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REVIEW

The influence of horizontal glass fiber posts on fracture strength and fracture pattern of endodontically treated teeth: A systematic review and meta-analysis of in vitro studies

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Abstract

Purpose: This systematic review and meta-analysis aimed to summarize available evidence regarding the effect of horizontal glass fiber posts (HGFPs) on fracture strength and fracture pattern of endodontically treated teeth (ETT) compared to controls without HGFP. The review protocol was registered on the OSF registries.

Methods: Literature searches were conducted in MEDLINE/PubMed, Scopus, Web of Science, Embase, Google Scholar, and ProQuest for all relevant studies published up to February 2022. All in vitro studies that assessed the influence of HGFPs on fracture strength and fracture pattern of ETT whether mesio-occluso-distal or mesio-occlusal or DO cavities were considered eligible. Review Manager (RevMan) was used for the meta-analysis. Subgroup and funnel plot analyses were also performed. Quality assessment was conducted by two independent reviewers.

Results: A total of 12 articles met the inclusion criteria, and 10 studies underwent quantitative evaluation. The pooled effect showed that fracture resistance of molar teeth restored with HGFP was significantly higher than teeth without HGFP (standardized mean difference [SMD]: 1.61, 95% confidence interval [CI]: 0.14, 3.09, $p = 0.03$), whereas marginally significant for premolars (SMD: 1.36, 95% CI: −0.00, 2.73, $p = 0.05$). Regarding fracture patterns, the presence of an HGFP significantly increased the occurrence of restorable fracture patterns for premolars (odds ratios [OR]: 4.15, 95% CI: 1.60, 10.82, $p = 0.004$) compared to controls, whereas the difference was not significant for molars (OR: 1.09, 95% CI: 0.43, 2.77, $p = 0.85$). Moderate risk of bias was identified in 9/12 studies; one study showed a high risk of bias and two studies showed a low risk of bias.

Conclusions: Within the limitations of this study, there is evidence from in vitro studies that the use of HGFP increases the fracture resistance of the ETT when compared to teeth without HGFP and also reduces the occurrence of non-restorable fractures for premolars. However, well-conducted in vitro and prospective clinical studies are warranted to validate this finding.

KEYWORDS
endodontically treated teeth, fracture pattern, fracture strength, horizontal glass fiber posts, in vitro studies, meta-analysis, systematic review

The prognosis of endodontically treated teeth (ETT) is influenced by different parameters, including the extent of dental tissue loss, design, and the size of the access cavity,[1,2] the height of ferrule preparation,[3] and type and material of post and core.[4] The amount of remaining tooth structure is critical for the ETT to resist fracture.[5] Endodontic access preparation jeopardizes structural integrity and increases functional cusp deflection leading to a higher risk of fractures.[6] The

presence of a mesio-occluso-distal (MOD) cavity may worsen the situation due to additional loss of tooth structure.[7]

Endodontically treated posterior teeth can be restored with different materials and techniques, including post and core, partial or full crowns, direct composite, amalgam, or ceramic restoration. Classes I and II cavities can be restored using low-and-high-viscosity composites as bulk-fill incremental restorations.[1] Severely destructed ETT can be treated with glass fiber posts that have favorable physical properties.[2] When an MOD cavity is present, using a horizontal glass fiber post (HGFP) combined with a direct composite restoration may influence fracture resistance[3] and reduce the occurrence of non-restorable fractures.[4]

HGFPs across the coronal cavity may increase resistance to coronal fracture in ETT.[8,9] However, most fractures in ETT occur at 2–3 mm below the coronal margin, which may complicate further restoration with unclear prognosis.[10] Types of potential fractures are related to loads applied to the tooth, and the greatest stress distribution, therefore, clinicians are required to design restorations of ETT to eliminate or reduce the effect of these factors to preserve any remaining tooth structure. Recently, Kim et al.[11] documented the first clinical case using HGFP in an endodontically treated molar in an effort to enhance and strengthen the coronal structure. More recently, Jakab et al.[12] conducted a systematic review investigating the effect of horizontal splinting techniques on the fracture resistance of ETT with MOD cavities; the results revealed that horizontal splinting improves the fracture resistance of teeth with large MOD cavities, compared to conventional direct composite restorations. Nevertheless, it should be noted that the latter review included only a very limited number of studies and did not perform any statistical analysis to quantify the differences in the fracture resistance between the groups. Therefore, this systematic review and meta-analysis were designed to provide evidence-based evaluations of the influence of HGFPs on fracture strength and fracture pattern of ETT. The null hypothesis was that the presence of an HGFP would not affect the fracture resistance and fracture pattern of ETT.

METHODS

The present systematic review and meta-analysis were conducted in compliance with Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA statement[13,14]), and a protocol was registered retrospectively in the OSF registries (https://osf.io/s4xgq). Using the PICOS (Population; Intervention; Comparison; Outcome; Study Design) framework, the review question was formulated as follows: "Does HGFP increase the fracture resistance and reduce the non-restorable fracture of an endodontically treated posterior tooth?"

The PICO inclusion criteria were as follows: (P): ETT, (I): ETT restored with HGFP, (C): no HGFP, (O): primary outcomes: fracture resistance; secondary outcomes: mode/pattern of fracture, and (S): in vitro controlled studies. Exclusion criteria were studies including teeth other than posterior teeth, lack of control group, using any post other than HGFP, animal studies, reviews, case reports, case series, and articles published in a language other than English.

A systematic literature search was conducted in five electronic databases (MEDLINE/PubMed, Web of Science, Scopus, Embase, and Google Scholar) by two independent investigators for all relevant studies published in English up to February, 2022 (Table 1). No potential studies in a language other than English were found. Additionally, the grey literature was searched via ProQuest. The following keywords were used: (["ETT" OR "endodontically treated molar" OR "endodontically treated premolar"] AND ["horizontal post" OR "transfixed"] AND ["fracture resistance" OR "fracture pattern" OR "failure mode"]). Furthermore, the online searches were supplemented with a manual search of the references of the included studies. The retrieved articles were then exported to EndNote software program (Version 9.00), and all duplicates were removed. Next, an assessment of the references was done based on title and abstracts, and irrelevant studies were excluded. The full texts of all potentially eligible studies were obtained and assessed by two independent reviewers. Eligible studies were processed for data extraction.

Data extraction was conducted by two reviewers independently using customized forms. For each study, the following information was extracted: authors, year of publication, study design, sample size, type of included teeth, and type of post/coronal diameter, type of composite resin, outcome measures, and the main results.

The statistical analyses were conducted using Review Manager (RevMan) Version 5.3. For continuous outcomes, the standardized mean difference (SMD) between the groups along with 95% confidence intervals (CIs) was calculated; however, for categorical outcomes, the odds ratios (OR) along with 95% CIs were calculated. Heterogeneity between studies was evaluated using the Chi-square test and the I^2 statistics. Fixed-effects model was used for low/moderate heterogeneity ($I^2 \leq 50\%$), whereas random-effect model was applied for significant heterogeneity ($p < 0.10$ and $I^2 > 50\%$). The potential publication bias was assessed using the funnel plots (RevMan) and Egger's test (Stata/MP-64 for Windows).

An assessment of the risk of bias was undertaken as described by Uzunoglu-Özyürek et al. and Alhajj et al.[15,16] In each included study, the following parameters were evaluated: randomization of teeth, the presence of control, standardization of teeth dimensions, reporting of age, description of sample size calculation, the use of materials according to the manufacturer's instructions, samples prepared by a single operator, and blinding of the observer during fracture test. The presence of each parameter was recorded as "yes," whereas absence was recorded as "no." Studies with 1–3 "yes" were classified as high risk of bias, 4–5 "yes" as medium risk, and 6–7 "yes" as low risk. If the two reviewers

TABLE 1 Databases, applied search strategy, and numbers of retrieved studies.

Database of published trials, dissertations, and conference proceedings	Search strategy used	Hits
MEDLINE searched via PubMed searched on February 1, 2022, via www.ncbi.nlm.nih.gov/sites	#1 Search (endodontically treated teeth OR endodontically treated molar OR endodontically treated premolar) 9351 #2 Search endodontic horizontal post OR transfixed post 244 #3 Search (fracture resistance) OR (fracture pattern) OR (failure mode) 53839 #4: #1 AND #2 AND #3: 39	39
ISI Web of Science Core Collection was searched via Web of Knowledge on February 1, 2022, via apps.webofknowledge.com	All = (endodontically treated teeth OR endodontically treated molar OR endodontically treated premolar) AND All = (endodontic horizontal post OR transfixed post) AND TS = (fracture resistance) OR (fracture pattern) OR (failure mode)	17
EMBASE searched via Ovid on February 1, 2022, via http://ovidsp.dc2.ovid.com	#1 #1 Search (endodontically treated teeth OR endodontically treated molar OR endodontically treated premolar) 499 ##2 Search endodontic horizontal post OR transfixed post 99 #3 #3 Search (fracture resistance) OR (fracture pattern) OR (failure mode) 23317 #4 #1 AND #3 53 #5 #4 (1 AND 3)OR #2 152	152
Scopus searched via Scopus on February 1, 2022, via https://www.scopus.com	All (endodontically treated teeth OR endodontically treated molar OR endodontically treated premolar) AND All (endodontic horizontal post OR transfixed post AND All [fracture resistance] OR [fracture pattern] OR [failure mode])	50
Google Scholar February 1, 2022, via https://scholar.google.com/	All (["endodontically treated teeth" OR "endodontically treated molar" OR" endodontically treated premolar"] AND ["horizontal post" OR "transfixed"] AND ["fracture resistance" OR "Fracture pattern" OR "failure mode"])	44
ProQuest was searched on November 16 via https://www.proquest.com/?accountid=13370	endodontically treated teeth, horizontal post, fracture	202
Total		504

disagreed, then a solution by discussion was reached in the form of consensus.

RESULTS

The initial online searches yielded 505 articles (PubMed: 39, WOS: 17, Embase: 152, Scopus: 50; Google Scholar 45; and ProQuest 202). There were 140 duplicates, which were eliminated. During the screening of titles and abstracts of the remaining 365 articles, 348 were found to be irrelevant (reviews or irrelevant to the focused question) and were excluded. The full texts of the 17 articles were assessed and 5 articles were excluded for various reasons (Supplementary table). The remaining 12 studies were included in the systematic review (Figure 1).

Tables 2 and 3 present the general characteristics of the included studies. In total, 12 in vitro studies were included in the present systematic review.[3,4,8,9,17–24] Of these, only 10 studies[3,4,9,17,19–24] were eligible for meta-analysis. Two studies were excluded from meta-analysis because they ddidn't report the numerical data regarding the fracture resistance, and no response was received after contacting the authors. Seven studies[3,4,8,18,21,22,24] used premolars, whereas the remaining five studies[9,17,19,20,23] used molars. The sample size ranged from 40 to 105 teeth. All test groups included MOD-ETT with an HGFP. The coronal diameter of the post varied across the studies, ranging from 1.1 to 1.9 mm. The included studies used different brands of composite resin, the majority of which used Filtek Z250 composite (Table 2). All included studies assessed the fracture resistance and fracture mode as the main primary outcomes (Table 2). With reference to thermal cycling, five studies[4,18,22–24] employed thermal cycling, and three studies[4,19,24] assessed dynamic fatigue loading. Only three studies simulated a PDL (Table 3).

The results of the risk of bias are summarized in Table 4. Two studies showed a low risk of bias, nine studies showed a moderate risk of bias, and one study high risk of bias. The most frequent shortcomings were related to the lack of sample size calculation, the absence of thermal cycling/cycling loading, and inadequate or absence of observer blinding.

Out of the 12 studies, 9 studies[3,8,9,17–19,22–24] revealed a significant increase in fracture resistance in HGFP group compared to the control group. However, three studies[4,20,21] did not find any significant differences in fracture resistance between HGFP group and control groups. With reference to fracture pattern, the studies revealed variable results: Six studies[4,8,21–24] showed a significantly higher percentage of restorable fractures in HGFP group, three studies[9,17,20] did not find any significant difference in the fracture pattern between the groups, and two studies showed higher unrestorable fractures in HGFP group.[3,19]

The subgroup analysis, based on the type of teeth used, revealed a significant ($p = 0.03$) increase in the fracture resistance of molar teeth in favor of HGFP groups ($I^2 = 90\%$; SMD: 1.61, 95% CI: 0.14, 3.09, $p = 0.03$) and marginally significant difference in fracture resistance of premolar teeth

TABLE 2 Summary of previous studies about the effect of horizontal glass fiber post (HGFP) on fracture resistance and fracture pattern of maxillary endodontically treated premolar (ETP) with mesio-occluso distal (MOD) cavities.

Author/references	Control group	Test group	Total number and type of teeth	Type of post/coronal diameter	Type of composite resin	Evaluated outcomes	Results
Beltrão et al.[17] (Brazil) 1HGFP	G1: sound teeth G2: MOD + RCT G3: MOD + RCT + CR	G1: MOD + RCT + HGFP G2: MOD + RCT + HGFP + CR	75 maxillary third molars	Glass fiber posts (Reforpost; Ângelus)	Filtek Z-250	FR: load on a universal testing machine with a crosshead speed of 1 mm/min on an inclined plane to the occlusal surface of the specimens parallel to the surface-long axis of the teeth Fracture pattern: analyzed under stereomicroscope ×30; classified as Pulp chamber floor (non-restorable) and cusp fracture (restorable)	The HGFP in an MOD cavity significantly increased the FR of the teeth restored with resin composite compared to control group HGFP group and control group showed comparable cusp fracture (restorable fracture)
Srinivasan et al.[18] (India) 1HGFP	G1: MOD + RCT + CR G2: MOD + RCT + GFP G3: MOD + RCT + PEF + CR	G1: MOD + RCT + HGFP + CR	40 maxillary premolars	A fiber post (no. 11, Tenax fiber post, Coltène/Whaledent)	ParaCore, Coltène/ Whaledent	FR: load on a universal testing machine with a crosshead speed of 0.5 mm/min on buccal and lingual cusps parallel to the long axis of the tooth	There is significant difference between HGFP group and control group. In favor to HGFP $p < 0.01$
Karzoun et al.[3] (Syria)	G1: sound teeth G2: MOD no CR G3: MOD + RCT + CR	G1: MOD + RCT + CR + HGFP G2: MOD + RCT + HGFP	60 upper premolars	Glass fiber posts (White Post DC no. 0.5; FGM Produtos Odontológicos Ltda, Joinville-SC, Brazil) of 1.4 mm diameter	Filtek Z250	FR: loaded with a crosshead speed of 1 mm parallel to the long axis of the tooth in a universal testing machine Fracture pattern: analyzed visually; classified as cervical third fracture (restorable) middle and apical thirds (catastrophic)	HGFP in a MOD cavity increased significantly the FR of the ETP compared to control group Yet HGFP could not prevent catastrophic fracture
Favero et al.[9] (Brazil) 2HGFP	G1: Sound teeth G2: MOD G3: MOD + RCT G4: MOD + RCT + CR	G1: MOD + RCT + CR + 2 HGFP 1.1 mm in diameter G2: MOD + RCT + CR + 2 HGFP 1.5 mm in diameter	84 upper third molars	Glass fiber posts (Reforpost; Ângelus) 1.5 mm	Amelogen Plus	FR: loaded with a crosshead speed of 1 mm parallel to the long axis of the tooth in a universal testing machine Fracture pattern: analyzed under the magnifying lens; classified as Pulp chamber floor (non-restorable) and cusp fracture (restorable)	HGFP with CR significantly increased the FR of molars compared to the control group The fracture pattern was similar between the tested groups

(Continues)

TABLE 2 (Continued)

Author/references	Control group	Test group	Total number and type of teeth	Type of post/coronal diameter	Type of composite resin	Evaluated outcomes	Results
Bromberg et al.[19] (Brazil) 2HGFP	G1: sound teeth G2: MOD + RCT + only G3: MOD + +RCT + inlay G4: MOD + RCT + CR	G1: MOD + RCT + CR + 2 HGFP	50 third molars	Glass fiber posts (Reforpost number 1, Angelus) 1.1 mm	Filtek Z350 XT	FR: loaded with a crosshead speed of 1 mm on the occlusal surface parallel to the long axis of the tooth in a universal testing machine Fracture pattern: analyzed under ×3 magnification; classified as not repairable (fracture of the pulp chamber floor) or repairable (fracture line involving the cusps fully or partially)	HGFP increased significantly the FR of molars compared to the control group HGFP group had a high unrepairable fracture
Aslan et al.[8] (Turkey)	G1: intact teeth G2: unfilled MOD G3: MOD + RCT + CR G4: MOD + 10 mm-long GFP + CR G5: MOD + RCT + 5 mm-long GFP + CR G6: MOD + RCT + Ribbond in the occlusal surface + CR	G1: MOD + RCT + HGFP + CR	105 mandibular premolars	Glass fiber post (RelyX Fiber Post)	Filtek Ultimate	FR: A universal testing machine loaded with a crosshead speed of 0.5 mm on the occlusal surface 45° oblique compressive Fracture pattern: analyzed visual inspection as favorable (occurred in the cervical third of the root) or unfavorable (middle and apical thirds of the root)	HGFP group was significantly more resistant to fractures than the control ($p < 0.05$) HGFP exhibit more favorable fracture (significant)
Abou-Elnaga et al.[20] (Egypt)	G1: control group G2: MOD traditional access cavity + RCT G3: MOD truss access cavity + RCT	G1: MOD artificial truss restoration + RCT (HGFP)	66 mandibular first molars	Glass fiber post (RelyX Blue; 3M ESPE, St Paul, MN) 1.9 mm	Polofil NHT, VOCO	FR: The samples were subjected to a vertical compressive force loaded at a crosshead speed of 1 mm/min parallels the tooth's long axis on the center of the occlusal surface of the samples Fracture pattern: all the samples were visually inspected using a dental operating microscope (17× magnification) classified as either favorable fracture or unfavorable fracture. The favorable fracture was considered when the level of fracture dissipated to not more than 1 mm below the cervical margin of the sample. The unfavorable fracture was considered when the level of fracture dissipated to more than 1 mm below the cervical margin of the sample	Non-significant difference between the groups for both FR and fracture pattern

(Continues)

TABLE 2 (Continued)

Author/references	Control group	Test group	Total number and type of teeth	Type of post/coronal diameter	Type of composite resin	Evaluated outcomes	Results
Mergulhão et al.[4] (Brazil)	G1: intact teeth G2: MOD + RCT + CR G4: MOD + RCT + bulk-fill CR G5: RCT + ceramic inlay	G1: MOD + CR + HGFP	50 maxillary premolars	Glass fiber posts (White Post DC number 0.5, FGM Produtos Odontológicos) of 1.4 mm diameter	Filtek Z350 Filtek Bulk Fill Posterior	FR: compressive load on the long axis of the restored teeth at a crosshead speed of 1 mm/min on occlusal surface of the restoration on the buccal and lingual cusp inclines. Fracture pattern: by Stereomicroscope and classified as repairable when the fracture line was above the simulated bone level and unrepairable when the fracture line was below the simulated bone level (2 mm below CEJ). SEM used for the studying of the fracture surface	Regarding FR no significant differences between groups However, HGFP showed a significant difference for repairable fracture rates compared to control
Bahari et al.[21] (Iran)	G1: intact teeth G2: RCT + MOD G3: RCT + MOD + CR G4: RCT + MOD + PEF + CR	G1: RCT + MOD + HGFP + CR G2: RCT + MOD + PEF + HGFP + CR	72 maxillary premolars	Glass fiber post (Angelus Ind. Prod. Odontológicos S/A, Londrina, PR, Brazil)	Valux Plus	FR: compressive force was applied at a crosshead speed of 0.5 mm/min parallel to the tooth long axis, in a universal testing machine. Fracture pattern: evaluated under a stereomicroscope at ×4 and categorized into favorable (fractures extending up to 1 mm below CEJ), unfavorable (fractures extending more than 1 mm below the CEJ)	No significant differences between all the experimental groups ($p > 0.05$) The fracture pattern was more favorable in HGFP (significant)
Ferri et al.[22] (Brazil)	G1: Sound tooth G2: MOD + RCT G3: MOD + RCT + CR	G1: RCT + MOD + HGFP + CR (Post placed in the center of the middle third of the crown) G5: RCT + MOD + HGFP + CR (Post placed 2 mm below the center of the middle third of the crown)	40 maxillary first premolars	Glass fiber posts Reforpost (Angelus, Londrina, Brazil) 1.1 mm	Filtek Z250	FR: compressive stress was applied at a crosshead speed of 0.5 mm/min parallel to the long axis of the tooth in contact with the buccal and palatal cusp Fracture pattern: by magnifying glass at 4× magnification, classified either as a pulp chamber floor fracture associated or not with the cusp, or as a cusp fracture only	Using HGFP regardless of the position increases the fracture resistance of ETP compared to control The presence of HGFP in the middle of the crown showed a more favorable fracture compared to control group

(Continues)

TABLE 2 (Continued)

Author/references	Control group	Test group	Total number and type of teeth	Type of post/coronal diameter	Type of composite resin	Evaluated outcomes	Results
Bainy et al.[23] (Brazil)	G1: Sound tooth G2: MO + RCT G3: MO + RCT + CR G4: MO + RCT + braided glass fiber + CR	G1: MO + RCT + HGFP + CR	50 maxillary third molars	Glass fiber posts Reforpost R (Angelus, Londrina, PR, Brazil) 1.1 mm	SonicFill 2	FR: compressive stress was applied at a crosshead speed of 0.5 mm/min parallel to the long axis of the tooth in contact with the buccal and palatal cusp using universal testing machine Fracture pattern: by magnifying glass at 4× magnification, classified either as a pulp chamber floor fracture associated or not with the cusp, or as a cusp fracture only	HGFP increases significantly the FR of molars compared to control The use of HGFP provided 100% favorable fractures similar to sound tooth
Abdulrab et al.[24] (South Africa)	G1: MOD + RCT with AH plus sealr + CR G2: MOD + RCT with TotalFill sealer + CR G3: MOD + RCT with BioRoot sealer + CR	G1: MOD + RCT with AH plus sealr + HGFP + CR G2: MOD + RCT with TotalFill sealer + HGFP + CR G3: MOD + RCT with BioRoot sealer + HGFP + CR	60 upper premolars	Glass fiber post (RelyX, 3M ESPE) size 1 (1.3 mm)	Filtek Z250	FR: load on a universal testing machine with a crosshead speed of 1 mm/on the buccal and lingual cusps Fracture pattern: by stereomicroscope and classified as restorable when the fracture line was above The simulated bone level (2 mm below CEJ) and unrestorable when the fracture line was below the simulated bone level (2 mm below CEJ)	HGFP in a MOD cavity increased significantly the FR of the ETP compared to control HGFP reduce the non-restorable fracture significantly compared to control

Abbreviations: CEJ, cementoenamel junction; CR, composite resin; ETP, endodontically treated premolars; FR, fracture resistance; MO, mesio-occluso; PEF, polyethylene fiber; RCT, root canal treatment; SEM, scan electron microscope.

TABLE 3 Additional summary of previous studies.

Study	Thermal cycling	Dynamic fatigue loading	Simulation of periodontal ligament (PDL)
Beltrão et al.[17]	N	N	N
Srinivasan et al.[18]	Thermal cycling (6000 cycles at 5–55°C, dwell 30 s, transfer time 5 s)	N	N
Karzoun et al.[3]	N	N	Y
Favero et al.[9]	N	N	N
Bromberg et al.[19]	N	Cyclic fatigue loading with 500,000 cycles in distilled water at 37°C	N
Aslan et al.[8]	N	N	Y
Abou-Elnaga et al.[20]	N	N	N
Bahari et al.[21]	N	N	N
Mergulhão et al.[4]	Thermocycled between 5 and 55°C in 5000 cycles	Cyclic loading 50,000 times	Y
Bainy et al.[23]	Thermocycled between 5 and 55°C for 500 cycles	N	N
Ferri et al.[22]	Thermocycled at 5–55°C for 500 cycles	N	N
Abdulrab et al.[24]	Thermocycled at 5–55°C for 5000 cycles	50,000 cyclic loading	N

Abbreviations: N, no; Y, yes.

TABLE 4 Assessments of risk of bias.

Study	Randomization of teeth	Teeth dimensions	Sample size calculation	Manufacturer's instructions	Single operator	Thermal cycling and/or cycling loading	Blinding of the observer of the testing machine	Risk of bias
Beltrão et al.[17]	Yes	Yes	No	Yes	Yes	No	No	Moderate
Srinivasan et al.[18]	No	No	No	No	No	Yes	No	High
Karzoun et al.[3]	Yes	Yes	No	Yes	Yes	No	No	Moderate
Favero et al.[9]	Yes	Yes	No	Yes	Yes	No	No	Moderate
Bromberg et al.[19]	Yes	Yes	Yes	Yes	Yes	Yes	No	Low
Aslan et al.[8]	Yes	Yes	No	Yes	Yes	No	No	Moderate
Abou-Elnaga et al.[20]	Yes	Yes	Yes	Yes	No	No	No	Moderate
Mergulhão et al.[4]	Yes	No	No	Yes	Yes	Yes	No	Moderate
Bahari et al.[21]	Yes	Yes	Yes	Yes	No	No	No	Moderate
Ferri et al.[22]	Yes	Yes	No	Yes	No	Yes	No	Moderate
Bainy et al.[23]	Yes	Yes	Yes	Yes	No	Yes	No	Moderate
Abdulrab et al.[24]	Yes	Yes	Yes	Yes	Yes	Yes	No	Low

Abbreviations: N, no; Y, yes.

(I^2 = 91%; SMD: 1.36, 95% CI: −0.00, 2.73, p = 0.05) (Figure 2). Sensitivity test was performed, and the Ferri et al. study[22] was excluded, and the results revealed a not significant difference (p = 0.22).

Although the values of the significance level (p-value) and I^2 refer to the low heterogeneity among the studies, we considered the variations in methodologies, and hence, we used the random-effect model. The pooled results of six studies[4,8,21–24] revealed a significantly higher percent of restorable fractures of premolar teeth in favor HGFP groups (I^2 = 40%; OR: 4.15, 95% CI: 1.60, 10.82, p = 0.004). However, the results of the pooled four studies

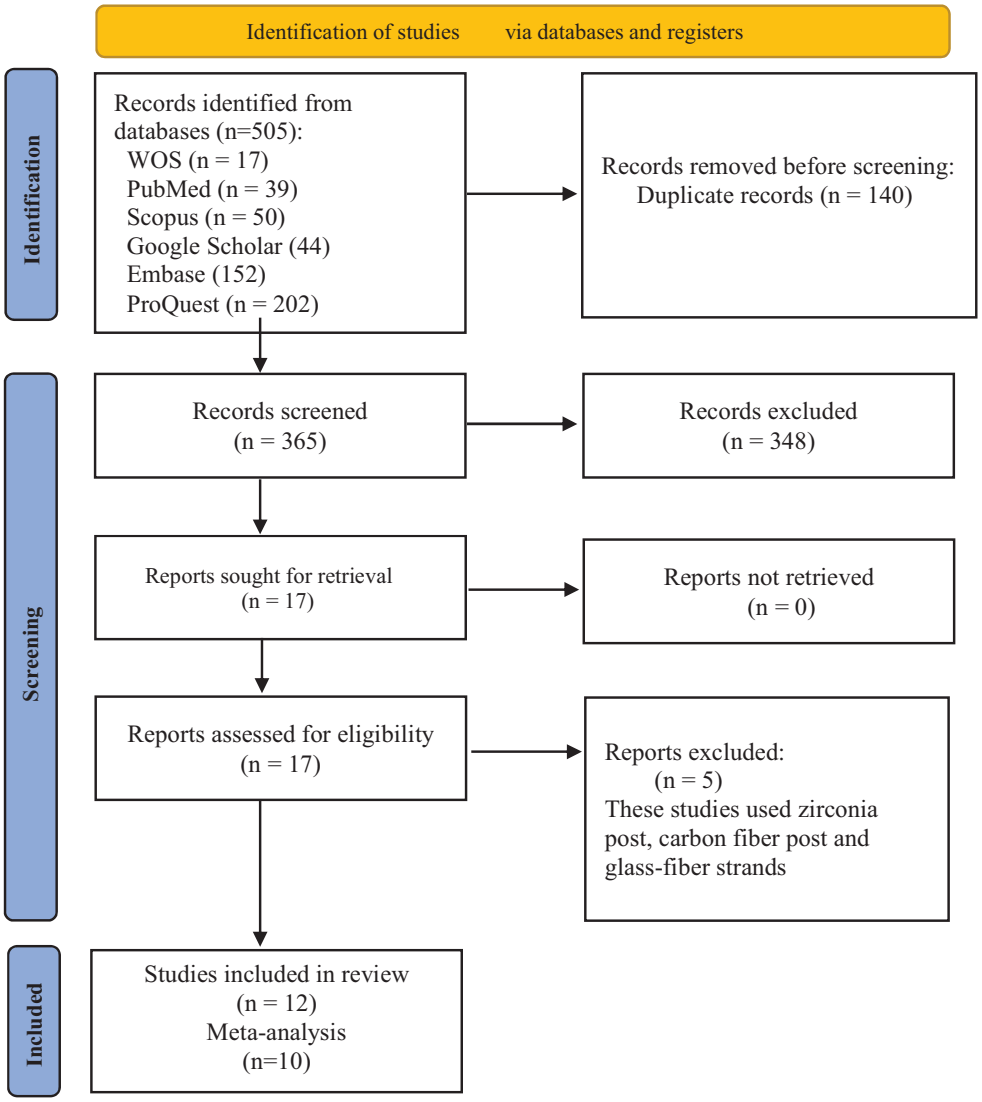


FIGURE 1 Flow diagram of the search strategy.

revealed no significant differences in the fracture pattern of molar teeth (I^2 = 0%; OR: 1.09, 95% CI: 0.43, 2.77, p = 0.85) between the HGFP and control group (Figure 3).

The funnel plot and Egger's test showed no significant publication bias among the studies (p = >0.05) (Figures 4 and 5).

DISCUSSION

Selection of the appropriate restoration for ETT is quite challenging for clinicians and still a highly debatable subject. Posterior teeth with root canal treatment can be coronally restored with different materials and techniques. Amalgam, ceramic, or direct composite restoration may not be the proper choice, especially with the gross loss of tooth structure.[1] HGFP combined with a direct composite restoration can be used for coronal restorations of severely destructed ETT due to HGFP physical properties that may influence fracture resistance of the ETT.[3–4] Therefore, this study aimed to investigate the effect of HGFP on the fracture resistance and fracture pattern of ETT.

The null hypothesis of this study was that the presence of an HGFP would not affect the fracture resistance or fracture pattern of ETT with MOD cavities restored with direct composite resin. This hypothesis was rejected based on the meta-analysis.

This systematic review and meta-analysis provide evidence that restoring ETT with an HGFP significantly increases fracture resistance compared to teeth restored without HGFP. This finding is consistent with the results of a recent review.[12] In addition, the presence of HGFP decreases the risk of unfavorable/non-restorable fracture patterns. Individual studies explained that the extension of an HGFP through the buccal and palatal walls strengthens the composite resin restoration and, through adhesion, strengthens the cusps,

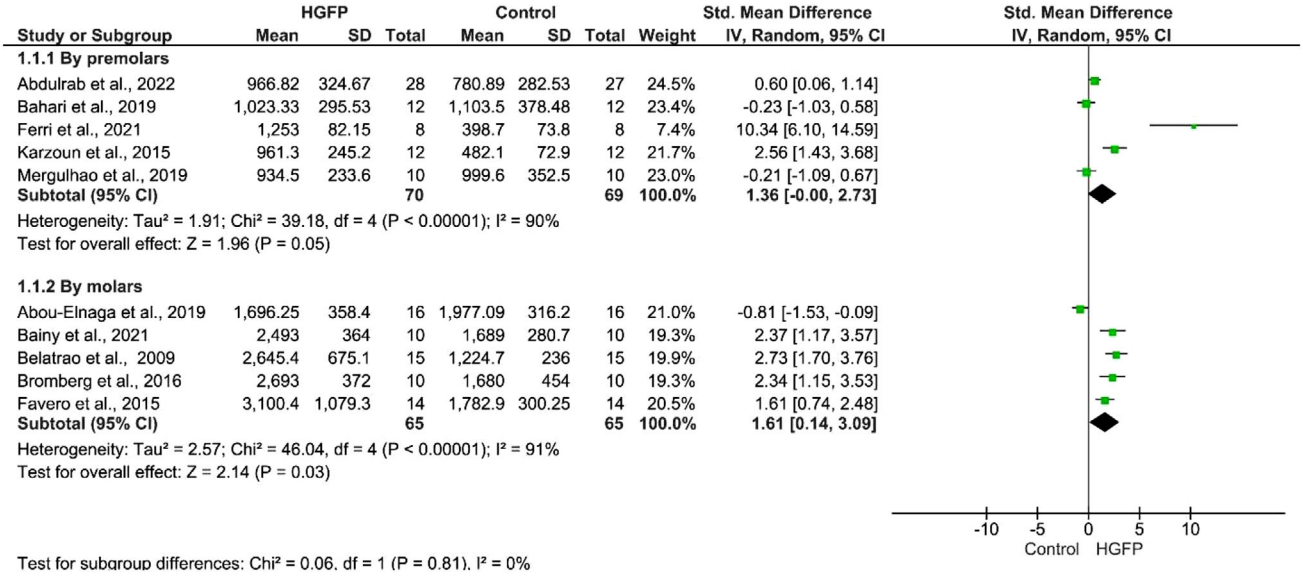


FIGURE 2 Forest plots of fracture resistance between horizontal glass fiber post (HGFP) and control.

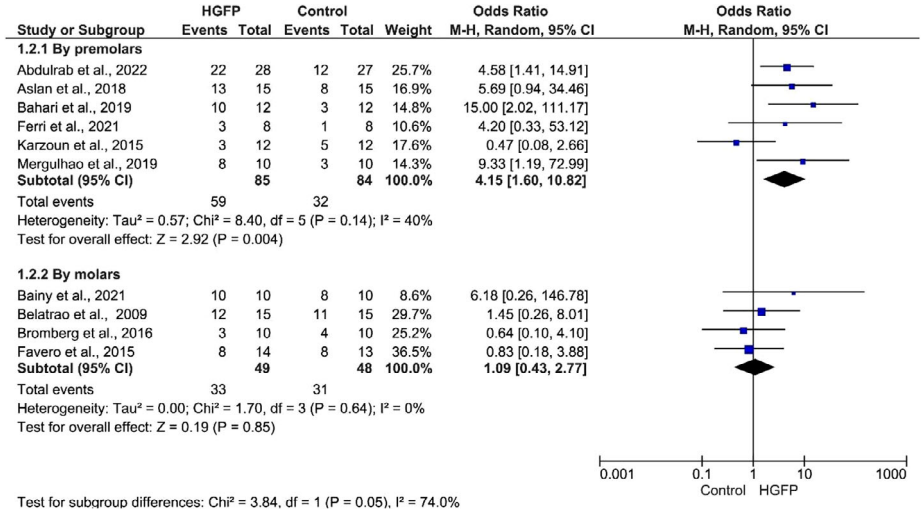
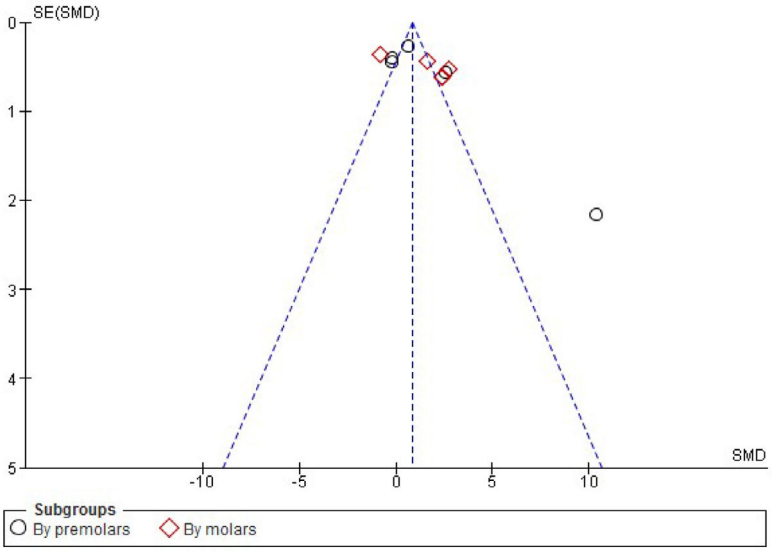


FIGURE 3 Forest plots of fracture pattern between horizontal glass fiber post (HGFP) and control.

increases the fracture resistance of ETT,[3,22] and reduces unrestorable fractures.[4,22]

Fracture resistance was significantly increased in 9 studies out of 12 included studies[3,8,9,17–19,22–24] in HGFP group compared to control group. However, three studies[4,20,21] did not find any significant difference in fracture resistance between HGFP group and control groups. This may be due to HGFPs having a low modulus of elasticity, which is similar to dentin, leading to an even distribution of the load forces. In addition, the horizontal direction of the post may absorb occlusal loads. The results of the present meta-analysis provide evidence that the presence of HGFPs significantly increases the fracture resistance for endodontically treated molars and premolars with MOD cavities. This suggests that the horizontal splinting techniques by means of an HGFP could be an alternative approach to cusp-coverage-indirect restorations.

Regarding fracture patterns, the included studies reported contradictory results. Six studies[4,8,21–24] showed a significantly higher percentage of restorable fractures in HGFP group, three studies[9,17,20] did not find any significant differences in the fracture pattern between the groups, and two studies showed higher unrepairable fractures in HGFP group.[3,19] The results of the present meta-analysis indicated that HGFP significantly increased restorable fractures of premolars teeth. However, for molar teeth, a meta-analysis indicated no significant difference. This may be attributed to some molar teeth studies using two HGFPs. The presence of



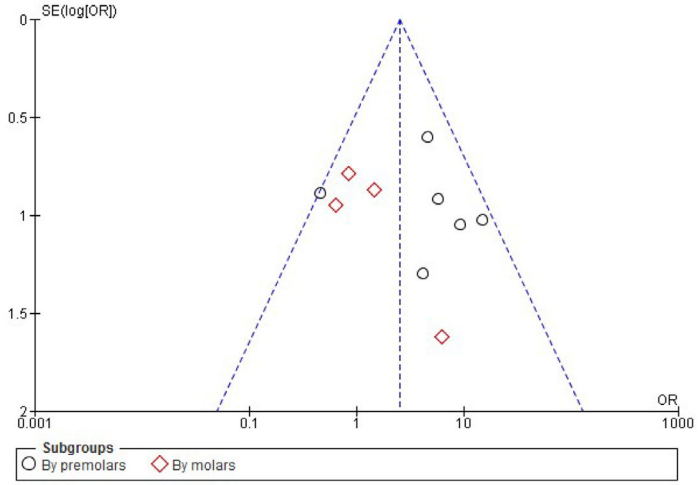
Number of studies = 10 Root MSE = 4.853

Std_Eff	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
slope	785.5891	251.6043	3.12	0.014	205.3885	1365.79
bias	-2.464925	2.849084	-0.87	0.412	-9.034924	4.105074

Test of H0: no small-study effects P = 0.412

FIGURE 4 Funnel plot and Egger's test reporting absence of publication bias in fracture resistance studies.

FIGURE 5 Funnel plot and Egger's test reporting absence of publication bias in fracture pattern studies.



Number of studies = 10 Root MSE = 1.349

Std_Eff	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
slope	.2308201	1.594646	0.14	0.888	-3.446439	3.908079
bias	.7840957	1.755696	0.45	0.667	-3.264547	4.832739

Test of H0: no small-study effects P = 0.667

two holes on the tooth wall might have negatively affected (more destructive) the teeth fracture patterns (weaken the walls) as a result of further removal of tooth structure and micro-crazing within tooth structure during preparation.

Considering the quality of evidence, the majority of the included studies presented a moderate risk of bias, and two studies presented a low risk of bias. Strength of evidence generated by this systematic review needs to be considered within this context. Further well-designed studies with a low risk of bias are recommended.

The intra-radicular placement of a post to strengthen the dental structure has been reported to be ineffective.[25–29] Further, post-space preparation may lead to the significant weakening of the root. Additionally, during post-space preparation, procedural errors may arise. Although not very common, perforations in the apical part of the root or the lateral mid-root wall of a "strip-perforation" can be included in these accidents. Placing posts may further increase the likelihood of root fracture and treatment failure.[30] Therefore, HGFP is a less invasive direct restorative technique, a fast and simple procedure, and cheaper that provides cuspal protection for MOD cavities and subsequently reinforces the ETT. Thus, the use of HGFP with composite resin in MOD cavities of ETT seems to be a promising approach for dental practitioners.

The scope of this meta-analysis was to investigate the evidence-based results regarding the influence of HGFP on fracture resistance and type of fracture. Although this meta-analysis provides evidence for the promising clinical application of HGFP with composite resin in MOD cavities of ETT, a limitation of this study is the high level of heterogeneity, particularly in the fracture resistance results. Therefore, the findings have to be interpreted with caution, and further analysis is recommended for variations among the studies, such as type, diameter, and the number of the post; type of composite restorative material; loading angle direction and crosshead speed; tip diameter of plunger; PDL simulation; teeth dimensions; thermal cycling and cyclic loading.

Extrapolation of results of in vitro studies must be considered with caution, particularly when complex restorations using a combination of different materials are studied, which need to function intra-orally for prolonged periods of time. Hence, studies that include a combination of thermal cycling and fatigue loading to simulate the clinical environment are recommended. Because of the complexity of the restorations, it is recommended that in vitro tests are supplemented with investigations that provide additional information and an increased understanding on the nature of the reinforcement effect of the HGFP. These include finite element analysis to study the distribution and absorption of forces and micro-computed tomography to identify the initiation and propagation of cracks. Further research needs to be performed to include these techniques.

CONCLUSION

Within the limitation of this systematic review and meta-analysis, it can be concluded that the use of HGFP improves the fracture resistance of ETT and also reduces the risk for non-restorable fractures for premolars. However, prospective clinical studies are warranted to test the validity of the HGFP technique.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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