracture resistance of teeth. *Braz Oral Res.* 2023;37:e096.
  - An in vitro study that highlighted the survival of endodontically treated teeth based on different access cavity designs, by evaluating root canal preparation, restorative protocols, and the fracture resistance of the teeth.
- Rahbani Nobar B, Dianat O, Rahbani Nobar B, Kazem M, Hicks ML. Influence of minimally invasive access cavities on load capacity of root-canal-treated teeth: A systematic review and meta-analysis. *Australian endodontic journal: the journal of the Australian Society of Endodontology Inc.* 2023;49(1):213–36.
  - A recent systematic review aimed to compare the effects of three conservative and traditional access cavity designs on the load-bearing capacity of endodontically treated teeth.
- Kapadia KH, Patni PM, Jain P, Raghuvanshi S, Pandey SH, Singhal RR. Assessment of minimally invasive file systems on resistance to fracture using traditional and contracted access cavity designs in the maxillary first and second molars. *Journal of conservative dentistry : JCD.* 2023;26(4):395–401.
  - An in vitro study that evaluated the effect of two access cavity designs on the fracture resistance of extracted maxillary first and second molars, shaped using three different techniques.
- Espino RJH, Iberico MÁC. Resistance to Fracture of Upper Premolars with Endodontic Treatment by Conservative and Traditional Access. *Revista Cubana de Estomatología.* 2023;60(2).
  - An in vitro study whose data were included in this systematic review with meta-analysis, which evaluated the fracture resistance of endodontically treated maxillary premolars with traditional and conservative access cavities, both with temporary and definitive restorations.

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**Data Availability** All the data generated or analysed during this study are included in this published article.

## Declarations

**Ethics Approval and Consent to Participate** Not applicable, no animal or human subjects by the authors were used in this study.

**Consent for Publication** Not applicable.

**Competing interests** The authors declare no competing interests.

**Human and Animal Rights and Informed Consent** Human and animal rights were respected, and informed consent for the publication of clinical images was obtained.

**Conflict of Interest** The authors declare no conflicts of interest.

**Institutional Review Board Statement** Not applicable.

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## References

- Polesel A. Restoration of the endodontically treated posterior tooth. *G Ital Endod.* 2014;28(1):2–16. <https://doi.org/10.1016/j.gien.2014.05.007>.
- Prado HS, Petean IBF, Franco NJS, Camargo RV, Carvalho KKT, Mazzi-Chaves JF, et al. Impact of access cavities on root canal preparation, restorative protocol quality, and fracture resistance of teeth. *Braz Oral Res.* 2023;37:e096. <https://doi.org/10.1590/1807-3107bor-2023.vol37.0096>.
- Mandil OA, Ghoulah KT, Hazzam BM, Alhijji HS, Al Abbas AH, Rehan AK, et al. Modern versus traditional endodontic access cavity designs. *J Pharm Bioallied Sci.* 2022;14(Suppl 1):S24–s7. [https://doi.org/10.4103/jpbs.jpbs\\_668\\_21](https://doi.org/10.4103/jpbs.jpbs_668_21).
- Silva E, De-Deus G, Souza EM, Belladonna FG, Cavalcante DM, Simões-Carvalho M, et al. Present status and future directions - Minimal endodontic access cavities. *Int Endod J.* 2022;55 Suppl 3:531–87. doi: 10.1111/iej.13696.
- Clark D, Khademi J. Modern molar endodontic access and directed dentin conservation. *Dent Clin North Am.* 2010;54(2):249–73. <https://doi.org/10.1016/j.cden.2010.01.001>.
- Rahbani Nobar B, Dianat O, Rahbani Nobar B, Kazem M, Hicks ML. Influence of minimally invasive access cavities on load capacity of root-canal-treated teeth: a systematic review and meta-analysis. *Aust Endod J.* 2023;49(1):213–36. <https://doi.org/10.1111/aej.12640>.
- Kapadia KH, Patni PM, Jain P, Raghuvanshi S, Pandey SH, Singhal RR. Assessment of minimally invasive file systems on resistance to fracture using traditional and contracted access cavity designs in the maxillary first and second molars. *J Conserv Dent.* 2023;26(4):395–401. [https://doi.org/10.4103/jcd.jcd\\_194\\_23](https://doi.org/10.4103/jcd.jcd_194_23).
- Neelakantan P, Khan K, Hei Ng GP, Yip CY, Zhang C, Pan Cheung GS. Does the orifice-directed dentin conservation access design debride pulp chamber and mesial root canal systems of mandibular molars similar to a traditional access design? *J Endod.* 2018;44(2):274–9. <https://doi.org/10.1016/j.joen.2017.10.010>.
- Motiwalla MA, Gul M, Ghafoor R. Effect of different access cavity designs on fracture toughness of endodontically treated teeth: a systematic review and network meta-analysis. *Evid Based Dent.* 2022. doi: 10.1038/s41432-022-0827-9.
- Silva E, Pinto KP, Ferreira CM, Belladonna FG, De-Deus G, Dummer PMH, et al. Current status on minimal access cavity preparations: a critical analysis and a proposal for a universal nomenclature. *International endodontic journal.* 2020;53(12):1618–35. doi: 10.1111/iej.13391.
- Shabbir J, Zehra T, Najmi N, Hasan A, Naz M, Piasecki L, et al. Access cavity preparations: classification and literature review of traditional and minimally invasive endodontic access cavity designs. *J Endod.* 2021;47(8):1229–44. <https://doi.org/10.1016/j.joen.2021.05.007>.
- Abou-Elnaga MY, Alkhawas MAM, Kim HC, Refai AS. Effect of truss access and artificial truss restoration on the fracture resistance of endodontically treated mandibular first molars. *J Endod.* 2019;45(6):813–7. <https://doi.org/10.1016/j.joen.2019.02.007>.
- Martella C, Martella A, Ramadan AIHA. Identifying key factors in designing data spaces for Urban Digital Twin Platforms: a data driven approach. *Proceedings – 2023 IEEE International Conference on Big Data, BigData 2023* 2023. p. 3985–94.
- Silva AA, Belladonna FG, Rover G, Lopes RT, Moreira EJJ, De-Deus G, et al. Does ultraconservative access affect the efficacy of root canal treatment and the fracture resistance of two-rooted maxillary premolars? *Int Endod J.* 2020;53(2):265–75. <https://doi.org/10.1111/iej.13219>.
- Divyasree V, Raghavendra Reddy J, Chandrasekhar V, Kasam S, Ramachandruni N, Penigalapati S, et al. Influence of Access Cavity Design on the Fracture Strength of Endodontically Treated Teeth Restored Using Short Fiber-Reinforced Composite and High Strength Posterior Glass Ionomer Cement. *Cureus.* 2022;14(8):e28135. doi: 10.7759/cureus.28135.
- Plotino G, Grande NM, Isufi A, Ioppolo P, Pedullà E, Bedini R, et al. Fracture strength of endodontically treated teeth with different access cavity designs. *J Endod.* 2017;43(6):995–1000. <https://doi.org/10.1016/j.joen.2017.01.022>.

17. Patil P, Newase P, Pawar S, Gosai H, Shah D, Parhad SM. Comparison of fracture resistance of endodontically treated teeth with traditional endodontic access cavity, conservative endodontic access cavity, truss endodontic access cavity, and ninja endodontic access cavity designs: an in vitro study. *Cureus*. 2022;14(8):e28090. <https://doi.org/10.7759/cureus.28090>.
18. Augusto CM, Barbosa AFA, Guimarães CC, Lima CO, Ferreira CM, Sassone LM, et al. A laboratory study of the impact of ultra-conservative access cavities and minimal root canal tapers on the ability to shape canals in extracted mandibular molars and their fracture resistance. *Int Endod J*. 2020;53(11):1516–29. <https://doi.org/10.1111/iej.13369>.
19. Espino RJH, Iberico MÁC. Resistance to Fracture of Upper Premolars with Endodontic Treatment by Conservative and Traditional Access. *Revista Cubana de Estomatología*. 2023;60(2).
20. Krithikadatta J, Gopikrishna V, Datta M. CRIS guidelines (checklist for reporting in-vitro studies): a concept note on the need for standardized guidelines for improving quality and transparency in reporting in-vitro studies in experimental dental research. *J Conserv Dent*. 2014;17(4):301–4. <https://doi.org/10.4103/0972-0707.136338>.
21. Saeed M, Al-Obadi M, Salim A, Alsawaf AY, Hadi K. Impact of access cavity design on fracture resistance of endodontically treated molars: a systematic review. *Clin Cosmet Investig Dent*. 2021;13:1–10. <https://doi.org/10.2147/ccide.s287995>.
22. Dioguardi M, Alovisi M, Comba A, Baldi A, Troiano G, Cadenaro M, et al. The influence of indirect bonded restorations on clinical prognosis of endodontically treated teeth: A systematic review and meta-analysis. *Dental Materials*. 2022;38(8):e203–e19. doi: 10.1016/j.dental.2022.06.018.
23. Saygili G, Uysal B, Omar B, Ertas ET, Ertas H. Evaluation of relationship between endodontic access cavity types and secondary mesiobuccal canal detection. *BMC Oral Health*. 2018;18:1–6.
24. Troiano G, Dioguardi M, Cocco A, Giannatempo G, Laino L, Ciavarella D, et al. Influence of operator's experience on the shaping ability of protaper universal and waveone systems: a comparative study on simulated root canals. *Open Dent J*. 2016;10:546–52. <https://doi.org/10.2174/1874210601610010546>.
25. Mendes EB, Soares AJ, Martins JNR, Silva E, Frozoni MR. Influence of access cavity design and use of operating microscope and ultrasonic troughing to detect middle mesial canals in extracted mandibular first molars. *Int Endod J*. 2020;53(10):1430–7. <https://doi.org/10.1111/iej.13352>.
26. Neelakantan P, Khan K, Hei Ng GP, Yip CY, Zhang C, Pan Cheung GS. Does the orifice-directed dentin conservation access design debride pulp chamber and mesial root canal systems of mandibular molars similar to a traditional access design? *J Endod*. 2018;44(2):274–9. <https://doi.org/10.1016/j.joen.2017.10.010>.

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