REVIEW ARTICLE

Evaluation of Fracture Resistance of Reattached Tooth Fragments Restored Using Fiber-reinforced Composites: A Systematic Review

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Abstract

Aim and background: This systematic review examined the current literature to evaluate the fracture resistance of the tooth fragments reattached using fiber-reinforced composites (FRC).

Materials and methods: An electronic search was performed on Scopus, PubMed, and Web of Science databases according to specific inclusion and exclusion criteria to identify relevant articles to be included until January 2023. Articles with full text available in the English language for randomized control studies, observational studies, retrospective studies, and *in vitro* studies conducted on permanent human teeth were selected. The risk of bias was assessed in all studies using the OHAT tool.

Results: Out of 16 search results, seven *in vitro* studies with a total of 415 samples were included in the review. Three studies reported that reinforcement using rigid FRC posts improves fracture resistance of reattached anterior teeth, three studies reported that reinforcement using flexible fiber bundles enhances the fracture strength of reattached posterior teeth and one study reported that the use of flexible polyethylene fibers improves fracture resistance in molars with reattached cusps.

Conclusion: Within the limitations of the studies included in the review, there is low-quality evidence that reinforcement of reattached fragments using FRC posts or fibers improves fracture resistance.

Clinical significance: The reattached fractured fragments may be susceptible to re-fracture. The use of FRC to reinforce the resin composite used for reattachment may enhance the bond strength and increase resistance to fracture.

Keywords: Dental trauma, Fiber-reinforced composite, Fracture resistance, Reattachment, Vertical root fracture.

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Introduction

Epidemiological studies have shown that a significant proportion of adolescents and children are affected by dental trauma,[1–3] with estimates of 28–44% of cases involving uncomplicated crown fractures and 18–22% involving fractures of maxillary incisors.[4–6] In such cases, the commonly applied treatment approach is to rebuild the crown portion using resin composite.[7] However, when the fractured tooth fragment is available, reattaching the fragment can be a more realistic and biologically favorable alternative. This technique offers an immediate, noninvasive, and esthetic treatment option, as the fractured tooth is rehabilitated with its own natural fragment, which wears off at the same rate and is more likely to elicit a positive emotional response from the patient.[8]

Changes in the tooth structure due to large carious defects, wear, aging, loss of vital pulp, and endodontic procedures may result in tooth fractures.[9] Excessive tooth structure removal due to over instrumentation and prolonged use of chemical irrigants may weaken the tooth structure to an extent that the root cannot withstand masticatory forces and may fracture.[10] The prevalence of vertical root fracture (VRF) in extracted teeth is 4.4–10.6%[11,12] and in endodontically treated teeth ranges between 11 and 30%.[13,14] If VRF occurs in multirooted teeth, resection of the fractured root may be a conservative treatment option. However, in single-rooted teeth, VRF has poor prognosis.[15] The ideal treatment plan would be to extract the tooth atraumatically, remove root filling and attached granulation tissue, and bond the separated fragments extra-orally followed by intentional replantation of the tooth.[16–19]

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The *in vitro* evaluation of the fracture resistance of the reattached coronal fragments after uncomplicated crown fracture was comparable with intact teeth or resin build-ups, but the bonding of tooth to tooth substance is limited.[20–22] The resin adhesion in reattached components decreases with time due to thermal, chemical, and mechanical stresses in the oral cavity.[23] The survival rate after 12–30 months is around 50%, possibly because of poor shear resistance. The resin composite can be reinforced using flexible fibers or rigid posts. Fiber-reinforced composites (FRC) placed with the resin composite may enhance the interfacial bonds and increase fracture strength. Woven polyethylene fibers, glass, silica or quartz fibers, and carbon fibers added to the polymer matrix reduce the vibration, provide even stress distribution, and increase the fatigue and fracture resistance.[24] The lock-stitch pattern of the

polywoven fibers transfers the forces through the weave without propagating the stresses into the resin and inhibits the crack from propagating.[25]

The design of preparation also affects the fracture strength.[26] Many procedures and designs ranging from no tooth preparation, circumferential bevel along fracture line, external or internal grooves, to over-contouring of composite on the fracture line have been evaluated.[21,27] This systematic review examined the data available in literature to evaluate the fracture resistance of the tooth fragments reattached using FRC.

Materials and Methods

Development of Protocol

The present systematic review was executed according to the Preferred Reporting for Systematic Reviews and Meta-analysis (PRISMA) statement 2020. The present review was registered in the Prospective Register of Systematic Reviews (PROSPERO) (registration number: CRD42023472112).

The focused question that was developed was "Does reinforcement of reattached tooth fragments using FRC affect their fracture resistance?"

Inclusion Criteria

(P) Population: Human permanent fractured teeth.
(I) Intervention: Reattachment of fractured fragments reinforced by glass fiber or polyethylene reinforced composite posts or composite.
(C) Control: Intact teeth; unrestored teeth; restoration using composite resin; reattachment using composite resin, dual-cure resin, or flowable resin.
(O) Outcome: Fracture resistance.
(S) Study type: Randomized control studies, controlled clinical trials, observational studies, retrospective studies, *in vitro* studies, experimental studies.

Exclusion Criteria

Animal studies, case reports, systematic reviews, literature or scoping review, opinion articles, letters to the editor, and articles in languages other than English were excluded.

Search Strategy

PubMed, Scopus, and Web of Science databases were searched electronically to identify the studies to be included in the review. Literature was searched for articles published up to January 2023, with no restrictions placed on the start date. Forward citation tracking was conducted using Google Scholar. Several search terms and strategies were applied to identify studies. These include strategies to search the fracture resistance of reattached tooth fragments restored using FRC. The search strategy is depicted in Table 1.

Screening Method

The search results were reviewed by three authors (N.H.A.; S.B.; S.G.P) independently. Duplicate and non-relevant articles were

Table 1: The search strategy

Source	*Keywords*	*No. of articles*
PubMed	("reattach"[All Fields] OR "reattached"[All Fields] OR "reattaches"[All Fields] OR "reattaching"[All Fields] OR "reattachment"[All Fields] OR "reattachments"[All Fields]) AND ("tooth fractures"[MeSH Terms] OR ("tooth"[All Fields] AND "fractures"[All Fields]) OR "tooth fractures"[All Fields] OR ("fractured"[All Fields] AND "teeth" [All Fields]) OR "fractured teeth"[All Fields]) AND ((("polyethene"[All Fields] OR "polyethylenes"[MeSH Terms] OR "polyethylenes"[All Fields] OR "polyethylene"[All Fields] OR "polyethylene"[MeSH Terms] OR "polyethylen" [All Fields]) AND ("fiber"[All Fields] OR "fiber s"[All Fields] OR "fiberized"[All Fields] OR "fibers"[All Fields] OR "fibre"[All Fields] OR "fibre s"[All Fields] OR "fibres"[All Fields]) AND ("reinforce"[All Fields] OR "reinforced" [All Fields] OR "reinforcement, psychology"[MeSH Terms] OR ("reinforcement"[All Fields] AND "psychology"[All Fields]) OR "psychology reinforcement"[All Fields] OR "reinforcement"[All Fields] OR "reinforcements"[All Fields] OR "reinforcer"[All Fields] OR "reinforcer s"[All Fields] OR "reinforcers"[All Fields] OR "reinforces"[All Fields] OR "reinforcing"[All Fields])) OR (("fiber"[All Fields] OR "fiber s"[All Fields] OR "fiberized"[All Fields] OR "fibers" [All Fields] OR "fibre"[All Fields] OR "fibre s"[All Fields] OR "fibres"[All Fields]) AND ("insert"[All Fields] OR "insert s" [All Fields] OR "inserted"[All Fields] OR "inserter"[All Fields] OR "inserters"[All Fields] OR "inserting"[All Fields] OR "insertion s"[All Fields] OR "insertional"[All Fields] OR "insertions"[All Fields] OR "inserts"[All Fields] OR "mutagenesis, insertional"[MeSH Terms] OR ("mutagenesis"[All Fields] AND "insertional"[All Fields]) OR "insertional mutagenesis"[All Fields] OR "insertion"[All Fields]) AND ("composite"[All Fields] OR "composite s" [All Fields] OR "composited"[All Fields] OR "composites"[All Fields] OR "compositing"[All Fields] OR "composition" [All Fields] OR "compositional"[All Fields] OR "compositions"[All Fields]))) AND (("fractur"[All Fields] OR "fractural" [All Fields] OR "fracture s"[All Fields] OR "fractures, bone"[MeSH Terms] OR ("fractures"[All Fields] AND "bone"[All Fields]) OR "bone fractures"[All Fields] OR "fracture"[All Fields] OR "fractured"[All Fields] OR "fractures"[All Fields] OR "fracturing"[All Fields]) AND ("resist"[All Fields] OR "resistance"[All Fields] OR "resistances"[All Fields] OR "resistant"[All Fields] OR "resistants"[All Fields] OR "resisted"[All Fields] OR "resistence"[All Fields] OR "resistences" [All Fields] OR "resistent"[All Fields] OR "resistibility"[All Fields] OR "resisting"[All Fields] OR "resistive"[All Fields] OR "resistively"[All Fields] OR "resistivities"[All Fields] OR "resistivity"[All Fields] OR "resists"[All Fields]))	4
WOS	TITLE-ABS-KEY (fracture AND resistance AND fiber AND reinforced AND composite AND reattached AND fractured AND teeth)	5
Scopus	(TITLE-ABS-KEY (fracture resistance AND fiber reinforced composite OR reattached fractured tooth (All Fields))	7

discarded. The three authors independently screened the titles and abstracts of the studies for inclusion based on the question: "Does reinforcement of reattached tooth fragments using FRC affect fracture resistance?". Any contention between the authors was resolved by discussion and consensus with a fourth author (D.H.A). Full-text articles for selected studies were obtained and examined for eligibility.

Data Extraction and Analysis

Two authors (N.H.A, S.B) independently conducted data extraction and it was verified by a third author (S.G.P). The following characteristics of the studies were extracted: authors names, year of publishing, country of research, sample size, study design, treatment regimen, primary outcome assessment, the outcome of the study, significant value, and inference. The data extracted from the included studies are reported in a customized template providing an overview of the studies in a tabular manner.

Assessment of Study Quality

The quality of the selected studies was assessed using relevant guidelines from the Cochrane Handbook for Systematic Reviews.[28] Extending the OHAT risk of bias assessment tool to *in vitro* studies, the domains used to assess the studies were randomization, allocation concealment, standardization of procedures, blinding of operating and research personnel, missing outcome data, outcome assessment, selective reporting of outcomes, and other sources of bias. A four-point scale based on the Clarity Group at McMaster University was used. The response for each domain was either high or low risk of bias. The presence of definitive evidence or information resulted in a low risk of bias for the particular domain, whereas the absence of pertinent information would result in a high risk of bias judgment. In case of insufficient or unclear information, the response to the particular domain would be "Probably High" or "Probably Low." The highest level of risk observed determined the overall risk of bias.

Quality of Evidence for Outcomes in Summary of Findings Table

Relating to each outcome in the Summary of Findings, the quality of evidence was assessed using the evidence grading system GRADE as described in Section 12.2 of the Cochrane Handbook for Systematic Reviews of Interventions. The GRADE system was applied by one author and the quality of evidence for each outcome was then discussed with the other two authors. The final decision on ratings was reached by consensus. Criteria for downgrading the quality of evidence included five domains: Risk of bias, Inconsistency of results, Indirectness of evidence, Imprecision of results, and Publication bias.

Results

Search Outcomes

Initial search results identified 4 articles from PubMed, 5 from Scopus, and 7 from Web of Science. After removing six duplicates, 10 abstracts were retained for further screening. After the removal of one case report, nine *in vitro* studies were considered for complete review. Two[29,30] studies were excluded because rather than reattaching the fractured fragment, they used FRC for crown build-up. A total of seven *in vitro* studies published between 2006 and 2022 were included in the present review.[31–37] Interrater agreement was high with a kappa statistic of 0.92 (95% confidence interval). The PRISMA flow diagram is shown in Figure 1.

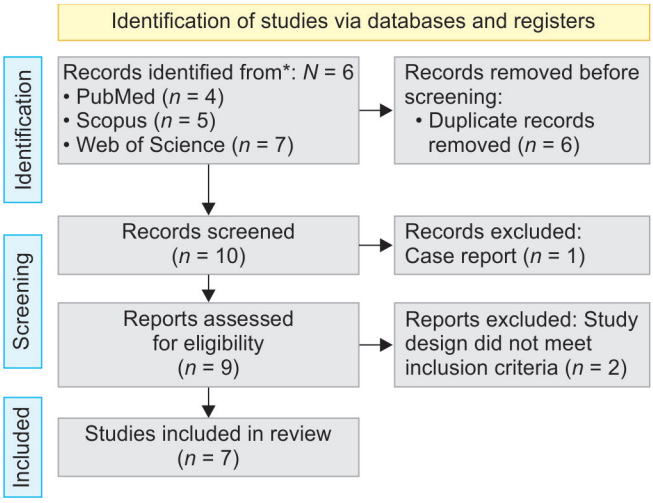

Fig. 1: PRISMA flowchart

Geographical Characteristics

The included studies were conducted predominantly in two continents. Four studies were conducted in Europe (Turkey[31,33,36] and Netherlands[32]) and three in Asia (India).[34,35,37]

Teeth Used and Fractures Induced

One study used mandibular molars, the lingual walls of cusps of mandibular molars were fractured at cemento enamel junction (CEJ) level using an indentor.[31] Three studies induced uncomplicated horizontal Ellis and Davey Class II fractures by cutting the crowns of maxillary incisors horizontally using a diamond disk.[32,35,37] Three studies used single-rooted mandibular premolars that were fractured using a hammer and tapered chisel to simulate VRF.[33,34,36]

Materials Compared

One study compared the reattachment of lingual cusps of endodontically treated mandibular molars with MOD cavities using self-cure adhesive resin cement, flowable composite, universal composite placed in bulk-fill technique, and reinforcement with polyethylene fibers.[31] One study compared the reattachment of fragments using a bonding agent, FRC mini anchors made of glass fibers, and crown build-up using resin composite.[32] Two studies[33,34] had nearly similar methodologies, with the only difference being that Şen et al. had two control groups and Kumar et al. had only one. They compared the fracture resistance of endodontically instrumented and/or obturated fractured mandibular premolars reattached using dual-cure resin cement and the resin cement reinforced either with polyethylene or glass fibers.[33,34] One study placed circumferential chamfer in the fracture line, removed dentin from the fractured segment and filled both the groups with resin composite, and compared it with the study group where two vertical grooves were placed on the labial surface of reattached teeth, perpendicular to fracture line and filled with two FRC posts and composite.[35] Similarly, another study compared the placement of polyethylene fibers and fiber posts in the vertical grooves on the labial surface.[37] One study used various strategies for placing quartz fiber posts and glass fibers with various ferrule designs.[36]

Comparator

Two studies had two control groups.[33,36] Four studies used intact teeth with no cavity preparation or root canal treatment as a control group.[31,35–37] One study compared coronal fragments that were reattached to the remaining tooth using resin composite.[32] Three studies used unfractured teeth with instrumented and obturated root canals[33,34] or only instrumented root canals.[33,36]

Outcome Assessment

All studies applied vertical compressive load by placing the samples that were embedded in acrylic resin on the lower compartment of the universal testing machine. Force was applied at a crosshead speed of 1 mm/min with a 5 mm diameter stainless steel bar[31] or using stainless steel wedge,[35,37] 0.5 mm/min applied with a stylus of 108 taper,[32] the axial force of 0.5 mm/min directed vertically parallel to the long axis of the roots.[33,34,36]

Characteristics of Outcomes

All but one[36] of the included studies reported an increase in the fracture resistance of the reattached fragments reinforced using either FRC post or composites. No statistically significant difference between the polyethylene fiber group and unfractured teeth;[33,34] between teeth reinforced with FRC posts placed in vertical grooves on the labial surface and intact teeth.[35]

One study reported lower fracture resistance in FRC anchors reinforced teeth than the samples in which crown was built up using resin composite.[32] Among fractured teeth, teeth reinforced with glass fibers had lower strength as compared with those reinforced with polyethylene fibers.[33,34] In contrast to Şen et al., Kumar et al. found that reinforcement with glass fibers yielded poor results than dual-cure resin cement and polyethylene fibers.[34] Kurnaz and Keçeci reported significantly reduced fracture strength in teeth with roots reattached using quartz fiber post as compared with other test groups. The placement of various ferrule designs with the quartz post and the placement of glass fibers with or without various ferrule designs increased the fracture resistance as compared with teeth reinforced only with quartz post.[36] In contrast, Sreen et al. reported the highest fracture resistance for teeth reattached using fiber post and the lowest fracture resistance for teeth reattached using polyethylene fibers with a statistically significant difference.[37] A summary of the characteristics of the selected studies is given in Tables 2 and 3.

Quality Assessment

The selected seven articles were subjected to assessment using the OHAT risk of bias rating tool. The overall risk of bias in most studies was high. The process of randomization of the extracted teeth for allocation into groups is not mentioned. None of the included studies have mentioned the blinding of the operating or assessing personnel. The methodology and assessment procedures are specific, standardized, and universally accepted in all the included studies. One study has a high risk of bias due to attrition.[35]

In the present review, there was a serious risk of bias found in randomization,[33,34,36,37] allocation concealment,[31–38] and reporting of the outcome in all studies.[35] There was no serious inconsistency, indirectness, imprecision, or publication bias observed. Due to the risk of bias, the level of certainty in the estimate of effect is limited; the actual effect of the reinforcement might be different from the reported effect. The summary of the assessment is presented in Figure 2.[39]

Discussion

The seven *in vitro* studies included in the present review evaluate the fracture resistance of reattached fractured teeth using FRC or posts. One study evaluated the reattachment of the lingual wall of the mandibular molar after root canal treatment and MOD cavity preparation, using polyethylene fibers Ribbond.[31] Three studies evaluated reattachment after Ellis and Davey Class II fracture in maxillary incisor teeth.[32,35,37] The tested materials in these studies are FRC mini anchors made of glass fibers,[32] FRC posts,[35,37] and polyethylene fibers[37] placed in two vertical grooves that were made perpendicular to the fracture line on the labial surface of the reattached teeth. Three studies[33,34,36] evaluated the fracture resistance of single-rooted mandibular premolars where VRF was induced after root canal instrumentation and/or obturation. The root fragments were reattached using a combination of dual-cure resin and polyethylene or glass fibers,[33,34] or resin composite and quartz fiber post or glass fiber bundles with various ferrule designs.[36]

Results indicated that in the central incisors, reattachment of fragments using FRC anchors resulted in better fracture resistance than just bonding alone. However, the fracture resistance was lower than the build-up of crown portion using resin composite.[32] Fragments reattached using FRC post showed no significant

Table 2: Summary of findings

Quality assessment						*Summary of findings*		
Outcome	*Risk of bias*	*Inconsistency*	*Indirectness*	*Imprecision*	*Publication bias*	*Impact*	*No. of participants (Studies)*	*Certainty of evidence (GRADE)*
Fracture resistance of reattached fragments using fiber-reinforced composites	Serious[a]	Not serious	Not serious	Not serious	Not serious	Our confidence in the effect estimate is limited: the true effect may be substantially different from the estimate of the effect	415 (7)	Low ⊕⊕

[a]Seven studies showed a high risk of bias with allocation concealment and blinding of operators and assessors, four studies showed a high risk of bias in randomization process, and one study showed a high risk of attrition bias

Table 3: Summary of the characteristics of the selected studies

Author	*Sample size*	*Study design*	*Intervention*	*Control used*	*Outcome assessment*	*Outcome*	*Inference*
Belli S et al.[31]	60 Mandibular molar teeth	G1: Control; no cavity preparation or root canal treatment G2–G6: Endodontically treated and MOD cavities prepared. G2: unrestored after MOD. G3–G6: Lingual walls fractured and reattached using self-curing adhesive resin cement. G3: Kept unrestored after reattachment G4: Composite restoration using bulk-fill technique G5: Flowable + universal composite G6: Flowable composite + polyethylene fiber Ribbond + universal composite	Leno weave ribbon formed of polyethylene fiber embedded into uncured flowable resin from the occlusal 1/3 of the buccal wall to the occlusal 1/3 of the lingual wall	Intact teeth: no cavity preparation or root canal treatment	Universal testing machine: vertical compressive force applied at 1mm/min with a 5 mm diameter stainless steel bar	Inserting a piece of UHMW polyethylene fiber ribbon from buccal to lingual direction under resin composite restoration significantly increased fracture strength (p 0.0001)	The insertion of Ribbond inside the cavity has a positive effect on fracture strength of endodontically treated molar teeth with MOD cavity preparation and cuspal fracture
Fennis WMM et al.[32]	45 Central upper incisors	G1: Fragment reattached by bonding G2: Fragment reattached using bonding + 2 mini-FRC anchors G3: Resin composite build-up	Before placing the coronal fragment onto the remaining tooth, cement was applied to the mini-FRC anchors and the anchors were placed in the tooth	Coronal fragments were reattached to the remaining tooth using resin composite	Universal testing machine: Vertical static load applied with 2 mm below the incisal edge at crosshead speed was 0.5 mm/min using a stylus of 108 taper	Mean fracture loads were 255 N (SD = 108 N) for group A, 599 N (SD = 465 N) for group B and 786 N (SD = 197 N) for group C (values significantly different, all p-values < 0.05). Group A showed purely adhesive failures, while groups B and C showed 73 and 53% fractures of remaining tooth substrate ($p < 0.05$)	Mini-FRC anchors increase fracture resistance of reattached coronal fragments, but induce more remaining tooth substrate fractures

(Contd...)

Table 3: *(Contd...)*

Author	*Sample size*	*Study design*	*Intervention*	*Control used*	*Outcome assessment*	*Outcome*	*Inference*
Şen BH et al.[33]	59 Mandibular premolars	Control group I: ($n = 7$) unfractured teeth with instrumented and obturated Control group II: ($n = 7$) only instrumented root canals but not obturated. Vertical root fractures induced and separated fragments were reattached by using group I: ($n = 15$) dual-cured resin cement (Clearfil SA) Group II: ($n = 15$) dual-cured resin cement + polyethylene fiber (Construct) group 3: ($n = 15$) dual-cured resin cement + glass fiber (Stick-Net)	Polyethylene or glass fibers are used for reinforcement along with dual-cure resin	Unfractured teeth with instrumented and obturated or only instrumented root canals	Universal testing machine: axial force applied at crosshead speed of 0.5 mm/min directed vertically parallel to the long axis of the roots using a steelball with a modified shape	Lowest fracture strength in Stick-Net group (243.27 N) ($p < 0.001$) followed by Clearfil SA (355.57 N) and Construct (582.0 N); fracture strength for control 1 = 842.52 N and control 2 = 665.85 N. There was no statistical difference when Construct was compared with Clearfil SA, control 1, and control 2 groups ($p > 0.05$)	Separated fragments of vertically fractured teeth can be reattached by using a dual-cured resin or by adding polyethylene fiber (Construct)
Kumar BS et al.[34]	60 Mandibular premolars	Control groups ($n = 15$ each) unfractured teeth with instrumented and obturated. Fractured teeth were divided into three groups ($n = 15$) and were attached using (1) Dual-cure resin cement (RelyX U100) (2) Dual-cure resin cement and polyethylene fiber (Ribbond) (3) Dual-cure resin cement and glass fibers (stick-net)	Polyethylene or glass fibers are used for reinforcement along with dual-cure resin	Unfractured teeth with instrumented and obturated with F3 Pro Taper gutta percha cones	Universal testing machine: axial force applied at crosshead speed of 0.5 mm/min, directed vertically parallel to the long axis of the roots	RelyX U100 group demonstrated lowest fracture resistance. Control group showed highest fracture resistance followed by Ribbond and Stick-Net groups. Statistically no significant difference was there between groups II, III and IV	Vertically fractured teeth can be treated by filling the root canal space with dual-cure adhesive resin cement or by adding polyethylene fiber or glass fiber to increase the fracture resistance of the reattached tooth fragments

(Contd...)

Table 3: *(Contd...)*

Author	*Sample size*	*Study design*	*Intervention*	*Control used*	*Outcome assessment*	*Outcome*	*Inference*
Karre D et al.[35]	53 Permanent maxillary incisors	Group I: ($n = 11$) after reattachment with composite, 1 mm circumferential chamfer in fracture line and filled with composite. Group II: ($n = 11$) two vertical grooves on labial surface perpendicular to fracture line and filled with two fiber-reinforced composite (FRC) posts and composite. Group III: ($n = 11$) dentin removed from fragment and filled with composite. Group IV: control: ($n = 20$) intact teeth	Fiber-reinforced composite posts and composite placed in vertical grooves on labial surface	Intact teeth	Universal testing machine: load applied in a labial to lingual direction by means of a reinforced stainless-steel wedge at a speed of 1 mm/min	No significant difference between groups I and IV. Teeth in groups I, II, III required lesser force to fracture when compared with group IV. When compared with group IV, group I showed a fracture resistance of 36%, group II 62%, and group III 32%	Among the various techniques and materials used for the fragment reattachment, vertical grooves with fiber-reinforced composite posts show the highest fracture resistance. When the fragment is intact, with adequate size and appropriately preserved margins, this method can be applied
Kurnaz S and Keçeci AD[36]	90 Mandibular premolars	Negative control (NC) group: intact teeth Positive control (PC) group: root canal-treated teeth. Group CB: (4-META/ MMA-TBB) resin, Group DT: 4-META/ MMA-TBB + quartz fiber post, Group TB: 4-META/ MMA-TBB + glass fiber bundles, Group DT +1F: 4-META/MMA-TBB + quartz fiber post + 1 mm ferrule, Group Tb +1F: 4-META/MMA-TBB + glass fiber bundles + 1 mm ferrule, Group DT + 2F :4-META/MMA-TBB + quartz fiber post + 2 mm ferrule, Group TB + 2F :4-META/ MMA-TBB + glass fiber bundles + 2 mm ferrule	Quartz fiber post or glass fiber bundles placed with or without different ferrules	Negative control (NC) group was composed of intact teeth, while the positive control (PC) group was composed of root canal-treated teeth	Universal testing machine: axial force applied at crosshead speed of 0.5 mm/min, directed parallel to the long axis of the root using a 3 mm diameter steel ball	The roots reattached with quartz fiber post demonstrated significantly less fracture strength (871.9 N) as compared with the other test and control groups ($p < 0.05$). There was no significant difference between the PC group and reattached fragments with different ferrule designs in terms of fracture resistance ($p > 0.05$)	The customized fiber bundles may be more suitable for reattachment of vertically fractured teeth than the rigid fiber posts. For reattachment procedures, the ferrule design may be preferred to increase the fracture strength of vertically fractured teeth

(Contd...)

Table 3: *(Contd...)*

Author	*Sample size*	*Study design*	*Intervention*	*Control used*	*Outcome assessment*	*Outcome*	*Inference*
Sreen D et al.[37]	48 Maxillary central incisors	Group I: control group (not sectioned). Groups II, III, and IV—standardized sections 2.5 mm from the incisal edge of the crown were made using a diamond disk to simulate an Ellis and Davey class 2 fracture Group II: reattachment followed by placement of two external vertical grooves on the labial surface and restored with polyethylene fibers and hybrid composite, Group III: reattachment followed by two external vertical grooves and filled with fiber posts and composite, Group IV: reattachment followed by circumferential chamfer at the fracture line and restored with composite	Placement of two external vertical grooves on the labial surface and restored with polyethylene fibers and hybrid composite	Intact teeth	Universal testing machine: load applied in a labio-palatal direction at fracture line using a stainless steel wedge at a speed of 1 mm/min	The highest values observed in the fiber post group and the lowest in the Ribbond group ($p < 0.05$). The fiber post group had significantly different results compared with the Ribbond and Chamfer preparation groups ($p < 0.05$), and not significantly different when compared with control group ($p > 0.05$)	The force required to fracture the fiber post group was closest to that of intact teeth followed by the chamfer and Ribbond groups, respectively

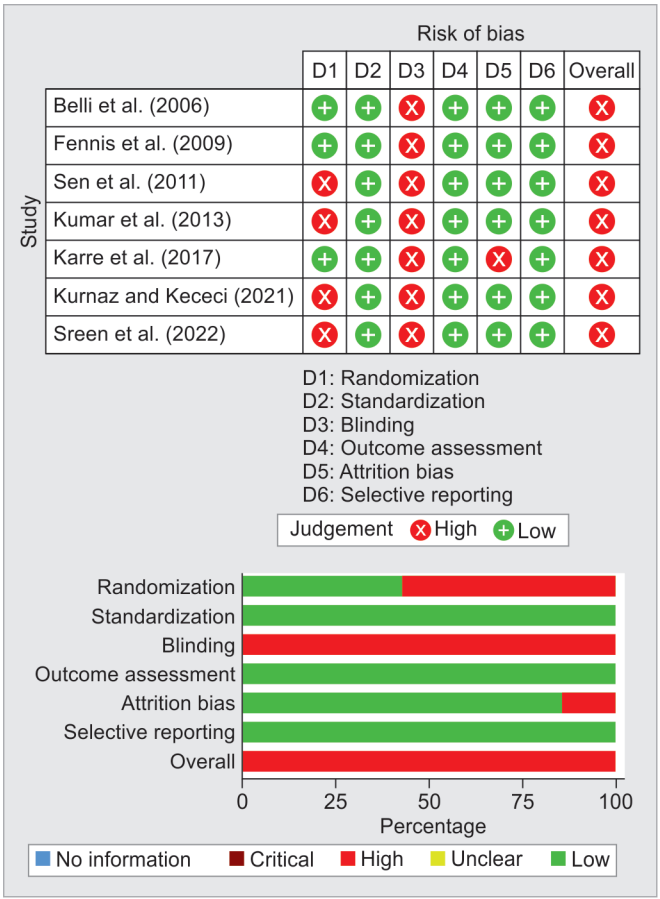

Fig. 2: Summary of risk of bias assessment

difference with intact teeth[35]and performed better than those reinforced with flexible polyethylene fibers.[37] The failure pattern of the teeth reinforced with FRC posts was mostly adhesive where the fracture occurred along the resin–enamel interface and cohesive failure occurred within the resin. The vertical posts did not undergo fracture even under high force.[35] The re-fracture occurred along the existing line of fracture.[37] The teeth that were reattached using composite in the circumferential chamfer showed 36% strength, the teeth reinforced with FRC posts showed 62% strength and the teeth filled with composite by replacing the dentin in the fractured fragment showed around 32% strength as compared with the intact teeth.[35]

However, among vertically fractured premolars, the placement of glass fibers in the root canal reinforced the tooth better than the rigid quartz fiber posts.[36] The fracture resistance of teeth reinforced with fiber posts was positively affected by the ferrule design, but the ferrule design had no impact on teeth reattached with fiber bundles.[36] Whereas, on comparing the fracture resistance of teeth reinforced by glass fibers with those reinforced by polyethylene fibers, the results for polyethylene groups were better.[33,34] The quartz fiber posts had high fracture resistance but it did not protect the tooth from undergoing re-fracture. Furthermore, it accentuated the fracture at the reattachment or the existing fracture line.[36] The prefabricated FRC posts simulate the mechanics of a healthy tooth, yet they generate high stresses in the dentin. Whereas customized composite posts or flexible polyethylene fibers produce less stress in the apical portion of the post space and reduce the risk of fracture at the original site.[40,41] This was exhibited by the prefabricated FRC posts causing 60% fractures along the reattachment line and fiber bundles causing 70% non-reparable fractures into multiple fragments.[36] The higher thickness and composition of polyethylene fibers may have also led to better performance as compared with glass fibers.[33] These results indicate that rigid prefabricated FRC posts are not recommended for the reattachment of vertically fractured teeth.

Overall Completeness and Applicability

All the studies have evaluated the outcomes of the fracture resistance, and the mode of failure. The results were nearly similar among studies evaluating horizontal fractures in incisors and among the studies evaluating VRFs in the premolars. The application of rigid posts or anchors yields better results for reattachment in horizontal fractures, whereas the application of flexible fibers yields better results for reattachment in VRFs. The calculation or estimation of sample size is not mentioned in any of the included studies. Karre et al. lost samples due to improper sectioning of the crowns while inducing fracture in the teeth and the sample size was not adjusted later.[35] The methodology used in all studies for inducing the fractures, preparing the separated fragment, reattachment procedure, and application of FRC fibers or posts was standardized. The outcome was assessed in all studies by mounting the samples, embedded in acrylic resin, on the lower compartment of the universal testing machine. The load was applied gradually on the labial aspect of incisors perpendicular to the fracture line and vertical load was applied on the premolars and molars along the long axis of the tooth. The force was applied using stainless steel ball or wedge at a standardized crosshead speed per ISO standard (ISO/TS 11405:2003-Dental Materials—Testing of adhesion to tooth structure).[42] The materials tested in the studies are commercially divergent but represent the majority of FRC products available in the market. The studies have also evaluated the mode of fracture under various magnifications using a stereomicroscope[31,33,34] or by photographing the fractured surfaces using a digital camera.[35]

Quality of the Evidence

We examined seven *in vitro* studies and 415 samples including 146 maxillary incisors, 209 single-rooted mandibular premolars, and 60 mandibular molars. None of the studies have mentioned sample size calculation, the number and blinding of operators or assessors. The process of randomization was not described in four studies.[33,34,36,37] A high risk of bias due to allocation concealment and blinding was observed in all the included studies. A high risk of bias was observed in four studies[33,34,36,37] due to the lack of randomization and in one study[35] due to attrition in the number of study samples. There was no imprecision, indirectness, or imprecision observed in the study designs. As stated by the authors, none of the studies were funded or supported by any commercial organization with any financial interest in the subject or the materials involved. The overall confidence in the body of evidence is low due to the high risk of bias in all studies. The actual effect of the interventions might be different than the effect estimated in the included studies.

A sensitive and wide-ranging search strategy was employed to identify studies for inclusion in this review. No restriction was placed on the publication date and multiple authors independently assessed eligibility using well-defined inclusion criteria to minimize any selection bias. During the selection of articles to be included in the review, only English language studies with full text available were considered. Despite the authors' best efforts, the limitations

of *in vitro* studies must be taken into consideration. As studies were conducted *in vitro*, the exact oral conditions could not be simulated, but the samples were subjected to compressive load to evaluate fracture resistance. In clinical conditions, root canal-treated or non-vital teeth may also undergo fracture due to fatigue failure. Hence, future studies should also use cyclic loading rather than limit the investigation to resistance to static load. Though biological aspects of the involved treatment protocols could not be evaluated, the mechanical properties relating to fracture resistance and the mode of failure were compared with intact and endodontically treated teeth. Further high-quality clinical trials should be designed using standardized protocols to evaluate the clinical longevity of the treatment protocols.

Conclusion

This systematic review evaluated the fracture resistance of reattached teeth that were reinforced using FRC fibers or posts. Seven *in vitro* studies were included in the review evaluating fracture resistance in horizontally fractured maxillary incisors and vertically fractured premolars and molars. Within the limits of the present review, we conclude that the incorporation of FRC fibers or posts increased the fracture strength of the reattached teeth.

Clinical Significance

There is low-quality evidence that rigid FRC posts or anchors increase the fracture resistance of reattached anterior teeth with horizontal crown fractures, and the flexible FRC fibers improve the fracture resistance of reattached posterior teeth with cuspal or VRFs.

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Authors Contribution

Nassreen H Albar carried out conceptualization, methodology, software, validation of data, analysis, investigation, visualization, resources, data curation, and original draft preparation. Albar was also involved in review and editing, supervision, and project administration, The author has read and agreed to publish this final version of the manuscript.

PROSPERO Registry Number

The present review was registered in Prospective Register of Systematic Reviews (PROSPERO) (registration number: CRD42023472112).

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