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Effectiveness of horizontal posts to support MOD cavities compared with other restorative approaches in endodontically treated teeth: systematic review with meta-analysis of laboratory studies

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Abstract

Background Endodontically treated teeth often face challenges in maintaining structural integrity, particularly when restored with MOD cavities. This systematic review aimed to evaluate the mechanical behavior of endodontically treated premolar and molar teeth with MOD cavities, restored with horizontal posts and composite materials, compared with alternative restorative approaches such as fiber-reinforced composites and indirect restorations.

Methods A comprehensive search was conducted in December 2024 across various databases, including PubMed, Scopus, Web of Science, and Google Scholar. All studies that examined the application of horizontal posts in posterior endodontically treated teeth compared to other restorative methods were included, and manual searches of included studies and associated scientific websites were performed. The meta-analysis was accomplished through the Review Manager (RevMan 5.4) of the Cochrane Collaboration.

Results The web search yielded 718 records, and 1 was added from the manual search. Following the PRISMA guidelines, 26 studies were ultimately included in this review. Horizontal posts in endodontically treated teeth significantly improved fracture resistance compared with untreated MOD cavities and many restorative methods, though they did not match sound teeth. Combining horizontal posts with materials like polyethylene fiber Ribbond or nanohybrid composites achieved fracture resistance comparable to sound teeth, while finite element analyses showed reduced stress concentrations. Horizontal posts also reduced non-restorable fractures compared to MOD cavities and bulk-fill composites, highlighting their mechanical advantage, especially when paired with advanced composites.

Conclusions The insertion of horizontal posts significantly increased the fracture resistance of endodontically treated premolars and molars compared to composite restorations. Notably, fracture resistance levels were comparable to

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those observed in teeth restored with glass-fiber-reinforced composite and indirect ceramic restorations. However, there was no evident benefit from inserting root canal posts in enhancing fracture resistance. None of the restorative approaches achieved the fracture resistance levels of intact premolar and molar teeth.

Clinical significant Proper support of ETTs with MOD cavities restored with direct composite restorations can preserve tooth integrity, particularly in case of large cavities. These supporting concepts are crucial in achieving complications-free restorations that maintain long-term clinical functionality.

Keywords Fiber posts, Inlay, Onlay, Horizontal posts, Stress distribution, Occlusal Ribbonds, Fiber reinforced composite, Fracture resistance, Mechanical behavior

Introduction

Numerous treatment modalities and restorative approaches are available in dental practice for coronal rehabilitation of endodontically treated teeth (ETT). The selection of a restorative approach for ETT is primarily dictated by the remaining tooth structure and available surface area for adhesion [1]. ETT are more susceptible to clinical complications compared to vital restored teeth [2], attributed to the considerable loss of tooth structure resulting from caries removal, access cavity preparation, root canal cleaning, and shaping, besides the application of chelating agents and detergents such as EDTA and NaOCl [3]. The predominant complications associated with ETT include fractures of restorations or underlying tooth structure [4]. Dental practitioners must be aware of both controllable and uncontrollable risks during treatment procedures to mitigate the likelihood of clinical complications [2].

The design and size of the cavity may influence the capability of the remaining tooth structure to dissipate stresses [5]. In posterior teeth, the presence of Class II cavities can diminish support for the remaining cusps, potentially resulting in linear movement of the cusps due to the polymerization shrinkage effects of the luting composite resins or composite restorations; this phenomenon is referred to as cuspal flexure or cuspal deflection [6]. This effect is more prominent with larger prepared cavities and is exacerbated following access cavity preparation, which leads to increased strain and micro cracking in ETT [7]. The phenomenon is more prevalent in premolars than in molars, attributable to anatomical variations and the reduced support of premolar cusps following MOD cavity preparation relative to molar teeth [8].

In the historical context of dentistry, MOD inlays were less advocated for premolars, particularly in cases involving extensive cavities [9]. For ETT, the access cavity preparation aggravates the destruction of the teeth, leading to higher risk factors for clinical failure in case of severe destruction [10]. It has been posited that expanding the preparation designs for onlays to include cuspal coverage may provide additional support to the cusps of posterior teeth, thereby improving the fracture resistance of MOD cavities [11]. The indication for cuspal coverage of ETT is the dentist's decision [12], particularly when aware of the controllable and uncontrollable fracture risk [2]. Moreover, the indications for cuspal coverage are cavity factor dependent, whereas the presence of more than 2 mm axial wall thickness does not imply cuspal coverage [13]. There is no sufficient evidence on the preference for cuspal coverage with complete crown and direct restorations, and decisions on this matter depend on the clinician's own experience [14]. The involvement of one proximal wall in the moderate-size prepared cavity might render restoration without cuspal coverage a perfect option; moderate MOD cavities of ETT might benefit from cuspal coverage, while large MOD cavities of endodntically titrated teeth will definitely benefit from cuspal coverage [5, 15].

In addition to the factor of cavity size, the routine maintenance of ETTs involves restoration using direct composite resin, accomplished through either incremental or Bulk-fill techniques. This preference is largely attributed to the direct technique's efficiency, simplicity, and cost-effectiveness. Evidence suggests no significant risk differences between direct and indirect restoration methods for restoring posterior teeth [16–18]. However, it has been observed that stresses and cuspal deflection are greater in composite restorations than indirect restorations due to the differences in the degree of conversion between the composite restoration and the thin luting resin of the indirect restorations. Moreover, the cuspal deflection is correlated to the prepared cavity size, rendering support of the MOD cavities of ETT a strong priority [19]. Furthermore, cuspal coverage is advocated in large cavities or the loss of contact with adjacent teeth, as in the case of MOD cavities [5, 20].

To mitigate these issues and enhance the fracture resistance of direct composite restorations, various laboratory-based solutions have been explored. These include the application of fiber-filled composite resins, the incorporation of occlusal fiber mesh or ribbonds, and the insertion of horizontal posts through the buccal and lingual walls of endodontically treated premolar and molar teeth with MOD cavities [21–23]. After root canal filling and before final restoration in case of

the direct composite filling approach, a hole is prepared in the lingual and buccal surface of the MOD-prepared posterior teeth to receive ready-made posts inserted buccolingually. The post is secured in place, and the excess is amputated; the tooth is filled with a direct composite restoration. The horizontal post technique has been reported to significantly improve the fracture resistance of ETT restored with direct composite materials, Fig. 1. To date, the existing evidence on this subject is limited, with only one systematic review conducted in 2022 that focused exclusively on glass fiber posts and included a total of 12 studies [24].

Therefore, this systematic review and meta-analysis aimed to compile all available records and provide conclusive evidence regarding the impact of horizontal posts on the fracture resistance and mode of failure of ETT with MOD cavities compared to other direct and indirect treatment modalities. The following PICO question was formulated to guide this systematic review: In ETT, does the use of horizontal posts influence fracture resistance compared to other restorative approaches?

Methods

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, as illustrated in Fig. 2.

Eligibility criteria

Eligible studies were those that evaluated the effect of horizontal posts on the fracture resistance of ETT with class II cavities compared to various restorative approaches. The comparisons included sound human teeth, unrestored prepared teeth, teeth restored with conventional composite resins, and indirect intra- or extra-coronal restorations. Selected studies reported outcomes related to mechanical performance and failure modes and were primarily limited to in vitro experimental designs and finite element analyses. Only studies published in English were considered for inclusion. Exclusion criteria encompassed reviews, studies lacking extractable results, single-arm reports, studies without comparators, and those focusing exclusively on primary teeth or non-human models.

Information sources and search strategy

In December 2024, a comprehensive search was performed across the following electronic databases: PubMed, Scopus, Web of Science, and Google Scholar. This search was further augmented by manual screening of reference lists from the included studies. The search strategy incorporated terminology related to "horizontal posts" and "endodontically treated teeth." Specific keywords and Boolean operators utilized in this search are detailed in Supplemental Table 1 (available online).

All search results were imported into reference management software (EndNote, Clarivate), and duplicates were removed. Two independent reviewers (AYA and AA) screened titles and abstracts for relevance. Full texts of relevant studies were retrieved and assessed for inclusion. Disagreements were resolved through discussion or consultation with a third reviewer (MAA).

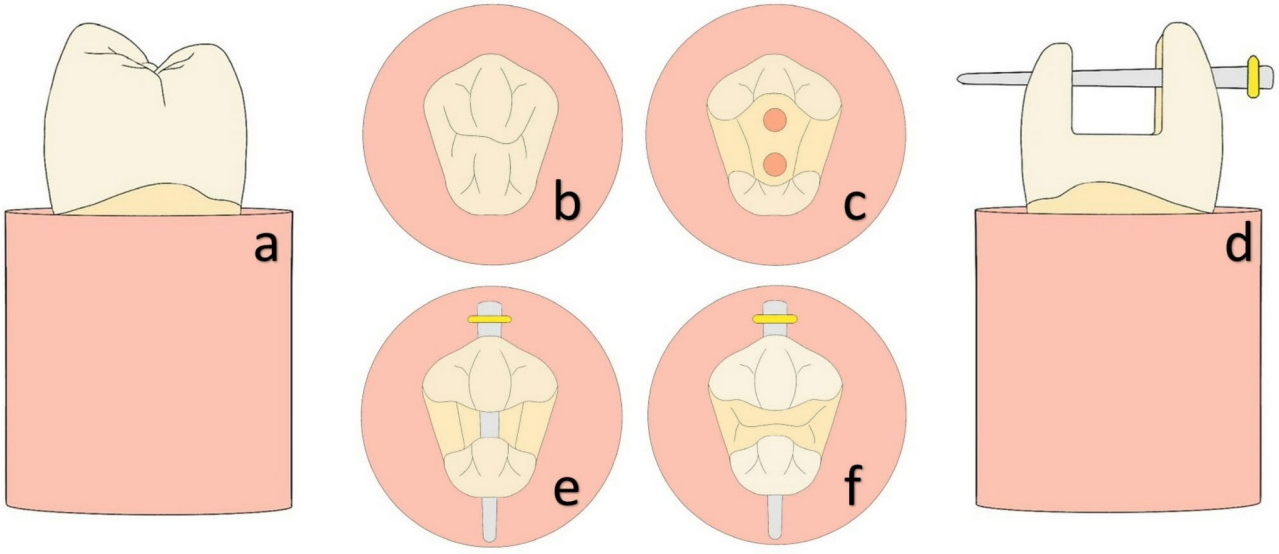

Fig. 1 Different preparation steps for horizontal post-supported MOD composite restoration in premolar. (**A**) Proximal view of sound premolar tooth, (**b**) occlusal view of sound premolar tooth, (**c**) occlusal view of a MOD cavity of premolar tooth after root canal treatment, (**d**) proximal view of premolar tooth with prepared MOD cavity, and horizontal post inserted buccolingually through and through, (**e**) occlusal view of MOD prepared cavity with a horizontal post in situ, (**f**) occlusal view of MOD restored cavity with horizontal post supported composite restoration

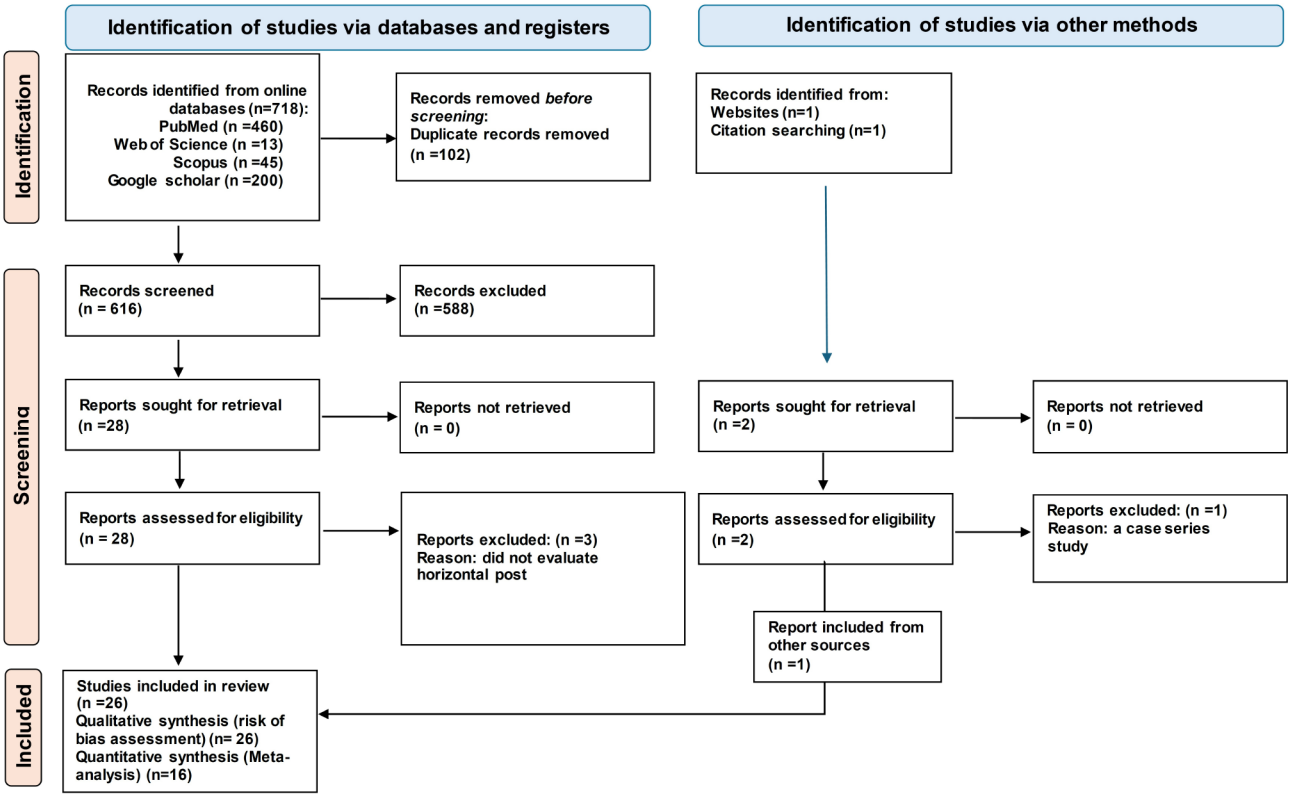

Fig. 2 Preferred reporting items for systematic reviews and meta-analyses (PRISMA2020) flow diagram

The studies were selected based on the PICO framework, focusing on the ETT with MOD cavities as the population (P), the horizontal post as the intervention (I), other direct and indirect treatment modalities as the comparison (C), and the fracture resistance and mode of failure of ETT with MOD cavities as the outcome (O).

A standardized data extraction form was employed to gather information regarding study characteristics, including author, year, study design, intervention and comparator, outcome measures, and key findings. Data extraction was performed independently by two reviewers, with any discrepancies resolved through consensus.

Quality assessment

The studies included in this review underwent a risk of bias assessment utilizing a modified CONSORT tool specifically tailored for laboratory studies on dental materials [25]. This evaluation was conducted by two authors (RSA and AYA), with a third author (MAA) consulted in the event of disagreements. The assessment tool comprised 14 criteria: six related to record structure and eight focusing on study design, methodology, and the presentation of results. Each criterion was scored as "YES" or "NO" based on the extent to which it was satisfied, and the studies were subsequently classified as exhibiting low, moderate, or high risk of bias according to the number of affirmative responses. A score of 11 to 14 affirmative responses indicated a low risk of bias, 8 to 10 responses indicated a moderate risk of bias, and seven responses or fewer indicated a high risk of bias, as detailed in Supplemental Table 4, which is available online. A visual presentation of the risk of bias is shown in Fig. 3. The visual representations and color codes (green for low risk, yellow for moderate risk, and red for high risk) were generated utilizing RevMan 5.4 software.

Data synthesis

The primary outcomes of the systematic review included the fracture resistance of ETT with MOD cavities restored using horizontal posts and direct composite restoration compared with alternative direct and indirect restorative methodologies. The secondary outcomes examined the impact of various composite materials, the behavior of horizontal posts for mesio-occlusal (MO) cavities with differing access designs, and the modes of failure across all comparisons and included studies. Quantitative analyses were performed for studies yielding extractable numerical data, employing standardized mean differences and 95% confidence intervals using RevMan 5.4. Heterogeneity was assessed utilizing the I^2 statistic, with random-effects models applied for I^2 values exceeding 40%, while fixed-effects models were used for lower heterogeneity. The comparisons were categorized into two primary groups based on the type of teeth

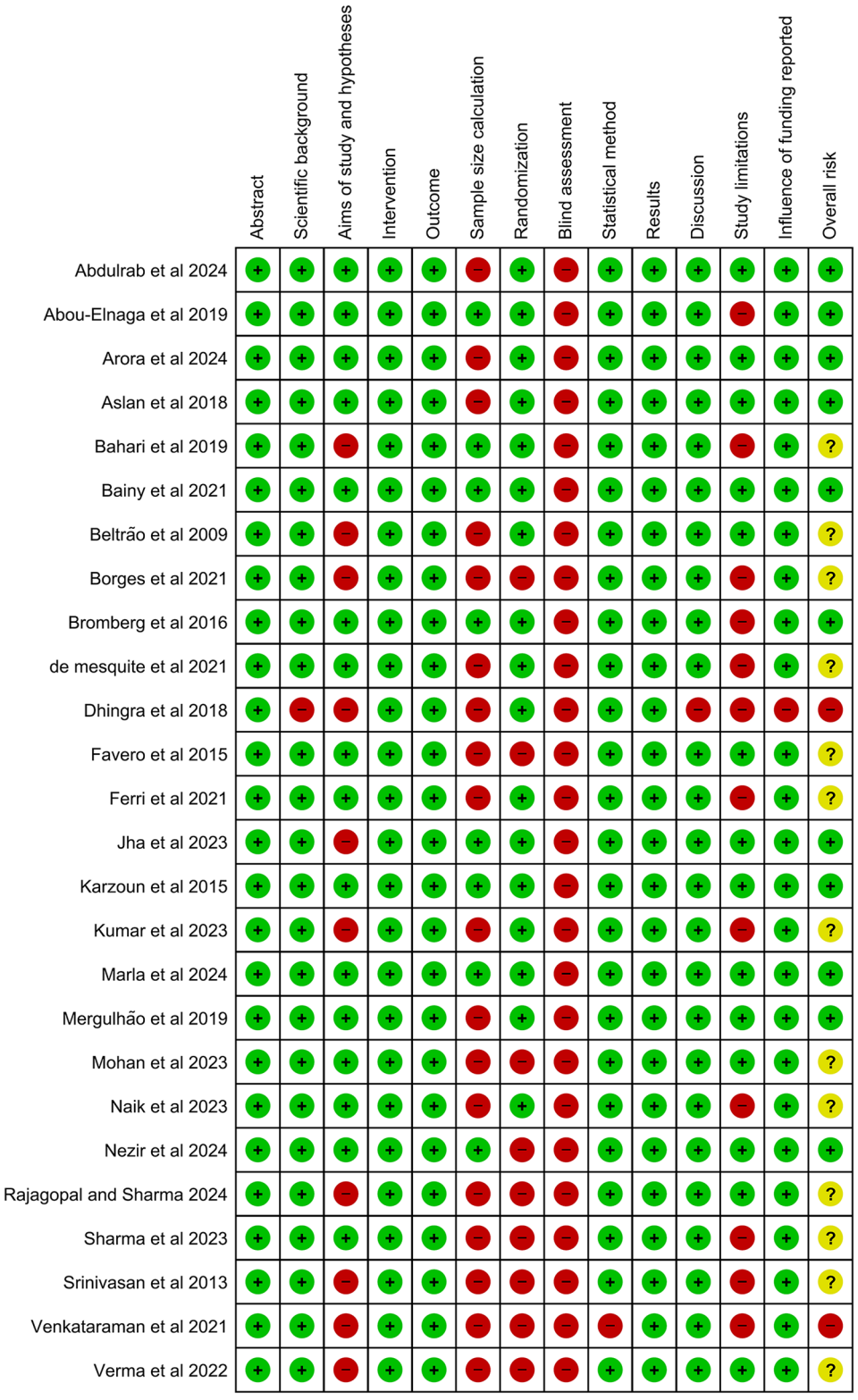

Fig. 3 Risk of bias assessment applying modified CONSORT statement for dental laboratory studies. Green: low risk, Red: high risk, Yellow: Moderate risk of bias

evaluated (molar and premolar). These two principal comparisons underwent subgroup analysis predicated on the restorative approach employed, with horizontal posts in conjunction with direct composite restoration serving as the control for all groups. Statistical significance was established at $P \leq 0.05$.

Results

Study selection

The web search resulted in a total of 718 records, from which 102 duplicates were eliminated. The screening of titles and abstracts led to the exclusion of 588 records, and 28 records were identified for retrieval. Additionally, one record was incorporated from a manual search of citation lists and relevant websites. Ultimately, a total of 26 records were included in the systematic review [21–23, 26–48]. Of these, only 16 studies were eligible for quantitative evaluation, while 10 underwent qualitative evaluation [22, 23, 29, 31, 32, 34, 41, 46, 48, 49]. Four records were excluded for specific reasons: three records did not evaluate horizontal post [50–52], and one record was categorized as a case series [53], Fig. 2.

Characteristics of the included studies

Most of the studies included in this review examined the fracture resistance and fracture mode of Premolar ana molar teeth restored with horizontal post and composite restorations compared to other restorative approaches. A total of 22 records primarily focused on fracture resistance [21, 23, 26, 28–40, 42–47], while four studies concentrated on finite element analysis [22, 27, 41, 48]. Additionally, one study investigated fracture resistance and finite element analysis [27]. Out of the studies, fifteen specifically examined premolar teeth [26–40], and 11 focused on molar teeth [21–23, 41–48]. The test groups encompassed MOD-RCT with horizontal posts, root canal posts, polyethylene fiber mesh, direct composite resin, inlays, onlays, and porcelain fused to metal crowns. The coronal diameter of the post varied among the studies, with measurements ranging from 1 to 2 mm. Various brands of composite resin were employed, with Filtek Z250 being the most prevalent. Concerning thermal cycling, nine studies [27, 30, 33, 34, 36, 38, 42, 43, 46] incorporated thermal cycling protocols. The comprehensive characteristics of the included studies are summarized in supplementary Tables 2 and 3.

Descriptive analysis of studies

The benefit of horizontal post support for direct composite restorations was concluded in this meta-analysis; another good choice to restore ETT is occlusal fiber mesh to strengthen the restorative material. Ribbond with composite resin was reported to have a higher or comparable fracture resistance compared with horizontal posts, surpassing MOD plan composite restorations, bulk-fill flowable composite restorations, and root canal fiber posts, confirming that the function of root canal posts is to retain the restoration rather than mechanical enhancement [31, 32, 34, 38]. To further enhance the fracture resistance, polyethylene fiber Ribbond were combined with horizontal posts, achieving maximum fracture resistance (994.4 N) compared to horizontal posts alone (493.3 N) [29]. Moreover, the combination of horizontal posts with fiber-reinforced and nanohybrid composite resins revealed comparable fracture resistance (1012.42 ± 214.22) to sound premolar teeth (1023.67 ± 76.52), and both were significantly higher than the same restoration without horizontal posts (588.17 ± 104.10) [37]. However, for molar teeth, fiber-reinforced composite resin (2007.15 ± 282.3) exhibited comparable fracture resistance to horizontal posts (1956.14 ± 197.2) [42]. Further, diagonally placed horizontal posts in molar teeth demonstrated comparable mean fracture resistance (758.17 N) to buccolingually placed horizontal posts (756.85 N), and both were significantly higher than the composite restoration of ETT without posts (684.17 N) [23].

Four studies [22, 27, 41, 48] used finite element analysis to assess horizontal posts in molar [22, 41, 48] and premolar [27] teeth. One study [22] found similar stress distribution among 1, 1.5, and 2 mm diameter horizontal posts compared with sound teeth. Another study [41] reported that horizontal posts effectively reinforced the tooth by deflecting incident forces and providing even stress distribution. A third study [48] found similar stress concentrations regardless of horizontal glass fiber post-insertion. A fourth study [27] reported higher restorable fracture resistance for horizontal glass posts than those without.

In terms of fracture patterns, using a horizontal post reduced the occurrence of non-restorable fractures compared to unfilled MOD cavities [32, 33, 37, 39, 42]. While seven studies [27, 32, 33, 37–39, 42] reported reduced non-restorable fractures of horizontal posts than solely applied MOD composite restorations, and five studies [26, 29, 36, 37] disagree with these findings. Moreover, lower unrepairable failures were reported for teeth restored with horizontal posts compared with those restored with ceramic inlays [37, 38], bulk-fill flowable and bulk-fill restorative composites [38], and with placement of fibers at occlusal position [39, 42]. Nevertheless, lower non-restorative failures were associated with fiber-reinforced composite resin and nanohybrid composite [37], porcelain fused to metal crown [26], or polyethylene fiber mesh [26, 29]. Furthermore, a similar fracture pattern was observed between the horizontal post and Ribbond at the occlusal surface [32].

Risk of bias assessment

Following the modified CONSORT checklist, eleven studies [21, 27, 29, 32, 35, 38, 40, 42, 43, 46, 47] demonstrated a low risk of bias, while 13 studies [22, 26, 28, 31, 33, 34, 36, 37, 39, 41, 44, 45, 48] exhibited a moderate risk of bias. Additionally, two studies [23, 40] were classified as having a high risk of bias. These findings are illustrated in Fig. 3, with a comprehensive evaluation provided in Supplemental Table 4, which is available online.

Meta-analyses

Premolar teeth restored with horizontal posts and composite restorations revealed significantly lower fracture resistance than sound premolar teeth ($P = 0.01$; Std MD:1.22; 95%CI: 0.29 to 2.16; heterogeneity: P<0.001, $I^2 = 86\%$), Fig. 4A. However, horizontal posts showed enhanced fracture resistance for MOD cavities with and without direct composite restorations (P<0.001; Std MD: -7.78; 95%CI: -10.19 to -5.37; heterogeneity: P<0.001, $I^2 = 90\%$), and (P<0.001; Std MD: -1.79; 95%CI: -2.70 to -0.87; heterogeneity: P<0.001, $I^2 = 88\%$) respectively,

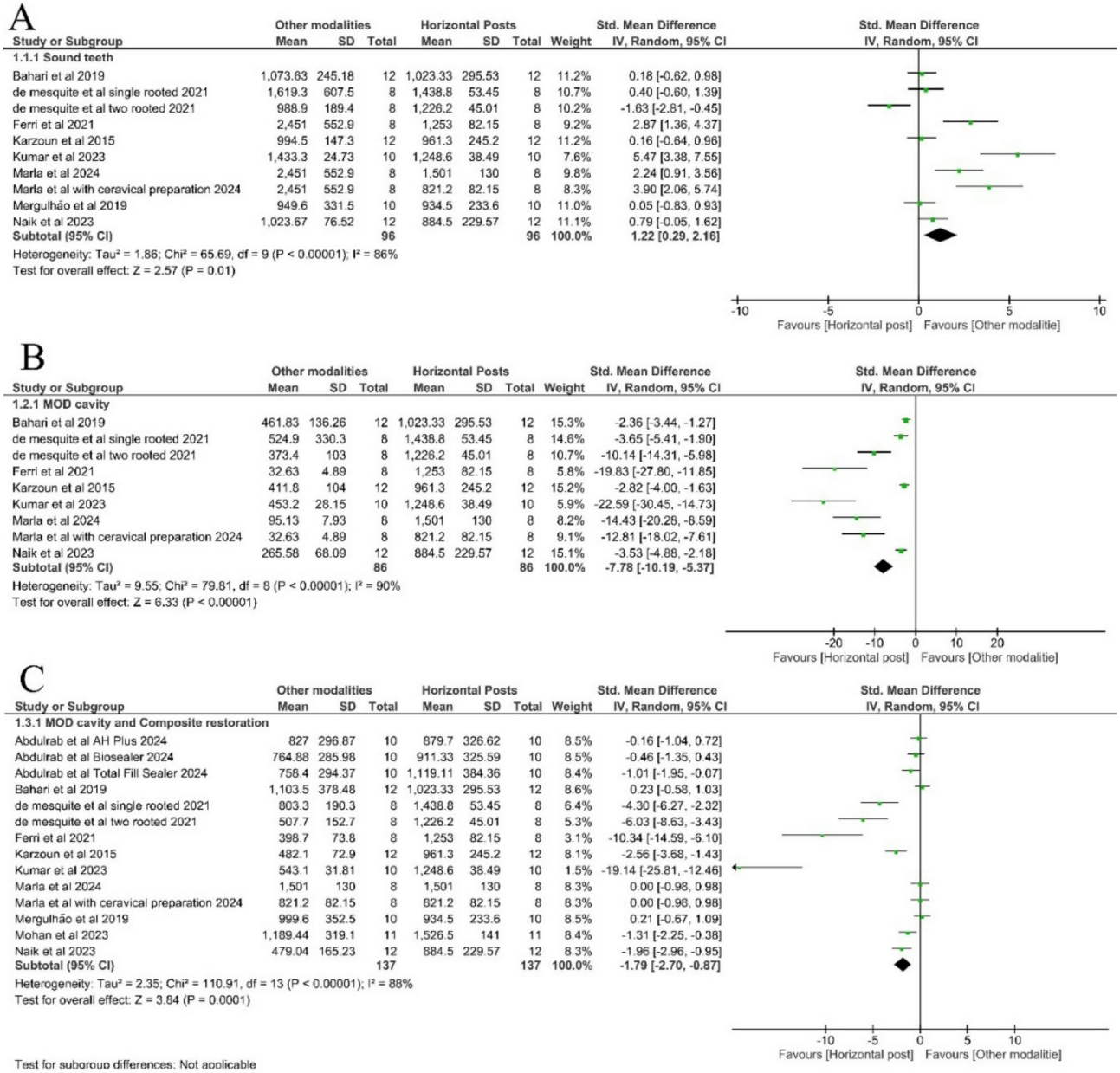

Fig. 4 Fracture resistance comparison of premolar teeth with various situations: (**A**) Comparison of horizontal post and MOD composite restoration to sound unprepared teeth. (**B**) Comparison of horizontal post and composite restorations to prepared MOD cavities without restorations. (**C**) Comparison of horizontal posts with MOD composite restorations to MOD cavities with composite restorations without extra support

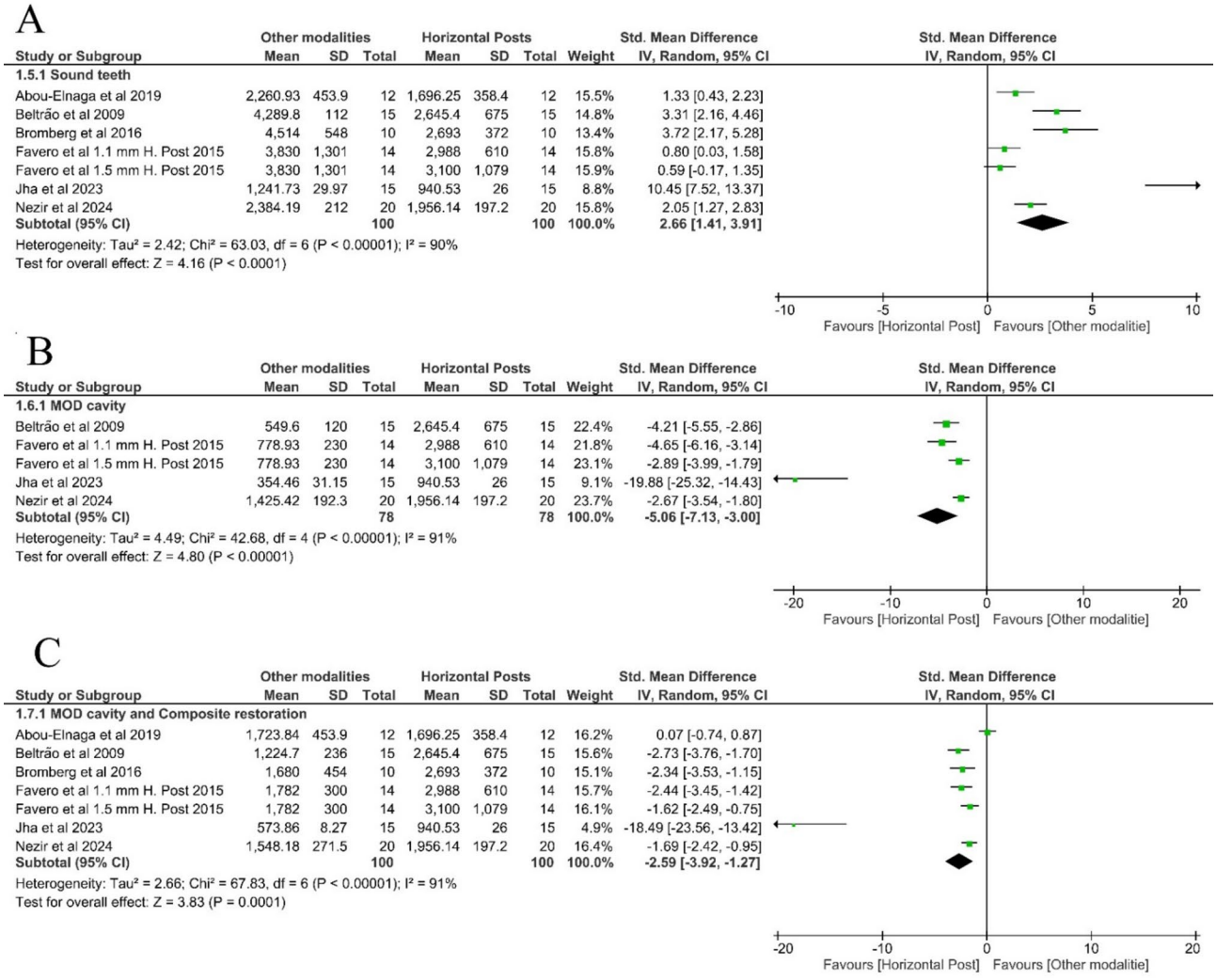

Fig. 5 Fracture resistance of molar teeth with various situations: (**A**) Comparison of horizontal post and MOD composite restoration to sound unprepared teeth. (**B**) Comparison of horizontal post and composite restorations to prepared MOD cavities without restorations. (**C**) Comparison of horizontal posts with MOD composite restorations to MOD cavities with composite restorations without extra support

Fig. 4B and C. One study [33] applied zirconia horizontal posts in single and double-rooted premolar teeth. There weren't subgroup assignments based on the post material since all studies share the same significant difference related to the fiber post studies.

For premolar teeth, horizontal posts with composite restorations revealed higher fracture resistance than porcelain fused to metal full crown (P<0.001; Std MD: -3.09; 95%CI: -4.47 to -1.71), the porcelain fused to metal crowns suffered chipping of the veneering ceramic. However, horizontal post with MOD composite restoration revealed comparable fracture resistance to MOD indirect lithium disilicate inlay ($P = 0.96$; Std MD: -0.02; 95%CI: -0.61 to 0.58; heterogeneity: $P = 0.96$; $I^2 = 0$), and comparable fracture resistance to composite restorations with occlusal fiber ribbon ($P = 0.38$; Std MD: -3.23; 95%CI: -10.48 to 4.01; heterogeneity: P<0.001, $I^2 = 97\%$). While root canal posts with composite restoration exhibited significantly lower fracture resistance than horizontal posts with MOD composite restorations (P<0.001; Std MD: -2.33; 95%CI: -3.46 to -1.26), S upplemental Fig. 1.

Horizontal posts in endodontically treated molar teeth with MOD cavities and composite restorations showed significantly lower fracture resistance than sound molar teeth (P<0.001; Std MD: 2.66; 95%CI: 1.41 to 3.49; heterogeneity: P<0.001, $I^2 = 90\%$), Fig. 5A. However, horizontal posts with composite restoration increased fracture strength significantly compared with MOD prepared cavities without restoration (P<0.001; Std MD: -5.06; 95%CI: -7.13 to -3.00; heterogeneity: P<0.001, $I^2 = 91\%$), and MOD cavities with composite restorations (P<0.001; Std MD: -2.59; 95%CI: -3.92 to -1.27; heterogeneity: P<0.001, $I^2 = 91\%$), Fig. 5B and C. Likewise, Horizontal posts with composite restoration showed statistically significantly

higher fracture resistance than indirect inlay restorations ($P = 0.001$; Std MD: -1.78; 95%CI: -2.85 to -0.71). Nevertheless, Horizontal posts with composite restorations showed comparable fracture resistance to indirect onlay restorations ($P = 0.42$; Std MD: 0.36; 95%CI: -0.52 to -1.25), and occlusal fiber Ribbond with composite restorations ($P = 0.52$; Std MD: 0.21; 95%CI: -0.42 to 0.83); Supplemental Fig. 2.

Discussion

The presented review aimed to compare the fracture resistance of ETT restored with horizontal posts and composite restorations to those restored with composite restorations, fiber-reinforced composite restorations, ribbonds with composite restorations, or indirect restorations. The purpose of endodontic treatment is to retain the teeth in function for as long as possible; the fulfillment of this goal is at risk with a high potential for clinical complications [2]. ETT is not always restored-with indirect restorations or full coverage crowns; direct composite restorations applying the incremental or Bulk-fill composite are viable options for daily dental practice [16]. In the case of MOD class II cavities, weak cuspal support can lead to a detrimental impact on teeth integrity, initiated by microcracks and flexural movement of the cusps [8, 16, 54]. Better support of cusps seems crucial to alleviate this issue and to improve the resistance to fracture. Horizontal post insertion has been proven worthy of such tasks, and the current meta-analysis concluded higher fracture resistance of teeth that were restored with horizontal posts and composite restorations [21–23].

There have been several treatment approaches to restore MOD cavities of ETT; among these approaches belong the cuspal coverage, fiber reínforced composite, and insertion of horizontal posts. While the effectiveness of cuspal coverage and fiber-reinforced composites effectiveness has been assessed in previous projects, horizontal post insertion evidence has not been concluded yet. Therefore, this systematic review was conducted to gain evidence on the efficiency of horizontal post insertion to support MOD cavities of endodontically treated teeth.

The risk of bias assessment in this systematic review relied on the modified consort statement for laboratory studies on dental material [25]. This criterion was more beneficial than other criteria applied for laboratory studies evaluation. The criteria evaluated both the structural and scientific parts of the included studies and their designs. Regarding structural evaluation, surprisingly, several articles revealed shortages or absence of the aim of the study, one study had weak scientific background, and several studies failed to report the studies' limitations in the discussion section. These structural shortages led to a relative increase in the negative evaluation the included studies had. Moreover, the most important criteria that seemed missing in most of the included studies are the sample size calculation and randomization process. While non of the included studies applied blind assessment of the results also. All these factors contribute to the predominance of studies exhibiting a moderate risk of bias, while two records were identified as having a high risk of bias. It is important to note that the risk of bias criterion employed utilized a binary YES/NO evaluation, indicating whether the information was reported in the original article. Should the authors apply this criterion and fail to disclose the relevant information, the study would consequently receive a negative assessment. This underscores the necessity for careful consideration in the design of future studies and emphasizes the importance of adhering to appropriate reporting standards when presenting original research articles in a more thorough and comprehensive manner.

This systematic review exhibited consensus of most of the included records on the effectiveness of horizontal post to support MOD cavities, revealing enhanced fracture resistance for premolar and molar teeth compared with prepared MOD cavities and cavities with composite restorations and also teeth with root canal posts, as the function of root canal post is pure retentive and not supportive, and this gave the superiority to utilize horizontal post rather than root canal post when the goal is to support the prepared cavity and restoration against fracture. Nevertheless, the meta-analysis revealed heterogeneity, as shown in the presented forest plots of Figs. 4 and 5; this could be attributed to the differences in the testing conditions and operator factors. In the presented meta-analyses, a comparison was performed for studies that shared the same outcome, leaving only 10 studies for qualitative syntheses. Moreover, the meta-analysis was carried out in separate comparisons for each outcome to avoid mixing analytical results; besides, the random effect model was adopted for each comparison, revealing I^2 results higher than 40%. Another crucial factor is the direction of the load, where vertically applied load might reveal comparable outcomes for different treatment approaches, leading to excessively high fracture resistance, irrespective of the treatment applied. Therefore, it is highly recommended that the oblique loading protocol be adopted to test the fracture resistance of restored human teeth [1].

However, the findings of this systematic review concluded enhanced fracture resistance of the teeth with occlusal ribbonds inserted with composite restorations. A total of 6 studies on molar and premolar teeth involve comparisons of occlusal fiber reinforcement of composite to horizontal post-supported composite restorations [26, 29, 31, 32, 34, 39]. Two studies indicated superior results of the horizontal posts compared with occlusal

fiber mesh or ribbonds when applied with direct composite restorations [26, 34]. In comparison, other studies reported higher fracture resistance of ribbonds compared with horizontal posts [31, 39, 42]. Moreover, the combinations of fiber ribbonds with horizontal posts and composite restorations enhance the fracture strength significantly compared with solely fiber posts [29].

Some studies applied two horizontal posts for molars; one runs through the mesial axial wall and the other through the distal axial wall; these two posts reported a significant increase in fracture resistance [43, 44, 48]. Further, the insertion of posts reported a slight reduction of stresses in enamel and dentin compared to cavities that were restored with composite only without posts [48]. The diameter of the inserted horizontal posts didn't impact the mechanical behavior of the specimens; comparable fracture resistance was reported for horizontal posts with 1.1 and 1.5 [44], and comparable biomechanical behavior was reported for ETT restored with direct composite restorations with 1, 1.5, and 2 mm diameter horizontal posts [22].

The type of horizontal posts didn't show different fracture resistance when glass fiber posts were compared with carbon fiber posts, while stainless steel fiber posts showed significantly lower fracture resistance than both glass and carbon fiber posts. This might be attributed to the higher flexural modulus of stainless steel posts compared with glass and carbon fiber posts, which are known for close flexural strength values to dentin, contributing to a better distribution of load stresses and, consequently, were associated with higher fracture resistance [40]. It is preferable to place horizontal posts at the center of the middle third of the cusp for higher support; a study reported higher fracture resistance of ETT restored with composite restoration and horizontal posts inserted in the center of the middle third than ETT with composite restoration and horizontal posts that were 2 mm below the center [36].

The amount of remaining tooth structure plays a significant role in the fracture resistance and the clinical behavior of the restored tooth [55]. Conservative truss access cavities with horizontal posts showed higher fracture resistance than conventional access cavities with horizontal posts [47]. Underscoring the crucial rule of remaining tooth structure on the laboratory mechanical behavior and the clinical survival of the restorations. The fiber-reinforced composite material was found to enhance the fracture resistance of ETT, exhibiting higher values compared with conventional composite restorations [37, 42], showing even comparable values to horizontal posts [42]. The fracture resistace of teeth can further be increased when occlusal ribbonds combined with horizontal posts [37]. However, materials like Bulkfill composite did not reveal enhanced fracture resistance values for premolar teeth [36]. Meanwhile, Bulkfill composite restorations for molars revealed relatively high and promising fracture resistance [21, 42, 46]. Moreover, The adoption of smart dentin replacement with Bulkfill composite showed increased fracture resistance compared with conventional composite restorations and enhanced the fracture resistance further when applied with horizontal posts compared with conventional composites and horizontal posts [21].

Notably, root canal posts in premolar teeth didn't show enhancement of fracture resistance when inserted with composite restorations [28, 31, 32, 34]. Confirming the role of root canal posts as a retentive means more than supportive and underscoring the indication of root canal posts for teeth with lost axial walls, particularly when less than two remain [56]. Two included studies reported even lower fracture resistance of the teeth with root canal posts than composite restorations without posts [28, 32]. Owing to the negative impact of the root canal preparation, significant loss of tooth structure to receive intracanal posts leads to a slight reduction in fracture resistance.

It is known in dental laboratory studies that the oblique loading protocols are the closest to simulating an actual clinical situation [1]. In the current systematic review, the quasistatic load was applied vertically on the occlusal surfaces and parallel to the long axis in most of the included studies. The quasistatic load was applied obliquely in five studies: 2 FEA [22, 41], one laboratory study on molar teeth [42], and two studies [31, 32] onpremolar teeth. In the premolar studies, loading at 45-degree was applied, and the fracture resistance mean values were lower than 370 N for all groups and treatment modalities [31, 32], which is not promising for clinical application. Such low values could be attributed to the lack of proper adhesive protocols, given that none was reported in these two studies. This justification was evident in another study in molars where adhesive protocols were reported, and the fracture resistance mean values were higher than 1500 N, which could be considered clinically promising for all tested restored groups [42].

The technique of horizontal post insertion or the placement of fiber ribbonds to strengthen the buccal and horizontal walls was concluded in this systematic review. However, these conclusions will need to be approved clinically with well-designed and high-quality randomized clinical trials; to the best of ourknowledte only one case series prooved the clinical feasibility of the innovative supportive technique [57]. Moreover, the insertion of horizontal posts can benefit wide MOD cavities of ETT, however, with reasonable buccal and lingual surface thicknesses (more than 2 mm at least) [12, 58]. In cases with very thin buccal and lingual walls, this type of post can not benefit the prepared posterior teeth, even if the horizontal post is applied with composite material

to support tooth structure as a core under an overlaying crown. In such situations, the cusp reduction would be the only reasonable approach, followed by overlay, onlay, or endocrown restorations [59]. Full-coverage restoration of an ETT is indeed an invasive and irreversible procedure. Using horizontal posts before full crown restorations can potentially compromise tooth integrity, particularly in cases where the remaining buccal and lingual walls are already thin due to extensive tooth preparation or microcrazing [60, 61]. This can weaken the tooth structure rather than provide the intended reinforcement.

This weakening of the tooth structure might negatively impact the fracture resistance of the teeth [60, 61]. However, the post inserted in the prepared holes with adequate and well-packed composite filling would substitute the supportive measures and reduce the negative concerns. The horizontal post technique may add longevity in some clinical situations, such as periodontal conditions, Apexification, or root resorption that may require long-term temporization [28]. Moreover, the benefit of the horizontal posts to support MOD cavities was included in this systematic review without adverse effects observations, as all included studies were conducted at the laboratory experimental level [21–23, 40, 57, 62].

The cementation of horizontal posts to fill the buccal and lingual prepared holes should be carried out with high professionalism; the cement will be prone to intraoral degradation, being in contact with oral fluids and saliva, discoloration of the cement ring might be inevitable; therefore continuous maintenance would be necessary [63]. Sever microleakage and recurrent caries are less likely to happen if the luting agents were selected properly with the corresponding primers and bonding agents, besides the proper surface pretreatment of enamel and the post surface. However, these complications are not completely avoidable but can be reduced to a minimum [64]. Given the higher discrepancies that might be created between the prepared holes and the horizontal posts, cementation with composite restorations rather than luting agents might be advantageous. Materials such as EverX Posterior, a fiber-reinforced composite, because of its fiber orientation, have been shown to decrease polymerization shrinkage and, thus, marginal microleakage. The strengthening effect of FRC has been attributed to the plasticization of the polymer matrix by linear polymer chains of poly-methylmethacrylate in the cross-linked matrix, which transfers the stress from the polymer matrix to the fibers [65]. Nevertheless, these issues would be better solved if minimum discrepancies existed between the horizontal posts and the prepared holes, keeping the cement thickness to a minimum and reducing the likelihood of dissolution, microleakage, discoloration, and recurrent caries. Therefore, it is highly advocated and recommended that dental companies produce parallel-sided posts with a corresponding drill that fits precisely and fulfills the purposes of this innovative technique.

Given the axial load direction in the bulk of included studies, their findings should be cautiously handled. Applying the fracture load vertically is the farthest method to simulate the situation in the oral cavity. Vertical load applications can result in unrealistic, very high fracture resistance reaching up to 6000 N as in the case of zirconia endocrown restorations [66], or result in non-logic preference of destructive designs over conservative tooth preparation; hence, the evaluation would test the compressive resistance of restorations, given higher results for bigger cavities and bigger restorations [67]. Whereas thermodynamic and fatigue loading could better evaluate prosthetic and restorative parts' behavior, oblique fracture load would be the closest to simulating the lateral excursive movements and extensive dynamic oral function.

The findings of the systematic review, regardless of the number of studies being illegible for meta-analyses and those included only in qualitative syntheses, were able to conclude the effectiveness of the horizontal post in supporting MOD cavities. Other approaches, such as occlusal ribbonds, also revealed enhanced fracture resistance of MOD cavities filled with composite restations. However, this systematic review was primarily concentrated on horizontal posts; the findings of occlusal ribbonds or fiber-reinforced composite restorations are presented in previous reviews or can be concluded in future evidence-based projects.

This systematic review might have some limitations such as the heterogeneity between studies, which was mitigated by assessing the studies based on the outcome and the tooth type, sorting the molar and premolar teeth into two different comparisons. Moreover, the subgroup comparisons were carried out based on the cavity designs and the materials and restoration techniques used. Nevertheless, some inevitable heterogeneities could be related to the test conditions, the operator factor, and the tested teeth microstructure or anatomical variations [68, 69]. Therefore, it is recommended to conduct more studies with a more homogenous designs, focusing on horizontal posts, fiber-reinforced restorations, and fiber mesh or ribbonds with extensive aging protocols, longer and higher loads of thermodynamic loading, and oblique quasistatic or fatigue loading parameters.

Conclusions

According to the evidence-based quantitative and qualitative analyses, the following can be concluded:

1. The findings of this systematic review support the placement of horizontal posts, and the meta-analyses revealed significant favorability of ETT with horizontal post and composite restoration compared with unrestored cavities or composite restorations without support.
2. The placement of occlusal fiber mesh or ribbonds can be as effective as horizontal posts; moreover, the combination of these two supportive measures further enhances fracture resistance compared to the application of only horizontal posts or occlusal ribbonds alone.
3. Fiber-reinforced composite has been evaluated in a few studies and may hold promise for clinical application, particularly in enhancing fracture resistance when used in conjunction with occlusal ribbonds or horizontal posts.
4. It is advisable to conduct additional studies utilizing oblique loading to draw further conclusions. It could be beneficial to assess the impact of other factors on fracture resistance such as the size of the cavity, the type of the tooth, or the impact of excessive loading conditions.

Abbreviations

MOD	Mesial, occlusal, distal cavities
ETT	Endodontically treated teeth
EDTA	Ethylenediaminetetraacetic acid
NaOCl	Sodium hypochlorite
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PROSPERO	International prospective register of systematic reviews
CONSORT	Consolidated Standards of Reporting Trials
RevMan	Review manager

Supplementary Information

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Supplementary Material 1

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