Effect of Endodontic Access Cavity Designs on Fracture Resistance of Mandibular Molars: A Systematic Review

Dr. Sumita Bhagwat[1], Dr. Lalita Gauri Mandke[2], Dr. Mansi Vandekar[3], Dr. Akash Lakshmanan[4]
Dr. Aishwarya Pawar[5], Dr. Mansi Patel[6]

[1,2]BDS, MDS, Professor, Department of Conservative Dentistry and Endodontics, Dy Patil University School of Dentistry, Nerul, Navi Mumbai, Maharashtra, India

[3]BDS, MDS, Head of the Department, Professor, Department of Conservative Dentistry and Endodontics, Dy Patil University School of Dentistry, Nerul, Navi Mumbai, Maharashtra, India

[4]BDS, Post Graduate Student, Department of Conservative Dentistry and Endodontics, Dy Patil University School of Dentistry, Nerul, Navi Mumbai, Maharashtra, India

[5]BDS, MDS, Lecturer, Department of Conservative Dentistry and Endodontics, Dy Patil University School of Dentistry, Nerul, Navi Mumbai, Maharashtra, India

[6]BDS, Post Graduate Student, Department of Conservative Dentistry and Endodontics, Dy Patil University School of Dentistry, Nerul, Navi Mumbai, Maharashtra, India)

Abstract—**Background**

The design of endodontic access cavities plays a pivotal role in determining the structural integrity and fracture resistance of endodontically treated teeth. With the growing emphasis on minimally invasive dentistry, newer access cavity designs have been introduced with the objective of preserving maximum tooth structure, particularly dentin, while still ensuring adequate canal debridement and disinfection.

Aim

The present systematic review aimed to evaluate the effect of different endodontic access cavity designs on the fracture resistance of mandibular molars.

Materials and Methods

A systematic review of both in vitro studies and finite element analysis models was conducted, focusing specifically on mandibular molars prepared using different access cavity designs, including traditional endodontic cavities, conservative endodontic cavities, truss access cavities, ninja access cavities, and ultraconservative designs. Fracture resistance was assessed using universal testing machines, while stress distribution patterns were analysed through finite element models.

Results

The findings across the included studies consistently demonstrated that preservation of coronal and pericervical dentin significantly enhances fracture resistance. Traditional access cavities, which involve extensive removal of tooth structure, exhibited comparatively lower fracture strength. In contrast, conservative and truss access cavity designs showed significantly improved fracture resistance, with truss access cavities demonstrating the highest resistance and superior fatigue performance. However, ninja and ultraconservative designs showed variable outcomes, suggesting that excessive restriction of access does not necessarily improve structural strength and may compromise clinical effectiveness. Finite element analysis further revealed that conservative designs distribute stresses in a manner more closely resembling intact teeth, whereas traditional designs tend to concentrate stresses, thereby increasing fracture susceptibility. Additionally, the use of restorative materials such as short fiber-reinforced composites was found to further enhance fracture resistance.

Conclusion

Preservation of dentin, particularly in the pericervical region, plays a critical role in improving the fracture resistance of mandibular molars. Conservative and truss access cavity designs offer a favourable balance between structural preservation and functional efficacy. However, further long-term clinical studies are required to validate these findings and establish definitive clinical guidelines.

I. INTRODUCTION

Endodontic access cavity preparation is a fundamental step in root canal treatment, as it directly influences the effectiveness of canal instrumentation, irrigation, and obturation, while simultaneously determining the structural integrity and long-term survival of the treated tooth. Traditionally, access cavity design has been guided by the principle of achieving straight-line access to the root canal system, which facilitates thorough debridement and minimizes procedural errors such as ledging, canal transportation, and instrument separation. However, this conventional approach often requires substantial removal of coronal dentin, particularly in the pericervical region, which plays a crucial role in maintaining the mechanical strength of the tooth Excessive loss of this critical dentin, especially in mandibular molars subjected to high occlusal forces, has been associated with an increased risk of catastrophic fractures, frequently leading to tooth loss

With the growing emphasis on minimally invasive endodontics, contemporary approaches have shifted toward preserving maximum tooth structure while maintaining treatment efficacy. This has led to the development of alternative access cavity designs that aim to balance adequate canal access with dentin conservation Among these, conservative, contracted, ninja, and truss access cavities have gained considerable attention. These designs are based on the concept that preservation of pericervical dentin, defined as the region extending approximately 4 mm above and below the cementoenamel junction, is essential for optimal stress distribution and resistance to fracture Conservative access cavities reduce the occlusal opening, thereby maintaining more coronal tooth structure, whereas ninja access cavities represent an ultraconservative approach with minimal dentin removal, often requiring advanced clinical skills and magnification . Truss access cavities further enhance structural preservation by maintaining dentinal bridges over the pulp chamber roof, potentially reinforcing the tooth against occlusal loading

Despite the theoretical advantages of these minimally invasive designs, their impact on fracture resistance and overall treatment success remains controversial. Several biomechanical studies have reported that conservative access cavity designs improve fracture resistance by preserving tooth structure and enhancing the tooth's ability to withstand functional forces. Conversely, other studies suggest that excessive conservation of dentin may compromise canal instrumentation and disinfection, potentially leading to inadequate cleaning and an increased risk of endodontic failure. Furthermore, the type of post-endodontic restoration plays a significant role in determining fracture resistance, with adhesive restorative materials such as fiber-reinforced composites showing improved mechanical performance compared to conventional restorations

Another critical concern associated with conservative access cavity designs is the potential compromise in clinical accessibility. Restricted access may limit direct visualization of canal orifices and complicate instrumentation procedures, necessitating the use of advanced technologies such as dental operating microscopes, ultrasonics, and guided endodontic techniques. Additionally, reduced cavity dimensions may result in altered stress distribution patterns, potentially leading to localized stress concentration and affecting long-term tooth stability under occlusal loads. Therefore, it is essential to evaluate these designs not only in terms of dentin preservation but also with respect to their influence on treatment efficacy and long-term outcomes.

The interpretation of existing literature is further complicated by methodological variations among studies. In vitro studies using extracted human mandibular molars provide valuable insights into fracture resistance; however, they may not accurately replicate intraoral conditions such as cyclic loading, thermal changes, and complex occlusal dynamics. Differences in experimental protocols, including sample preparation, loading techniques, and fracture testing methods, contribute to variability in reported outcomes. While some studies utilize static compressive loading through universal testing machines, others incorporate cyclic fatigue loading to better simulate clinical conditions. Variations in dentin preservation, canal preparation techniques, and restorative approaches further influence the results, highlighting the need for a comprehensive and systematic evaluation.

Given the evolving concepts in access cavity design and their potential implications for long-term tooth survival, a systematic review is essential to critically analyse the available evidence. A clear understanding of the relationship between access cavity design, fracture resistance, and restorative strategies is crucial for optimizing endodontic treatment outcomes. Therefore, the present systematic review aims to evaluate the effect of different endodontic access cavity designs on the fracture resistance of mandibular molars, with the objective of providing evidence-based insights that support a balance between effective canal debridement and preservation of tooth structure.

II. METHODOLOGY

Study Design
This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure methodological rigor, transparency, and reproducibility. A structured protocol was developed prior to the commencement of the review to guide the systematic identification, selection, and analysis of relevant studies.

Review Question
This systematic review was designed to address the following research questions:

1. How does conservative access cavity preparation compare with traditional access cavity designs in terms of fracture resistance in mandibular molars?
2. What is the effect of minimally invasive endodontic access cavity designs, including contracted, ninja, and truss cavities, on the structural integrity of mandibular molars following endodontic treatment?
3. Does the type of access cavity design influence the overall mechanical performance, longevity, and failure patterns of mandibular molars under occlusal loading?
4. How do different restorative protocols, such as adhesive and non-adhesive restorations, affect fracture resistance when used in conjunction with various access cavity designs?
5. What methodological variations exist among studies evaluating fracture resistance of mandibular molars with different access cavity designs, and how do these variations influence the reported outcomes?

Search Strategy
A comprehensive literature search was performed across multiple electronic databases, including PubMed/MEDLINE, Scopus, Web of Science, Embase, Cochrane Library, and Google Scholar for grey literature. The search included studies published from the year 2000 to the present. A combination of Medical Subject Headings (MeSH) terms and free-text keywords related to endodontic access cavities, fracture strength, mandibular molars, and tooth biomechanics was used to maximize the scope and sensitivity of the search. Boolean operators were applied to refine the search strategy, and the reference lists of selected articles were manually screened to identify additional relevant studies.

Eligibility Criteria
Studies were included based on predefined criteria to ensure consistency and relevance. In vitro studies conducted on extracted human mandibular molars that evaluated fracture strength following different access cavity preparations were considered eligible. Studies assessing the influence of restorative materials on post-endodontic fracture resistance and those reporting quantitative fracture strength values were also included. Only studies with comparative groups evaluating multiple access cavity designs were selected. Studies involving maxillary teeth, premolars, anterior teeth, animal models, finite element analysis, case reports, and review articles were excluded.

Study Selection Process
The study selection process was carried out in two stages to ensure accuracy and minimize bias. Initially, titles and abstracts were independently screened by two reviewers to identify potentially relevant studies. Subsequently, full-text articles of selected studies were assessed for eligibility. Any disagreements between reviewers were resolved through discussion or consultation with a third reviewer.

Data Extraction
Data extraction was performed using a standardized and pre-validated data collection form. Relevant information such as study characteristics, sample details, type of access cavity design, fracture strength measurement methods, restorative materials used, and fracture patterns was systematically recorded. Where available, details regarding dentin preservation and remaining dentin thickness were also included. To ensure reliability, data extraction was conducted

independently by two reviewers, and discrepancies were resolved through consensus.

Risk of Bias Assessment

The methodological quality of the included studies was assessed using the Quality in Non-Randomized Studies (QUIN) tool, which is specifically designed for evaluating in vitro and non-randomized experimental studies. This tool assesses multiple domains, including selection bias, performance bias, detection bias, attrition bias, reporting bias, and other potential sources of bias. Studies with well-defined methodologies, standardized procedures, and objective outcome measurements were considered to have a low risk of bias, whereas studies with methodological limitations or incomplete reporting were categorized as having some concerns or high risk. As all included studies were laboratory-based, attrition bias was minimal.

Data Synthesis and Statistical Analysis

Data synthesis was carried out using both qualitative and quantitative approaches. A narrative synthesis was performed to summarize and compare findings across studies based on different access cavity designs and methodological characteristics. Where sufficient homogeneity was observed, a meta-analysis was conducted using RevMan 5.4 software. Effect sizes were calculated using mean differences or standardized mean differences with 95% confidence intervals, and statistical heterogeneity was assessed using the I^2 statistic to determine the appropriate analytical model. Publication bias was evaluated using funnel plots and Egger's regression test.

Subgroup Analysis

To explore potential sources of variability, subgroup analyses were conducted based on access cavity design, type of restorative protocol, fracture testing methodology, and dentin thickness preservation. These analyses provided a more detailed understanding of the factors influencing fracture resistance and helped identify possible reasons for heterogeneity among the included studies.

III. RESULTS

This systematic review identified and synthesized findings from a total of 21 in vitro studies that evaluated the impact of different endodontic access cavity designs on the fracture resistance of mandibular molars (Figure 1). The extracted data from these studies have been systematically compiled and presented in the Master Chart (Annexure 1). The included studies primarily compared traditional endodontic access cavities (TEC/TAC) with various minimally invasive designs, including conservative (CEC/CAC), truss (TREC/TRAC), ninja (NAC/NEC), and ultraconservative (UEC/UAC) access cavities. Fracture resistance across the studies was commonly assessed using universal testing machines under either static or cyclic loading conditions. Additionally, several studies incorporated thermocycling procedures to simulate intraoral aging and better approximate clinical conditions. [20–39]

Traditional vs. Conservative Access Cavity Designs

Several studies evaluated the difference in fracture resistance between traditional and conservative access cavity designs. Corsentino et al. (2018) and Ozuryek et al. (2018) reported no statistically significant difference in fracture strength between traditional endodontic cavities (TEC) and conservative endodontic cavities (CEC) ($p > 0.05$) . However, Ozuryek et al. highlighted that the type of restorative material had a greater influence on fracture resistance than the access cavity design itself, with SDR restorations demonstrating superior performance compared to EverX. Similarly, Sabeti et al. (2018) found that although conservative access cavities did not significantly improve fracture resistance compared to traditional designs, both groups exhibited significantly lower strength than intact teeth ($p < 0.05$).

In contrast, more recent studies have demonstrated a beneficial effect of conservative access designs. Shah et al. (2024) reported significantly higher fracture resistance in mandibular molars prepared with conservative cavities compared to traditional designs ($p = 0.0431$), although no significant difference was observed in maxillary molars. Mustafa et al. (2020) further noted that conservative access cavities significantly improved fracture strength compared to traditional designs when only two residual walls were present ($p < 0.05$). Additionally, Patil et al. (2022) and Vishwaja et al. (2022) reported that conservative cavities exhibited greater fracture resistance than traditional designs, although their performance remained inferior to more advanced minimally invasive designs such as truss and ninja cavities

Traditional vs. Truss Access Cavity Designs

Truss access cavities have been proposed to enhance fracture resistance by preserving dentinal bridges and maintaining structural integrity. Elnaga et al. (2019) demonstrated that truss access cavities significantly increased fracture resistance compared to traditional designs ($p < 0.05$), although artificial truss restorations did not provide additional benefits. Similarly, Saberi et al. (2020) reported that truss cavities exhibited superior fracture resistance under thermocycling conditions compared to traditional cavities ($p < 0.05$). These findings were further supported by Patil et al. (2022) and Vishwaja et al. (2022), who consistently reported higher fracture resistance values for truss designs compared to both traditional and conservative cavities

However, not all studies were in agreement. Corsentino et al. (2018) found no significant difference in fracture resistance among traditional, conservative, and truss access cavities ($p > 0.05$), suggesting that factors such as marginal ridge preservation may play a more critical role than access cavity design alone. Barbosa et al. (2020) also reported that truss access cavities resulted in increased areas of un instrumented canals and residual pulp chamber tissue, indicating potential limitations in effective canal debridement

Ninja and Ultraconservative Access Cavity Designs

Minimally invasive approaches such as ninja and ultraconservative access cavity designs have also been investigated. Augusto et al. (2020) and Silva et al. (2021) reported no significant improvement in fracture resistance when comparing ultraconservative designs with traditional cavities ($p \approx 0.05$ and $p = 0.975$, respectively), indicating that excessive dentin preservation does not necessarily translate into improved mechanical strength

Conversely, Patil et al. (2022) and Vishwaja et al. (2022) demonstrated that ninja access cavities exhibited significantly greater fracture resistance than both traditional and conservative designs ($p < 0.05$), although their performance was comparable to truss cavities. Kodama et al. (2023) further supported these findings, showing that ninja cavities required more load cycles to initiate crack propagation compared to traditional cavities, although they remained inferior to truss designs in overall resistance

Finite Element Analysis (FEA) Studies

Finite element analysis studies provided valuable insights into stress distribution patterns associated with different access cavity designs. Wang et al. (2023) reported that guided and conservative access cavities exhibited stress distributions most similar to intact teeth, whereas traditional cavities showed the highest stress concentration under lateral loading. Truss cavities, on the other hand, demonstrated higher stress under vertical loading conditions. Kodama et al. (2023) found that truss cavities required the highest number of load cycles before crack propagation, followed by ninja and traditional designs, further supporting the biomechanical advantages of minimally invasive approaches

Effect of Restorative Materials on Fracture Resistance

The type of restorative material used to follow endodontic treatment was found to significantly influence fracture resistance outcomes. Ozuryek et al. (2018) and Divyasree et al. (2022) reported that short fiber-reinforced composite restorations provided significantly higher fracture resistance compared to conventional glass ionomer cement ($p < 0.01$). Ninkovic et al. (2024) observed that Fuji IX performed optimally in truss cavity restorations, while a combination of EverX and Filtek composites significantly improved fracture resistance in traditional cavities. Furthermore, Shirani et al. (2023) emphasized the importance of marginal ridge preservation, demonstrating that teeth with intact ridges exhibited significantly higher fracture resistance compared to those without ($p < 0.001$) .

Risk of Bias Assessment

The risk of bias was assessed using the Quality in Non-Randomized Studies (QUIN) tool across six domains, including selection, performance, detection, attrition, reporting, and other biases. Overall, most studies demonstrated a low to moderate risk of bias. Selection bias was generally low, as most studies utilized extracted mandibular molars with standardized inclusion criteria. However, finite element analysis studies were associated with some concerns due to their reliance on computational models rather than actual specimens.

Performance bias was minimal across studies due to the use of standardized endodontic and testing protocols, although the absence of operator blinding in some studies introduced minor concerns. Detection bias was moderate in certain studies where blinding of outcome assessors was not reported. Attrition bias was negligible, as all studies were conducted under controlled in vitro conditions without loss of samples. Reporting bias was generally low, although some finite element studies demonstrated selective reporting of outcomes. Other sources of bias, including methodological limitations and reliance on simulated models, were noted in a few studies. Overall, the included studies provided reasonably reliable evidence, although certain limitations must be considered when interpreting the findings

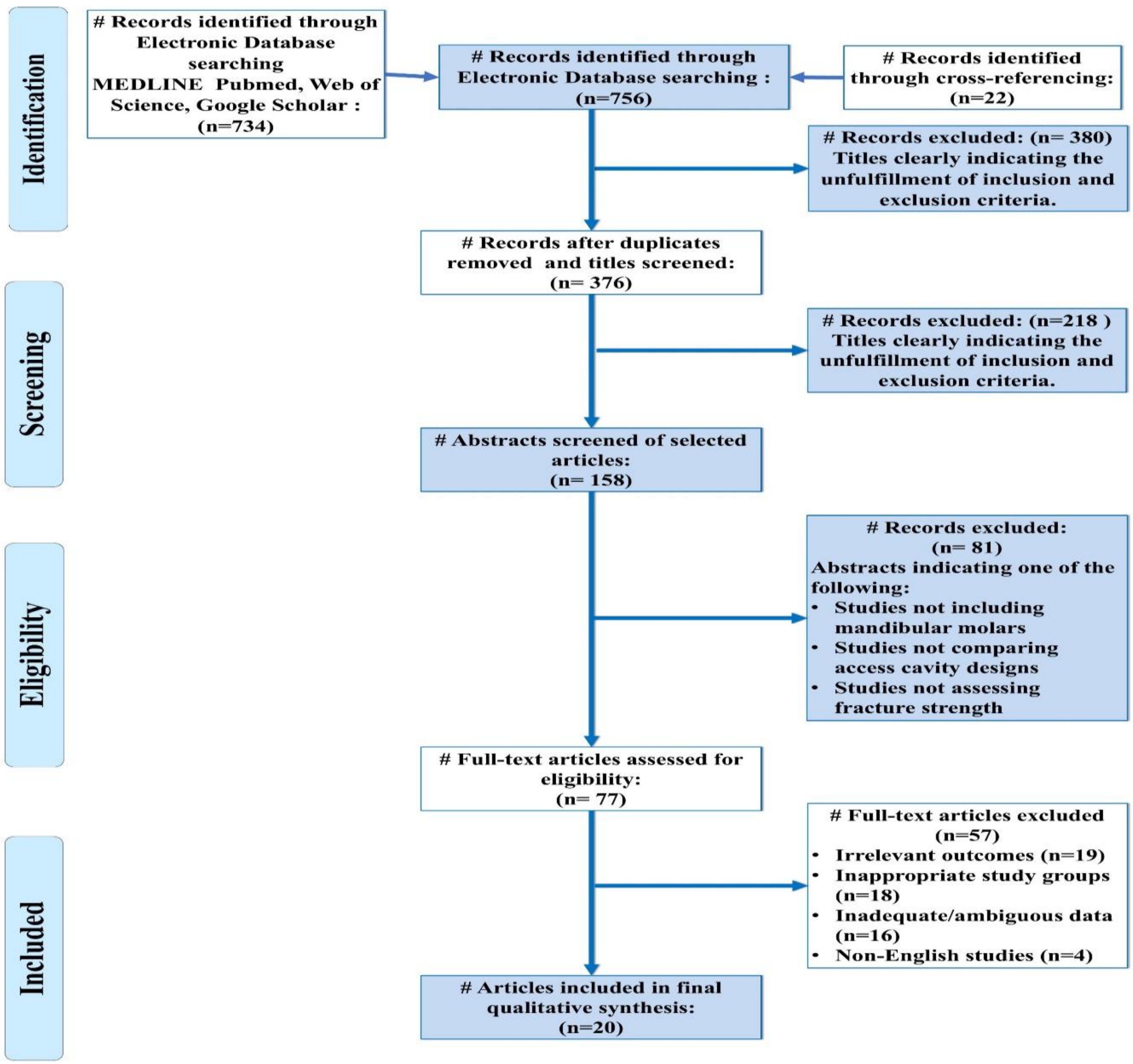

Figure 1: PRISMA Flow diagram indicating the selection process of the articles in the systematic review

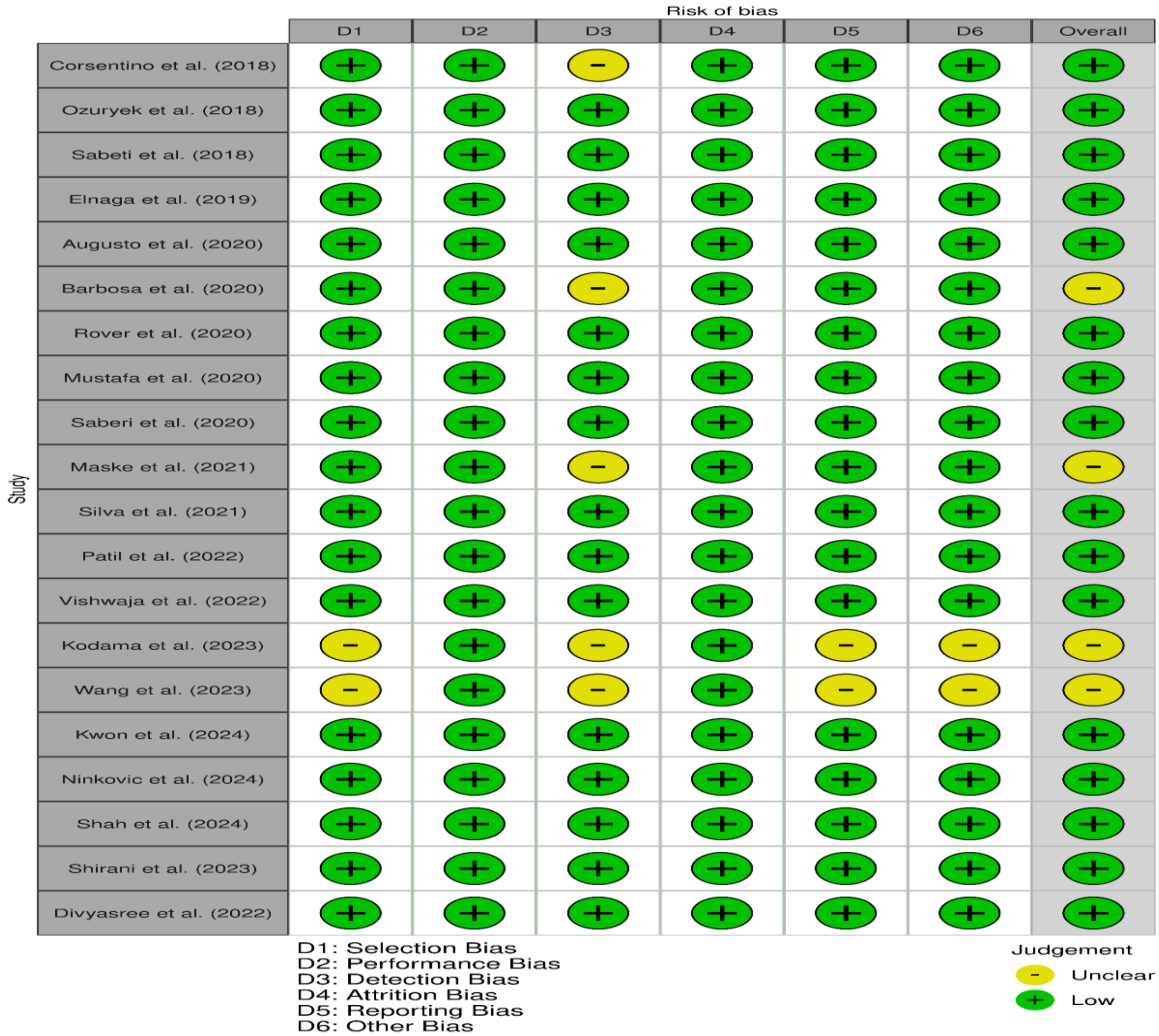

Figure 2: Risk of bias in the individual studies included in the review

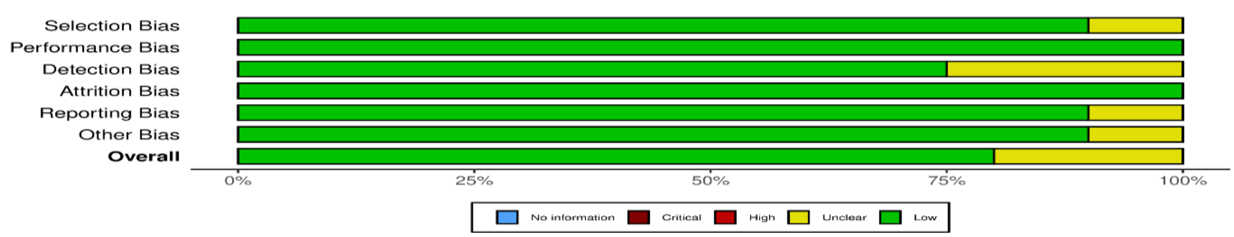

Figure 3: Collective overall summary of risk of bias of the studies included in the review

Summary of Findings

The findings of this systematic review indicate that truss and ninja access cavity designs generally demonstrate superior fracture resistance compared to traditional and conservative access cavities, with more pronounced improvements observed under thermocycling conditions. In contrast, ultraconservative access cavities did not consistently enhance fracture resistance, suggesting that excessive preservation of dentin does not necessarily translate into improved mechanical performance. Finite element analysis studies further supported that guided and contracted access cavities exhibit stress distribution patterns more closely resembling intact teeth, whereas traditional designs tend to concentrate higher stresses. Additionally, the selection of restorative materials was found to play a crucial role in determining final fracture resistance. Preservation of marginal ridges also emerged as a key factor in maintaining structural integrity following endodontic treatment. Overall, although minimally invasive access cavity designs such as truss, ninja, and conservative cavities tend to improve fracture resistance compared to traditional designs, their impact on clinical efficacy, canal debridement, and long-term outcomes remains an area requiring further investigation.

IV. DISCUSSION

The present systematic review provides a comprehensive evaluation of the influence of different endodontic access cavity designs on the fracture resistance of mandibular molars. The overall findings emphasize that preservation of coronal and pericervical dentin plays a critical role in enhancing the structural durability of endodontically treated teeth. However, fracture resistance is not determined by access cavity design alone, as it is also influenced by restorative strategies, testing conditions, and methodological variations among studies

The majority of the included studies were in vitro investigations conducted on extracted human mandibular molars under controlled laboratory conditions. Standardized fracture testing methods, primarily using universal testing machines, were employed to simulate occlusal forces, while some studies incorporated thermocycling to mimic aging and finite element analysis to evaluate stress distribution. Although these approaches provide valuable biomechanical insights, they do not fully replicate intraoral conditions such as dynamic occlusal loading, periodontal ligament support, and long-term functional stresses, which limits the direct clinical applicability of the findings

Variations in sample size, ranging from 30 to 120 teeth, and differences in tooth selection criteria contributed to heterogeneity across studies. Most studies focused on mandibular molars due to their functional significance in mastication and higher susceptibility to fracture under occlusal loads. The access cavity designs evaluated included traditional, conservative, truss, ninja, and ultraconservative approaches, each differing in the extent of dentin preservation. Control groups typically consisted of intact teeth or traditionally prepared cavities, allowing comparison of structural outcomes following varying degrees of dentin removal

Traditional access cavity designs consistently demonstrated lower fracture resistance due to extensive removal of tooth structure. Although some studies reported no statistically significant difference between traditional and conservative designs, others highlighted that conservative cavities offer improved fracture resistance, particularly when residual tooth structure is limited. Importantly, these findings suggest that dentin preservation alone may not be sufficient to significantly enhance fracture strength unless combined with appropriate restorative strategies.

Truss access cavities emerged as one of the most favourable designs in terms of fracture resistance. By preserving dentinal bridges and maintaining structural continuity, truss designs demonstrated higher resistance to fracture and better performance under aging conditions. Similarly, ninja access cavities showed promising results, particularly in delaying crack initiation and propagation. However, ultraconservative designs yielded inconsistent outcomes, indicating that excessive restriction of access may not provide additional biomechanical advantages and may even compromise treatment efficiency.

Finite element analysis studies reinforced these findings by demonstrating that conservative and guided access cavities distribute stresses more evenly, closely resembling the behaviour of intact teeth. In contrast, traditional access cavities were associated with higher stress concentrations, particularly under lateral loading, which may increase fracture susceptibility. These findings highlight the importance of strategic dentin preservation, particularly in the pericervical region, for optimizing stress distribution and improving fracture resistance

Another critical factor influencing fracture resistance is the choice of restorative material. Studies consistently demonstrated that adhesive restorative materials, particularly short fiber-reinforced composites, significantly enhance fracture resistance compared to conventional materials such as glass ionomer cement. Furthermore, the preservation of marginal ridges was identified as a key determinant of structural integrity, with teeth retaining intact ridges showing substantially higher fracture resistance.

Despite these promising findings, several limitations must be acknowledged. The reliance on in vitro studies limits the generalizability of results to clinical scenarios. Additionally, variations in study design, testing protocols, and restorative techniques contribute to heterogeneity, making direct comparisons challenging. There is a clear need for well-designed long-term clinical trials to validate the effectiveness of minimally invasive access cavity designs in real-world settings.

In conclusion, this systematic review highlights that while minimally invasive access cavity designs, particularly truss and conservative approaches, improve fracture resistance by preserving critical dentin structures, a balanced approach is essential. Optimal outcomes are achieved not only through appropriate access cavity design but also through effective canal debridement and the use of suitable restorative materials. Future research should focus on standardizing methodologies and evaluating long-term clinical outcomes to establish definitive guidelines for endodontic access cavity preparation.

V. CONCLUSION

he findings of this systematic review provide important insights into the influence of different endodontic access cavity designs on the fracture resistance of mandibular molars. A comprehensive analysis of the included studies highlights the critical role of strategic dentin preservation in maintaining the mechanical integrity of endodontically treated teeth. Although traditional access cavities (TEC/TAC) facilitate ease of instrumentation and effective canal debridement, they are consistently associated with reduced fracture resistance when compared to conservative (CEC/CAC) and truss (TREC/TRAC) access cavity designs. The reviewed evidence indicates that minimally invasive cavity designs generally demonstrate higher fracture strength values, with several studies reporting statistically significant improvements, particularly in truss and ninja access preparations. However, the effectiveness of ultraconservative access cavities remains inconclusive. Studies such as those by Augusto et al. (2020) and Silva et al. (2021) reported no significant enhancement in fracture resistance despite extensive dentin preservation, suggesting that excessive restriction of access may not provide additional biomechanical benefits. These findings emphasize that while dentin conservation is essential, an optimal balance between structural preservation and adequate canal accessibility is necessary to achieve favourable clinical outcomes.

The methodological quality of the included studies adds strength to these findings; however, certain limitations must be considered. Most studies were conducted under in vitro conditions, which, although valuable for controlled mechanical evaluation, do not fully replicate the complex intraoral environment. Factors such as periodontal ligament simulation, cyclic occlusal loading, and biological responses are often absent in laboratory settings, thereby limiting the direct clinical applicability of the results. Additionally, variability in sample sizes, with some studies including fewer than 50 specimens, may affect the statistical robustness of the conclusions. Finite element analysis studies provided complementary insights into stress distribution, demonstrating that guided and conservative access cavities produce stress patterns more comparable to intact teeth, whereas traditional access cavities exhibit higher stress concentrations, particularly under lateral loading. Although these computational findings support the biomechanical advantages of selective dentin preservation, they are inherently limited by their inability to fully simulate the complexity of real-life occlusal forces and long-term fatigue behaviour.

From a clinical perspective, the results of this review support a shift toward more conservative access cavity designs that prioritize preservation of critical tooth structure without compromising treatment efficacy. While truss and ninja access cavities exhibit superior fracture resistance, their routine clinical application may be challenging due to restricted visibility and limited access for instrumentation and debridement. Furthermore, the choice of restorative material plays a significant role in determining post-endodontic fracture resistance, with evidence suggesting that short fiber-reinforced composites and bulk-fill resins provide superior mechanical reinforcement compared to conventional restorative materials. Future research should focus on well-designed clinical trials to evaluate the long-term performance of various access cavity designs under functional conditions. Such studies should incorporate clinically relevant parameters, including tooth survival rates, patient-reported outcomes, and retreatment success, to establish evidence-based guidelines for optimizing endodontic access cavity design.

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