J Prosthodont Res. 2023; **(**): ****–****

OPEN ACCESS

Journal of Prosthodontic Research

Review article

Effect of partial ferrule on fracture resistance of endodontically treated teeth: A meta-analysis of *in-vitro* studies

Fuad Ateik Al-Sanabani [a,b], Bandar Mohammed AL-Makramani [a,b], Wafa Hassan Alaajam [c,d], Mohammed Sultan Al-Ak'hali [e,f,*], Mohammed Nasser Alhajj [g], Mohammad Zakaria Nassani [h], Mounzer Assad [i], Sadeq Ali Al-Maweri [j]

[a] Department of Prosthetic Dental Sciences, College of Dentistry, Jazan University, Jazan, Saudi Arabia
[b] Department of Restorative Dentistry, Faculty of Dentistry, Sana'a University, Sana'a, Yemen
[c] Department of Restorative Dental Science, College of Dentistry, King Khalid University, Abha, Saudi Arabia
[d] Department of Conservative Dentistry, Faculty of Dentistry, Sana'a University, Sana'a, Yemen
[e] Department of Preventive Dental Sciences, College of Dentistry, Jazan University, Jazan, Saudi Arabia
[f] Department of Periodontology, Faculty of Dentistry, Sana'a University, Sana'a, Yemen
[g] Department of Prosthodontics, Faculty of Dentistry, Thamar University, Dhamar, Yemen
[h] Department of Restorative and Prosthetic Dental Sciences, College of Dentistry, Dar Al Uloom University, Riyadh, Saudi Arabia
[i] Department of Oral Surgery, Faculty of Dentistry, Tishreen University, Lattakia, Syria
[j] College of Dental Medicine, QU Health, Qatar University, Doha, Qatar

Abstract

Purpose: The present meta-analysis aimed to answer the following research question: In endodontically treated teeth (ETT), what is the effect of partial ferrule (PF) on fracture resistance compared to complete ferrule (CF) and/or no ferrule (NF)?
Study selection: PubMed, Scopus, Web of Science, and Google Scholar were searched for relevant studies published until May 20, 2022. In vitro studies that compared the effect of partial ferrule with that of complete ferrule and/or no ferrule on fracture resistance of ETT were included. The studies were assessed for risk of bias, and a meta-analysis was performed.
Results: Seventeen in vitro studies comprising 807 teeth were included. Nine studies were at a high risk of bias and eight presented a moderate risk of bias. Overall, the results showed that CF was superior to PF in increasing fracture resistance ($SMD= 0.93$, $CI_{95\%}= 0.57\text{-}1.29$, $P< 0.0001$), with no change in the effect based on the type of teeth ($P< 0.001$). However, the subgroup analysis found that PF 2 mm buccal, lingual, and buccal and lingual ferrule were comparable to CF ($P= 0.06$). Additionally, the PF group showed significantly higher fracture resistance than the NF group ($SMD= 2.02$, $CI_{95\%}= 1.54\text{-}2.49$, $P< 0.00001$).
Conclusions: Although CF design provided the highest fracture resistance to restored ETT, PF can still be a viable option for restoring ETT in cases where CF is not feasible.

Keywords: Partial ferrule, Fracture resistance, Endodontically treated teeth

Received 15 June 2022, Accepted 8 November 2022, Available online 14 January 2023

1. Introduction

Despite being challenging, the restoration of severely damaged nonvital teeth can be the first treatment option for many practicing dentists. This is because of the various potential functional, psychological, and financial merits of retaining/restoring a tooth versus tooth extraction and prosthetic replacement[1]. Commonly, restoration of endodontically treated teeth (ETT) involves posts and cores and crown restorations of varying designs, materials, and cements/luting agents[2]. However, when a decision is made to restore an ETT, the long-term prognosis of the contemplated restoration is of paramount importance[3]. In this respect, many factors may play a role in improving the survival and fracture resistance of the restored ETT; these include volume and integrity of the remaining tooth structure, anatomy/morphology of the root canal, position of the tooth in the dental arch, presence of proximal contacts, nature of occlusion, core material, restoration design, ferrule effect, and number of remaining walls[4,5]. Among the former factors, the ferrule effect and number of remaining walls seem to be particularly important[6]. A ferrule effect was introduced by Eissman and Radke[7] to describe the 360-degree ring of cast metal and recommended the extension of the definitive cast restoration at least 2 mm apical to the junction of

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DOI: https://doi.org/10.2186/jpr.JPR_D_22_00170

***Corresponding author:** Mohammed Sultan Al-Ak'hali, Department of Preventive Dental Sciences, College of Dentistry, Jazan University, Jazan city, Saudi Arabia. Department of Periodontology, Faculty of Dentistry, Sana'a University, Sana'a, Yemen.
E-mail address: sultanperiodontics@gmail.com

the core and the remaining tooth structure to reduce the risk of tooth fracture by decreasing the stresses affecting the restored tooth[7]. A height of 1.5-2.0 mm and thickness of at least 1 mm are the minimum required height/thickness for a ferrule to achieve an adequate ferrule effect[8].

While current literature suggests a positive impact of the presence of a ferrule on the longevity and fracture resistance of the ETT, evidence is still conflicting regarding the best configuration for a ferrule to provide the optimal fracture resistance for an ETT[6,9,10]. It is worth mentioning here that while complete ferrule (CF) is effective in improving the fracture resistance and longevity of the restoration of ETT[11], it is not possible to secure/provide CF in all clinical cases. For example, deep proximal boxes are a common sequela of interproximal caries in both anterior and premolar teeth, resulting in a compromised ferrule in these areas. Therefore, the clinical decision needs to weigh the benefits and the risks of achieving an 'all around' uniform ferrule. The clinical implications of a crown lengthening procedure may include many complications such as damage to adjacent teeth, reduction of the attached gingiva width, tooth sensitivity, and the risk of postoperative tooth recession[12]. Such complications should be evaluated against the biomechanical risks of a crown that does not have a CF.

When extensive lateral forces are not anticipated, PF can be useful and may replace CF in ETT to preserve the remaining tooth structure and save the clinician's time and effort[11,13]. In this context, a number of in vitro studies have been conducted to assess the effect of PF on the fracture resistance of ETT and have reported inconsistent results. While many studies reported inferiority of PF in increasing the fracture resistance compared to CF[11,13–15], others have found comparable results[16,17] or even better outcomes in favor of PF[18,19]. Based on the above-mentioned findings, it seems that there is controversy regarding the effect of PF on the fracture resistance of ETT. Additionally, there is a clear need for evidence-based knowledge to guide clinical decisions and adequately plan the restorative dental treatment of ETT. Hence, the present study aimed to systematically review and evaluate the available evidence regarding the effect of PF on the fracture resistance of ETT compared to CF or no ferrule (NF). The focused question is: In ETT (P), what is the effect of partial ferrule (I) on the fracture resistance (O) compared to CF and/or NF (C)?

2. Materials and Methods

The present meta-analysis was performed according to PRISMA (2020) guidelines and PICO principles[20].

2.1. *Eligibility criteria*

All in vitro studies that compared PF with either the CF or NF group, and fulfilled the following criteria were included:1) intervention (I): partial ferrule, 2) comparison group (C): complete ferule and/or no ferrule; 3) population (P): anterior or posterior ETT; 4) outcomes (O): fracture resistance; and 5) a minimum sample size of five teeth.

The exclusion criteria were:1) clinical studies, 2) uncontrolled studies, 3) missing relevant numerical data, and 4) editorials and reviews.

2.2. *Search strategy and information sources*

A detailed search strategy is presented in **Table S1**. The following online databases (PubMed, Scopus, Web of Science, and Google scholar) were searched on May 21, 2022, by two independent investigators to identify all relevant studies published up to May 20, 2022. The list of retrieved references was manually searched for additional relevant studies. Disagreements between the two investigators were resolved by discussion or consultation with a third reviewer. The following keywords were used in combination: ((“endodontically treated teeth” OR “endodontically treated molar” OR “endodontically treated premolar”) AND (“dental restoration” OR “fiber post” OR “metal post” OR “ferrule” OR “partial ferrule” OR “circumferential Ferrule”) AND (“fracture resistance” OR “fracture”))

2.3. *Screening and selection process*

All identified studies were exported to the Endnote software program version 9, and duplicate studies were removed. Two investigators (MS and SA) independently screened the titles and abstracts of all the studies, and irrelevant articles were removed. The full texts of the remaining studies were then obtained and evaluated for inclusion.

2.4. *Data extraction*

The following data were extracted by two independent investigators (MA and FA): authors and country of the study, type of teeth, sample size, ferrule configuration, numerical data pertaining to fracture resistance, and conclusions. Additional data were extracted, including the type of post and crown, loading angle, crosshead speed, and fracture mode.

2.5. *Quality assessment*

Two independent investigators (FA and BA) appraised the methodological quality of the included studies by utilizing a previously used tool for in vitro studies[21]. The following parameters were evaluated: teeth randomization, teeth free from caries, adherence to manufacturer's instructions, teeth with similar dimensions, simulation of the periodontal ligament, single operator, blinding of the operator, and sample size calculation. Based on this, the risk of bias was judged as high, moderate, or low.

If the authors reported the parameter in question, the study receive a “Y” (yes or low risk) on that specific parameter. If the parameter was not reported or it was not possible to find the information, the paper received “N” (no or high risk). Accordingly, the study was classified as either having a high risk of bias (reported only 1-3 parameters), moderate risk of bias (reported 4-6 parameters), or low risk of bias (reported 7 or 8 parameters).

2.6. *Statistical analysis*

Statistical analysis was performed using the Review Manager software (RevMan Version 5.3.; The Cochrane Collaboration, 2014). Meta-analyses were conducted using Cohen's d as a measure of the effect size by calculating the standardized mean difference (SMD) for the groups along with 95% confidence intervals (CIs). Heterogeneity was evaluated using the chi-square test and I^2 statistics. The fixed-effects model was used for low/moderate heterogeneity ($I^2 \leq 50\%$), while the random-effects model was applied for significant

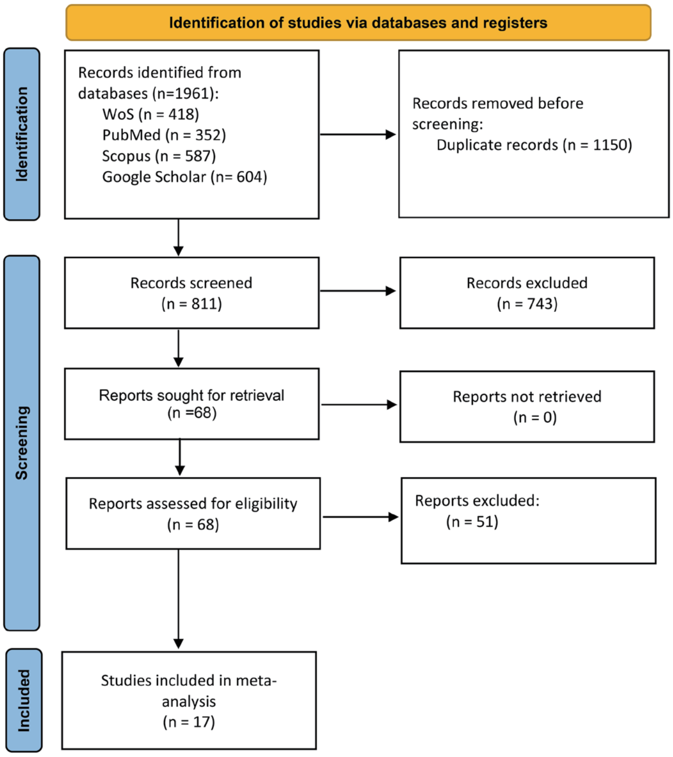


Fig. 1. Flowchart of the search strategy

heterogeneity ($P < 0.10$ and $I^2 > 50\%$)[22,23]. Potential publication bias was assessed using funnel plots and Egger's test. For the two studies[24,25], the median, mean, and SD were calculated based on the median, range, and sample size, according to the formulas suggested by Hozo et al.[26]. A P-value less than 0.05 was considered significant for all tests.

3. Results

Figure 1 illustrates the search strategy used in the review process. A total of 1961 studies were identified from the search databases (**Table S1**). In the first round of review, 1150 records were removed as duplicates, and the remaining 811 records were assessed based on titles and abstracts. Furthermore, 743 records were excluded as they were irrelevant. In the second round of review, the full texts of the remaining 68 studies were extracted and screened for eligibility. Of these, 51 studies were excluded as ineligible (**Table S2**). Finally, 17 studies were included in the qualitative and quantitative analysis[11,13–17,19,24,25,27–34].

3.1. Characteristics of the included studies

Table 1 shows the characteristics of the 17 in vitro studies included in this analysis. Regarding the type of teeth, eight used maxillary incisors[11,14–16,24,30,31,34], four used mandibular premolars[17,28,32,33], two used maxillary anterior teeth[19,25], one study used maxillary canines[29], one study used maxillary canines and mandibular premolars[13], and another study used different types of teeth in the same group[27]. A total of 848 teeth were used in these studies to determine the parameters of interest. The sample size for each group ranged from 7 to 12 teeth, with most studies using 10 teeth in each group (**Table 2**). Six studies used glass fiber posts[13,14,17,24,28,32], four used quartz fiber posts[16,19,25,29], three used fiber posts without mentioning the type[30,33,34], and four used cast posts[11,15,27,31]. Nine studies used metal crowns, two used all-ceramic crowns, two used metal copings, and three did not report the type of crown. The loading angle ranged from 25° to 135°, with most studies used 135° loading angle. The cross-head ranged from 0.5 to 10 mm/min, with most studies using 1 mm/min, one study used 2.5 mm/min, and another study using a speed of 10 mm/min. Regarding the failure mode, three studies did not report the failure mode, whereas 14 studies reported the failure mode of fracture with different assessment criteria. The additional details are provided in **Table 2**.

3.2. Outcome measures

Only tested groups related to the objectives of the review were selected for the analysis. In total, 85 groups were independently tested. Three studies[24,30,33] compared only a 2 mm circular ferrule (positive control) with different PF designs, twelve studies[11,13–17,19,25,28,29,31,34] compared 2 mm circular ferrule (positive control) and NF (negative control) with different PF designs, and two studies[27,32] compared only NF (negative control) with different PF designs. In relation to the PF design, eight studies used either buccal or lingual walls[11,16,17,19,24,28,30,31,34]; four studies[15,25,29,33] used either buccal, lingual, or proximal walls; one study[14] used only one proximal wall with different heights; one study[13] used a uniform ferrule (2 mm) except 0.5mm height at the buccal, lingual, or proximal walls; and one study[27] used only buccal walls with different heights.

Eight studies[11,13–15,28,29,31,34] showed that the 2 mm CF (positive control) was the best, six studies[19,24,25,27,30,33] showed that PF (including different designs) was the best, while only three studies[16,17,32] showed no significant effect of the ferrule design. All studies reported fracture resistance in newtons(N). Thirteen studies reported the mean and standard deviation, while two studies reported the median and range. The recorded force ranged from 130.01N (NF) to 1181.66N (CF). Only one study showed a higher value in the negative control group; however, the difference was not significant.

3.3. Quality assessment and risk of bias

Table 3 summarizes the results of the quality evaluation. In brief, eight studies were graded as having a moderate risk of bias, and the other nine studies were graded as having a high risk of bias. Most methodological flaws were related to the criteria of "Endodontic treatment performed by a single operator," "Sample size calculation" and "Blinding of the operator of the testing machine."

3.4. Meta-analysis results:

Four models of meta-analysis were performed to investigate possible methods of comparison as follows:

3.4.1. 2 mm CF vs. PF:

Fifteen studies were included in the model. Overall, the 2 mm CF group showed significantly higher fracture resistance than the PF group (SMD= 0.93, $CI_{95\%}$= 0.57-1.29, $P< 0.00001$). The result was the same for subgroup analysis based on the type of teeth (SMD= 0.99, $P< 0.0001$ and SMD= 0.76, $P= 0.006$ for anterior and premolar

Table 1. Characterizations of the included studies

Study	Sample size	Ferrule configuration	Fracture resistance	Conclusion
Sulaiman et al.,	Mand. premolars	Buccal wall (2 mm)	472.9 ± 101.4	2 mm ferrule on the lingual side was the best (P< 0.003).
2021	(N= 50)	Lingual wall (2 mm)	723.5 ± 181.3	
Malaysia	(n=10 each group)	Mesial wall (2 mm)	598.1 ± 96.4	
		Distal wall (2 mm)	559.1 ± 129.5	
		Complete ferrule (2 mm)	591.3 ± 149.7	
Pantaleon et al.,	Max. incisors	One proximal wall (1 mm)	469 ± 72	2 mm complete circular ferrule was the best (P< 0.05).
2019	(N= 60 teeth)	One proximal wall (2 mm)	494 ± 137	
Dominican	(n = 10 each group)	One proximal wall (3 mm)	514 ± 117	
		One proximal wall (4 mm)	557 ± 177	
		Complete ferrule (2 mm)	707 ± 162	
		Non-ferrule (0 mm)	355 ± 34	
Elavarasu et al.,	Max. incisors	Buccal (2 mm) & lingual (3 mm) walls	1019.00 ± 52.56	2 mm complete circular ferrule was the best (P< 0.001).
2019	(N= 28 teeth)	Buccal (2 mm) & lingual (4 mm) walls	971.59 ± 66.52	
India	(n = 7 each group)	Complete ferrule (2 mm)	1181.66 ± 68.3	
		Non-ferrule (0 mm)	888.0 ± 60.57	
Pantaleon et al.,	Max. incisors	Buccal (2 mm) & lingual (2 mm) walls	697 ± 165	2 mm complete circular ferrule was the best (P< 0.05).
2018	(N= 50 teeth)	Buccal (3 mm) & lingual (3 mm) walls	844 ± 143	
Dominican	(n = 10 each group)	Buccal (4 mm) & lingual (3 mm) walls	853 ± 115	
		Complete ferrule (2 mm)	932 ± 236	
		No ferrule (0 mm)	494 ± 110	
Haralur et al.,	Max. canines	**Canines**		2 mm complete circular ferrule was the best (P< 0.001).
2018	(N= 50)	Uniform (2 mm) except 0.5 height at lingual wall	656.79 ± 37.89	
KSA	Mand. premolars	Uniform (2 mm) except 0.5 height at buccal wall	742.64 ± 51.69	
	(N= 50)	Uniform (2 mm) except 0.5 height at proximal wall	773.63 ± 49.29	
	(n= 10 each group)	Complete ferrule (2 mm)	821.56 ± 46.54	
		Non-ferrule (0 mm)	566.63 ± 47.59	
		Premolars		
		Uniform (2 mm) except 0.5 height at lingual wall	586.65 ± 33.26	
		Uniform (2 mm) except 0.5 height at buccal wall	662.04 ± 32.29	
		Uniform (2 mm) except 0.5 height at proximal wall	679.34 ± 27.09	
		Complete ferrule (2 mm)	730.75 ± 27.91	
		Non-ferrule (0 mm)	500.90 ± 25.05	
Jasim et al.,	Max. canines	Palatal wall 180° (2mm)	747.7 ± 149.20	2 mm complete circular ferrule was the best (P< 0.05).
2016	(N= 50)	Labial wall 180° (2mm)	347.3 ± 137.22	
Iraq	(n= 10 each group)	Proximal wall 180° (2mm)	386.6 ± 128.55	
		Complete ferrule (2 mm)	803.7 ± 170.63	
		Non-ferrule (0 mm)	186.7 ± 125.54	
Dua et al.,	Mand. premolars	Buccal wall (2 mm)	855 ± 88.53	2 mm complete circular ferrule was the best (P< 0.001)
2016	(N= 50)	Lingual wall (2 mm)	720.40 ± 105.36	
India	(n= 10 each group)	Buccal & lingual walls (2 mm)	733.20 ± 160.97	
		Complete ferrule (2 mm)	923.20 ± 177.07	
		Non-ferrule (0 mm)	276.55 ± 53.59	
Zhang et al.,	Max. incisors	Buccal (1 mm) & lingual (0 mm) walls	167.32 ± 46.20	2 mm complete circular ferrule was the best (P< 0.05).
2015	(N= 60 teeth)	Buccal (2 mm) & lingual (0 mm) walls	203.56 ± 67.93	
China	(n= 10 each group)	Buccal (0 mm) & lingual (1 mm) walls	280.24 ± 59.26	
		Buccal (0 mm) & lingual (2 mm) walls	380.17 ± 87.35	
		Complete ferrule (2 mm)	532.82 ± 126.42	
		Non-ferrule (0 mm)	130.01 ± 30.31	
Samran et al.,	Mand. premolars	Buccal wall (2 mm)	826.6 ± 193.9	No significant differences were found among the groups (P> 0.05).
2015	(N= 60)	Lingual wall (2 mm)	930.3 ± 259.4	
Germany	(n= 12 each group)	Buccal & lingual walls (2 mm)	795.2 ± 245.5	
		Complete ferrule (2 mm)	856.9 ± 235.9	
		Non-ferrule (0 mm)	791.1 ± 234.3	

Table 1. Continued

Study	Sample size	Ferrule configuration	Fracture resistance	Conclusion
Muangamphan et al., 2015	Max. anteriors	Buccal wall (2 mm)	454.74 ± 57.89	labial, mesial, and palatal ferrule was the best (P < 0.01).
	(N= 60 teeth)	Lingual wall (2 mm)	545.72 ± 91.58	
Thailand	(n = 10 each group)	Buccal & lingual walls (2 mm)	735.98 ± 191.14	
		Buccal, lingual, & mesial walls (2 mm)	778.14 ± 224.81	
		Complete ferrule (2 mm)	668.92 ± 170.49	
		Non-ferrule (0 mm)	425.42 ± 141.07	
Sherfudhin et al., 2011	Mand. premolars	Buccal (2 mm) & lingual (1 mm) walls	952.8 ± 246	No significant differences were found among the groups (P= 0.780).
	(N= 30)	Buccal (3 mm) & lingual (2 mm) walls	909.2 ± 226	
KSA	(n= 10 each group)	Non-ferrule (0 mm)	996.7 ± 279	
Izadi et al.,	Max. incisors	Buccal wall (2 mm)	828.90 ± 118.27	2 mm facial ferrule was the best (P= 0.006)
2010	(N= 40 teeth)	Lingual wall (2 mm)	634.75 ± 133.35	
Iran	(n = 10 each group)	Buccal & lingual walls (2 mm)	678.78 ± 160.24	
		Complete ferrule (2 mm)	533.79 ± 232.28	
Dikbas et al.,	Max. incisors	Buccal wall (2 mm)	489.2 ± 179.4	No significant differences were found among the groups (P> 0.05).
2007	(N= 50 teeth)	Lingual wall (2 mm)	474.4 ± 139.5	
Turkey	(n = 10 each group)	Buccal & lingual walls (2 mm)	460.3 ± 136	
		Complete ferrule (2 mm)	544.2 ± 269.5	
		Non-ferrule (0 mm)	313.9 ± 150.8	
Naumann et al.,	Max. incisors	Buccal wall (2 mm)	899 (396-1176)	2 mm facial ferrule was the best (P= 0.014).
2006	(N= 40 teeth)	Lingual wall (2 mm)	658 (280-827)	
Germany	(n = 10 each group)	Buccal & lingual walls (2 mm)	360 (279-646)	
		Complete ferrule (2 mm)	502 (326-561)	
Ng et al.,	Max. anteriors	Palatal wall 180° (2mm)	782 (726-838)	Partial 180° palatal ferrule was the best (P< 0.001).
2006	(N= 50 teeth)	Labial wall 180° (2mm)	358 (327-389)	
USA	(n = 10 each group)	Proximal wall 180° (2mm)	375 (352-398)	
		Complete ferrule (2 mm)	607 (443-771)	
		Non-ferrule (0 mm)	172 (158-186)	
Tan et al.,	Max. incisors	Buccal, lingual (2 mm), and proximal (0.5 mm) walls	427 ± 88	2 mm complete circular ferrule was the best (P< 0.001).
2005	(N= 30 teeth)	Complete ferrule (2 mm)	587 ± 110	
USA	(n = 10 each group)	Non-ferrule (0 mm)	583.67 ± 86.09	
Al-Wahadni et al.,	Max. incisors	Buccal wall (3 mm)	271 ± 79.99	
2002 Jordan	Max. & Mand. canines and premolars	Buccal wall (4 mm) Buccal wall (5 mm)	238 ± 57.51 238.60 ± 43.43	3 mm buccal ferrule was the best (P= 0.024)
		Non-ferrule (0 mm)	209.20 ± 46.20	
	(N= 40 teeth)			
	(n = 10 each group)			

teeth, respectively). The subgroup analysis showed no significant difference between the anterior and premolar teeth (P= 0.52) (**Fig. 2**).

3.4.2. 2 mm CF vs. 2 mm buccal, lingual, and buccal & lingual partial ferrule:

Eight studies were included in this analysis. The test for overall effect revealed no significant difference (P= 0.06) in fracture resistance between 2 mm CF vs. 2 mm buccal, lingual, and buccal and lingual partial ferrule. The results were also the same for each category (P= 0.17 for the comparison with the 2 mm buccal ferrule, P= 0.68 for the comparison with the 2 mm lingual ferrule, and P= 0.13 for the comparison with the 2 mm buccal & lingual ferrule) (**Fig. 3**).

3.4.3. NF vs. PF

Two models are used in this study. Fourteen studies were included in the first model to compare the overall effects. However, for subgroup analysis (anterior vs. posterior) in the second model, one study was excluded because different types of teeth were used in the same group. The test for overall effect in the first model showed significantly higher fracture resistance of PF than NF (SMD= 2.02, $CI_{95\%}$= 1.54-2.49, P< 0.00001) (**Fig. 4**). In the second model, PF also showed significantly higher fracture resistance compared to NF for both anterior and premolar teeth, with no significant difference between the groups (P= 0.49) (**Fig. 5**).

3.5. Heterogeneity and Publication bias

All the tested models showed high heterogeneity levels, ranging from 53% to 92%. Qualitative funnel plots and quantitative Egger's

Table 2. Additional characterizations and experiment parameters of the included studies

Study	Type of post	Type of crown	Loading angle	Cross-head speed	Fracture mode
Sulaiman et al., 2021	Fiber post	Metal crown	25°	0.5 mm/min	Yes
Pantaleon et al., 2019	Fiber post	Metal crown	45°	0.5 mm/min	Yes
Elavarasu et al., 2019	Cast post	NA	135°	1 mm/min	No
Pantaleon et al., 2018	Cast post	Metal crown	45°	0.5 mm/min	Yes
Haralur et al., 2018	Fiber post	Metal coping	130° canines 45° premolars	0.5 mm/min	No
Jasim et al., 2016	Fiber post	Metal crown	135°	0.5 mm/min	Yes
Dua et al., 2016	Fiber post	Metal crown	160	1 mm/min	Yes
Samran et al., 2015	Fiber post	Metal crown	30	1 mm/min	Yes
Muangamphan et al., 2015	Fiber post	Metal crown	135°	1 mm/min	Yes
Zhang et al., 2015	Fiber post	Metal coping	45°	0.5 mm/min	Yes
Sherfudhin et al., 2011	Fiber post	Ceramic crown	45°	1 mm/min	Yes
Izadi et al. 2010	Fiber post	NA	135°	1 mm/min	Yes
Dikbas et al., 2007	Fiber post	Metal crown	135°	1 mm/min	Yes
Naumann et al., 2006	Fiber post	Ceramic crown	135°	1 mm/min	Yes
Ng et al., 2006	Fiber post	Metal crown	135°	0.5 mm/min	Yes
Tan et al., 2005	Cast post	Metal crown	45°	2.5 mm/min	Yes
Al-Wahadni et al., 2002	Cast post	NA	130°	10 mm/min	No

Table 3. Assessment of risk of bias of the included studies

N	Study	Teeth Randomization	Teeth Free of Caries or Restoration	Materials Used According to the Manufacturer's Instructions	Teeth With Similar Dimensions	Simulation of periodontal ligament	Endodontic Treatment Performed by a Single operator	Sample Size Calculation	Blinding of the Operator of the Testing Machine	Risk of Bias
1	Sulaiman et al., 2021	Y	Y	N	Y	Y	N	N	N	Moderate
2	Pantaleon et al., 2019	N	Y	Y	Y	N	N	Y	N	Moderate
3	Elavarasu et al., 2019	Y	Y	N	Y	N	N	N	N	High
4	Pantaleon et al., 2018	N	Y	Y	Y	N	N	N	N	High
5	Haralur et al., 2018	Y	Y	N	N	Y	N	N	N	High
6	Jasim et al., 2016	Y	Y	Y	Y	N	Y	N	N	Moderate
7	Dua et al., 2016	N	Y	N	Y	Y	N	N	N	High
8	Samran et al., 2015	N	N	Y	Y	Y	N	N	N	High
9	Muangamphan et al., 2015	N	Y	N	Y	Y	N	N	N	High
10	Zhang et al., 2015	Y	Y	Y	Y	Y	N	N	N	Moderate
11	Sherfudhin et al., 2011	Y	Y	Y	Y	Y	N	N	N	Moderate
12	Izadi et al., 2010	Y	Y	N	Y	Y	N	N	N	Moderate
13	Dikbas et al., 2007	N	Y	N	Y	Y	N	N	N	High
14	Naumann et al., 2006	Y	Y	Y	Y	Y	N	N	N	Moderate
15	Ng et al., 2006	Y	Y	N	N	N	N	N	N	High
16	Tan et al., 2005	Y	Y	N	Y	N	Y	N	Y	Moderate
17	Al-Wahadni et al., 2002	N	Y	N	Y	N	N	N	N	High

tests showed publication bias among the studies for all comparisons (**Figs. 6A and B**).

4. Discussion

The impact of PF on the fracture resistance of ETT has been a subject of debate for many years[14,35–37]. Hence, the present meta-analysis sought to investigate the effect of PF on the fracture resistance of ETT in comparison with that of CF and/or NF. The results of the present meta-analysis revealed that CF is more effective in reducing fractures than PF; however, the subgroup analysis found that some PFs (buccal 2 mm, lingual 2 mm, and buccal and lingual 2 mm) were comparable to CF. Additionally, the results revealed that PF significantly increased fracture resistance as compared to NF.

A key finding of the present study was that CF was superior to PF in terms of fracture resistance. This finding supports a previous systematic review and meta-analysis[10], which reported that CF

Study or Subgroup	Partial Mean	Partial SD	Partial Total	Complete Mean	Complete SD	Complete Total	Weight	Std. Mean Difference IV, Random, 95% CI
1.2.1 Anterior								
Dikbas et al., 2007	474.4	139.5	10	544.2	269.5	10	2.2%	-0.31 [-1.19, 0.57]
Dikbas et al., 2007	460.3	136	10	544.2	269.5	10	2.2%	-0.38 [-1.26, 0.51]
Dikbas et al., 2007	489.2	179.4	10	544.2	269.5	10	2.2%	-0.23 [-1.11, 0.65]
Elavarasu et al., 2019	1,019	52.56	7	1,181.66	68.3	7	1.7%	-2.50 [-4.01, -0.99]
Elavarasu et al., 2019	971.59	66.52	7	1,181.66	68.3	7	1.6%	-2.92 [-4.57, -1.27]
Haralur et al., 2018	656.79	37.89	10	821.56	46.54	10	1.7%	-3.72 [-5.28, -2.16]
Haralur et al., 2018	742.64	51.69	10	821.56	46.54	10	2.1%	-1.54 [-2.56, -0.51]
Haralur et al., 2018	773.63	49.29	10	821.56	46.54	10	2.1%	-0.96 [-1.89, -0.02]
Izadi et al., 2010	634.75	133.35	10	533.79	232.28	10	2.2%	0.51 [-0.38, 1.40]
Izadi et al., 2010	678.78	160.24	10	533.79	232.28	10	2.2%	0.70 [-0.21, 1.60]
Izadi et al., 2010	828.9	118.27	10	533.79	232.28	10	2.1%	1.53 [0.51, 2.56]
Jasim et al., 2016	386.6	128.55	10	803.7	170.63	10	1.9%	-2.64 [-3.91, -1.38]
Jasim et al., 2016	747.7	149.2	10	803.7	170.63	10	2.2%	-0.33 [-1.22, 0.55]
Jasim et al., 2016	347.3	137.22	10	803.7	170.63	10	1.9%	-2.82 [-4.14, -1.51]
Muangamphan et al., 2015	778.14	224.81	10	668.92	170.49	10	2.2%	0.52 [-0.37, 1.42]
Muangamphan et al., 2015	735.98	191.14	10	668.92	170.49	10	2.2%	0.35 [-0.53, 1.24]
Muangamphan et al., 2015	545.72	91.58	10	668.92	170.49	10	2.1%	-0.86 [-1.79, 0.06]
Muangamphan et al., 2015	454.74	57.89	10	668.92	170.49	10	2.1%	-1.61 [-2.65, -0.57]
Naumann et al., 2006	836.9	227.5	10	469.8	69.9	10	2.0%	2.09 [0.95, 3.23]
Naumann et al., 2006	416.4	110	10	469.8	69.9	10	2.2%	-0.55 [-1.45, 0.34]
Naumann et al., 2006	600.5	160.8	10	469.8	69.9	10	2.1%	1.01 [0.07, 1.95]
Ng CC. et al., 2006	358	17.9	10	607	94.7	10	1.7%	-3.50 [-4.99, -2.01]
Ng CC. et al., 2006	782	32.3	10	607	94.7	10	1.9%	2.37 [1.17, 3.57]
Ng CC. et al., 2006	375	13.3	10	607	94.7	10	1.8%	-3.29 [-4.72, -1.85]
Pantaleon et al., 2018	697	165	10	932	236	10	2.1%	-1.11 [-2.06, -0.15]
Pantaleon et al., 2018	844	143	10	932	236	10	2.2%	-0.43 [-1.32, 0.46]
Pantaleon et al., 2018	853	115	10	932	236	10	2.2%	-0.41 [-1.30, 0.48]
Pantaleon et al., 2019	514	117	10	707	162	10	2.1%	-1.31 [-2.29, -0.32]
Pantaleon et al., 2019	494	137	10	707	162	10	2.1%	-1.36 [-2.35, -0.37]
Pantaleon et al., 2019	469	72	10	707	162	10	2.0%	-1.82 [-2.90, -0.74]
Pantaleon et al., 2019	557	177	10	707	162	10	2.1%	-0.85 [-1.77, 0.08]
Tan et al., 2005	427	88	10	587	110	10	2.1%	-1.54 [-2.56, -0.51]
Zhang et al., 2015	380.17	87.35	10	532.82	126.42	10	2.1%	-1.35 [-2.34, -0.35]
Zhang et al., 2015	167.32	46.2	10	532.82	126.42	10	1.7%	-3.68 [-5.22, -2.13]
Zhang et al., 2015	203.56	67.93	10	532.82	126.42	10	1.8%	-3.11 [-4.49, -1.72]
Zhang et al., 2015	280.24	59.26	10	532.82	126.42	10	1.9%	-2.45 [-3.67, -1.23]
Subtotal (95% CI)			**354**			**354**	**72.8%**	**-0.99 [-1.44, -0.54]**
Heterogeneity: Tau² = 1.60; Chi² = 235.58, df = 35 (P < 0.00001); I² = 85%								
Test for overall effect: Z = 4.29 (P < 0.0001)								
1.2.2 Posterior								
Dua et al., 2016	855	88.53	10	923.2	177.07	10	2.2%	-0.47 [-1.36, 0.42]
Dua et al., 2016	720.4	105.36	10	923.2	177.07	10	2.1%	-1.33 [-2.32, -0.34]
Dua et al., 2016	733.2	160.97	10	923.2	177.07	10	2.1%	-1.08 [-2.03, -0.12]
Haralur et al., 2018	586.65	33.26	10	730.75	27.91	10	1.5%	-4.50 [-6.28, -2.71]
Haralur et al., 2018	662.04	32.29	10	730.75	27.91	10	2.0%	-2.18 [-3.34, -1.02]
Haralur et al., 2018	679.34	27.09	10	730.75	27.91	10	2.0%	-1.79 [-2.86, -0.72]
Samran et al., 2015	826.6	193.9	12	856.9	235.9	12	2.2%	-0.14 [-0.94, 0.67]
Samran et al., 2015	795.2	245.5	12	856.9	235.9	12	2.2%	-0.25 [-1.05, 0.56]
Samran et al., 2015	930.3	259.4	12	856.9	235.9	12	2.2%	0.29 [-0.52, 1.09]
Sulaiman et al., 2021	723.5	181.3	10	591.3	149.7	10	2.1%	0.76 [-0.15, 1.68]
Sulaiman et al., 2021	472.9	101.4	10	591.3	149.7	10	2.1%	-0.89 [-1.82, 0.04]
Sulaiman et al., 2021	559.1	129.5	10	591.3	149.7	10	2.2%	-0.22 [-1.10, 0.66]
Sulaiman et al., 2021	598.1	96.4	10	591.3	149.7	10	2.2%	0.05 [-0.82, 0.93]
Subtotal (95% CI)			**136**			**136**	**27.2%**	**-0.76 [-1.30, -0.21]**
Heterogeneity: Tau² = 0.75; Chi² = 51.61, df = 12 (P < 0.00001); I² = 77%								
Test for overall effect: Z = 2.73 (P = 0.006)								
Total (95% CI)			**490**			**490**	**100.0%**	**-0.93 [-1.29, -0.57]**
Heterogeneity: Tau² = 1.32; Chi² = 288.29, df = 48 (P < 0.00001); I² = 83%								
Test for overall effect: Z = 5.12 (P < 0.00001)								
Test for subgroup differences: Chi² = 0.41, df = 1 (P = 0.52), I² = 0%								

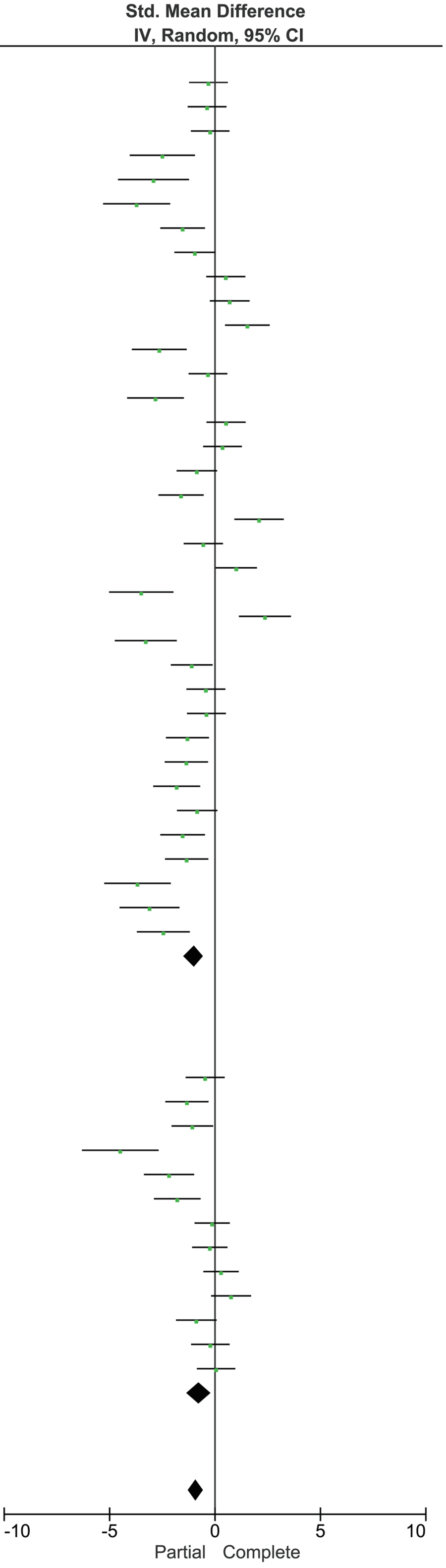
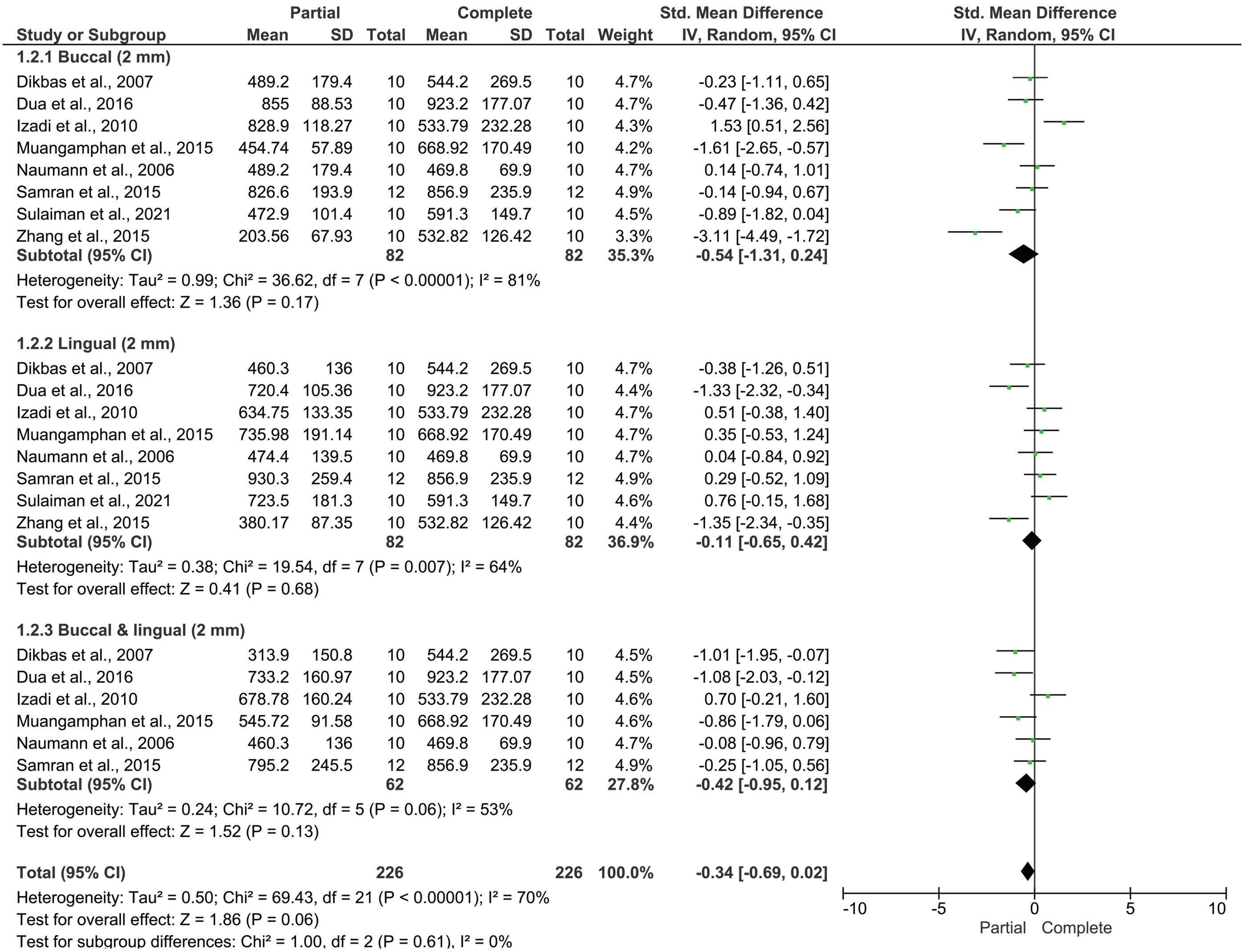


Fig. 2. Forest plot of the included studies for the comparison between 2 mm CF vs. partial ferrule

was very effective in increasing the fracture resistance of ETT. Additionally, many clinical studies have reported better survival rates for ETT with CF compared to those with NF[38–40]. The superiority of CF could be explained by the following: the placement of the crown margin on sound dentin around the tooth allowed for greater dissipation of occlusal force, and the presence of sufficient circumfer-



Study or Subgroup	Partial Mean	Partial SD	Partial Total	Complete Mean	Complete SD	Complete Total	Weight	Std. Mean Difference IV, Random, 95% CI
1.2.1 Buccal (2 mm)								
Dikbas et al., 2007	489.2	179.4	10	544.2	269.5	10	4.7%	-0.23 [-1.11, 0.65]
Dua et al., 2016	855	88.53	10	923.2	177.07	10	4.7%	-0.47 [-1.36, 0.42]
Izadi et al., 2010	828.9	118.27	10	533.79	232.28	10	4.3%	1.53 [0.51, 2.56]
Muangamphan et al., 2015	454.74	57.89	10	668.92	170.49	10	4.2%	-1.61 [-2.65, -0.57]
Naumann et al., 2006	489.2	179.4	10	469.8	69.9	10	4.7%	0.14 [-0.74, 1.01]
Samran et al., 2015	826.6	193.9	12	856.9	235.9	12	4.9%	-0.14 [-0.94, 0.67]
Sulaiman et al., 2021	472.9	101.4	10	591.3	149.7	10	4.5%	-0.89 [-1.82, 0.04]
Zhang et al., 2015	203.56	67.93	10	532.82	126.42	10	3.3%	-3.11 [-4.49, -1.72]
Subtotal (95% CI)			**82**			**82**	**35.3%**	**-0.54 [-1.31, 0.24]**
Heterogeneity: Tau² = 0.99; Chi² = 36.62, df = 7 (P < 0.00001); I² = 81%								
Test for overall effect: Z = 1.36 (P = 0.17)								
1.2.2 Lingual (2 mm)								
Dikbas et al., 2007	460.3	136	10	544.2	269.5	10	4.7%	-0.38 [-1.26, 0.51]
Dua et al., 2016	720.4	105.36	10	923.2	177.07	10	4.4%	-1.33 [-2.32, -0.34]
Izadi et al., 2010	634.75	133.35	10	533.79	232.28	10	4.7%	0.51 [-0.38, 1.40]
Muangamphan et al., 2015	735.98	191.14	10	668.92	170.49	10	4.7%	0.35 [-0.53, 1.24]
Naumann et al., 2006	474.4	139.5	10	469.8	69.9	10	4.7%	0.04 [-0.84, 0.92]
Samran et al., 2015	930.3	259.4	12	856.9	235.9	12	4.9%	0.29 [-0.52, 1.09]
Sulaiman et al., 2021	723.5	181.3	10	591.3	149.7	10	4.6%	0.76 [-0.15, 1.68]
Zhang et al., 2015	380.17	87.35	10	532.82	126.42	10	4.4%	-1.35 [-2.34, -0.35]
Subtotal (95% CI)			**82**			**82**	**36.9%**	**-0.11 [-0.65, 0.42]**
Heterogeneity: Tau² = 0.38; Chi² = 19.54, df = 7 (P = 0.007); I² = 64%								
Test for overall effect: Z = 0.41 (P = 0.68)								
1.2.3 Buccal & lingual (2 mm)								
Dikbas et al., 2007	313.9	150.8	10	544.2	269.5	10	4.5%	-1.01 [-1.95, -0.07]
Dua et al., 2016	733.2	160.97	10	923.2	177.07	10	4.5%	-1.08 [-2.03, -0.12]
Izadi et al., 2010	678.78	160.24	10	533.79	232.28	10	4.6%	0.70 [-0.21, 1.60]
Muangamphan et al., 2015	545.72	91.58	10	668.92	170.49	10	4.6%	-0.86 [-1.79, 0.06]
Naumann et al., 2006	460.3	136	10	469.8	69.9	10	4.7%	-0.08 [-0.96, 0.79]
Samran et al., 2015	795.2	245.5	12	856.9	235.9	12	4.9%	-0.25 [-1.05, 0.56]
Subtotal (95% CI)			**62**			**62**	**27.8%**	**-0.42 [-0.95, 0.12]**
Heterogeneity: Tau² = 0.24; Chi² = 10.72, df = 5 (P = 0.06); I² = 53%								
Test for overall effect: Z = 1.52 (P = 0.13)								
Total (95% CI)			**226**			**226**	**100.0%**	**-0.34 [-0.69, 0.02]**
Heterogeneity: Tau² = 0.50; Chi² = 69.43, df = 21 (P < 0.00001); I² = 70%								
Test for overall effect: Z = 1.86 (P = 0.06)								
Test for subgroup differences: Chi² = 1.00, df = 2 (P = 0.61), I² = 0%								

Fig. 3. Forest plot of the included studies for the comparison between 2 mm CF vs. 2 mm buccal, lingual, and buccal & lingual partial ferrule

ential coronal dentin could improve the stability of the post and core and increase its resistance to rotation[15]. Tooth without ferrule can increase the stress at the root cement/post interfaces. Therefore, the lower resistance to fracture of teeth without ferrule is a consequence of both increased stress and tension in the root dentin and detachment of the post[41].

Interestingly, however, subgroup analyses demonstrated that some PF designs, such as buccal 2 mm, lingual 2 mm, buccal, and lingual 2 mm, were comparable to CF in increasing the fracture resistance of ETT, supporting the notion that some PFs can successfully increase the fracture resistance and longevity of restored ETT. These findings could be clinically significant for clinical decision making; that is, the circumferential ferrule can be considered as the first ideal solution for restoration of ETT; however, if this option is not possible for any reason, then the PF could be an appropriate alternative option. The in vivo direction of occlusal forces on teeth supports the aforementioned assumption, although it is based on the findings of in vitro studies. In posterior teeth, the direction of occlusal force is occlusogingival and bucolingual, which means that the absence of proximal ferrules does not have a negative effect on the longevity of the tooth. The palatal ferrule in maxillary anterior teeth can resist fractures because they are loaded from the palatal side, and when the palatal wall of the upper incisor is missing, the non-axial load from the palatal side in the maxillary anterior crown challenges the post/core/root junction. Mandibular anterior teeth are loaded from the buccal side; therefore, the buccal ferrule could be more resistant to fractures[25]. Furthermore, Tan (2005)[15] stated that maxillary central incisors with 2 mm buccal and lingual PF would possess sufficient fracture resistance to maximal clenching based on the recorded in vitro fracture resistance of 427 N[15].

The results of the present study support the positive effect of PF in improving the fracture resistance of ETT compared with NF. This finding is consistent with those of many studies[11,13,14,27,42]. The level of evidence obtained from any meta-analysis is primarily dependent on the quality of individual studies. Therefore, the quality of all the included studies was scrutinized by two independent reviewers using a validated assessment tool. Unfortunately, approximately half of the included studies showed poor quality, as reflected by the high risk of bias related to lack of blinding and absence of sample size calculation. This may have negatively affected the strength of

	Partial			None				Std. Mean Difference
Study or Subgroup	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Weight**	**IV, Random, 95% CI**
Al-Wahadni et al., 2002	238.6	43.43	10	209.2	46.2	10	2.6%	0.63 [-0.28, 1.53]
Al-Wahadni et al., 2002	271	79.99	10	209.2	46.2	10	2.6%	0.91 [-0.02, 1.84]
Al-Wahadni et al., 2002	238	57.51	10	209.2	46.2	10	2.6%	0.53 [-0.37, 1.42]
Dikbas et al., 2007	489.2	179.4	10	313.9	150.8	10	2.6%	1.01 [0.07, 1.96]
Dikbas et al., 2007	460.3	136	10	313.9	150.8	10	2.6%	0.98 [0.04, 1.92]
Dikbas et al., 2007	474.4	139.5	10	313.9	150.8	10	2.6%	1.06 [0.11, 2.01]
Dua et al., 2016	733.2	160.97	10	276.55	53.59	10	2.2%	3.65 [2.11, 5.18]
Dua et al., 2016	720.4	105.36	10	276.55	53.59	10	1.9%	5.09 [3.12, 7.05]
Dua et al., 2016	855	88.53	10	276.55	53.59	10	1.5%	7.57 [4.81, 10.33]
Elavarasu et al., 2019	1,019	52.56	7	888	60.57	7	2.3%	2.16 [0.75, 3.57]
Elavarasu et al., 2019	971.59	66.52	7	888	60.57	7	2.4%	1.23 [0.05, 2.41]
Haralur et al., 2018	679.34	27.09	10	500.9	25.05	10	1.6%	6.55 [4.12, 8.98]
Haralur et al., 2018	586.65	33.26	10	500.9	25.05	10	2.4%	2.79 [1.49, 4.09]
Haralur et al., 2018	662.04	32.29	10	500.9	25.05	10	1.9%	5.34 [3.30, 7.38]
Haralur et al., 2018	742.64	51.69	10	566.63	47.59	10	2.2%	3.39 [1.93, 4.86]
Haralur et al., 2018	773.63	49.29	10	566.63	47.59	10	2.1%	4.09 [2.43, 5.76]
Haralur et al., 2018	656.79	37.89	10	566.63	47.59	10	2.5%	2.01 [0.89, 3.13]
Jasim et al., 2016	747.7	149.2	10	186.7	125.54	10	2.2%	3.90 [2.29, 5.50]
Jasim et al., 2016	347.3	137.22	10	186.7	125.54	10	2.6%	1.17 [0.20, 2.13]
Jasim et al., 2016	386.6	128.55	10	186.7	125.54	10	2.5%	1.51 [0.49, 2.53]
Muangamphan et al., 2015	454.74	57.89	10	425.42	141.07	10	2.6%	0.26 [-0.62, 1.14]
Muangamphan et al., 2015	778.14	224.81	10	425.42	141.07	10	2.5%	1.80 [0.72, 2.88]
Muangamphan et al., 2015	545.72	91.58	10	425.42	141.07	10	2.6%	0.97 [0.03, 1.91]
Muangamphan et al., 2015	735.98	191.14	10	425.42	141.07	10	2.5%	1.77 [0.70, 2.84]
Ng CC. et al., 2006	782	32.3	10	172	8.1	10	0.3%	24.81 [16.19, 33.44]
Ng CC. et al., 2006	358	17.9	10	172	8.1	10	0.8%	12.82 [8.30, 17.34]
Ng CC. et al., 2006	375	13.3	10	172	8.1	10	0.5%	17.66 [11.49, 23.83]
Pantaleon et al., 2018	853	115	10	494	110	10	2.3%	3.06 [1.68, 4.43]
Pantaleon et al., 2018	697	165	10	494	110	10	2.5%	1.39 [0.39, 2.39]
Pantaleon et al., 2018	844	143	10	494	110	10	2.4%	2.63 [1.37, 3.89]
Pantaleon et al., 2019	469	72	10	355	34	10	2.5%	1.94 [0.84, 3.04]
Pantaleon et al., 2019	514	117	10	355	34	10	2.5%	1.77 [0.70, 2.84]
Pantaleon et al., 2019	557	177	10	355	34	10	2.5%	1.52 [0.50, 2.54]
Pantaleon et al., 2019	494	137	10	355	34	10	2.5%	1.33 [0.34, 2.32]
Samran et al., 2015	795.2	245.5	12	791.1	234.3	12	2.6%	0.02 [-0.78, 0.82]
Samran et al., 2015	930.3	259.4	12	791.1	234.3	12	2.6%	0.54 [-0.27, 1.36]
Samran et al., 2015	826.6	193.9	12	791.1	234.3	12	2.6%	0.16 [-0.64, 0.96]
Sherfudhin et al., 2015	952.8	246	10	996.7	279	10	2.6%	-0.16 [-1.04, 0.72]
Sherfudhin et al., 2015	909.2	226	10	996.7	279	10	2.6%	-0.33 [-1.21, 0.55]
Tan et al., 2005	427	88	10	583.67	86.09	10	2.5%	-1.72 [-2.78, -0.66]
Zhang et al., 2015	380.17	87.35	10	130.01	30.31	10	2.2%	3.66 [2.12, 5.21]
Zhang et al., 2015	203.56	67.93	10	130.01	30.31	10	2.5%	1.34 [0.35, 2.33]
Zhang et al., 2015	167.32	46.2	10	130.01	30.31	10	2.6%	0.91 [-0.02, 1.85]
Zhang et al., 2015	280.24	59.26	10	130.01	30.31	10	2.3%	3.06 [1.68, 4.43]
Total (95% CI)			**440**			**440**	**100.0%**	**2.02 [1.54, 2.49]**

Heterogeneity: Tau² = 2.04; Chi² = 312.17, df = 43 (P < 0.00001); I² = 86%
Test for overall effect: Z = 8.34 (P < 0.00001)

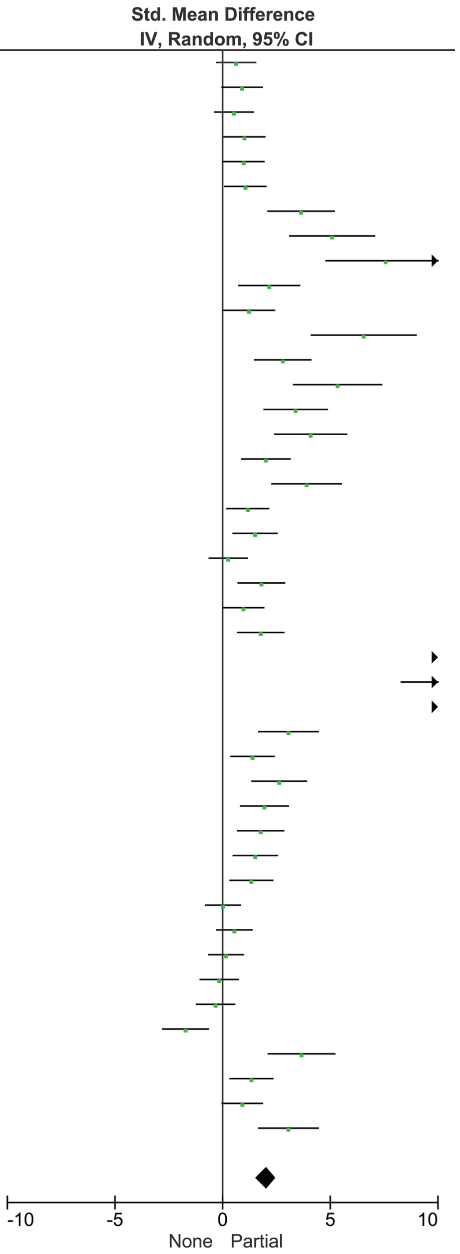
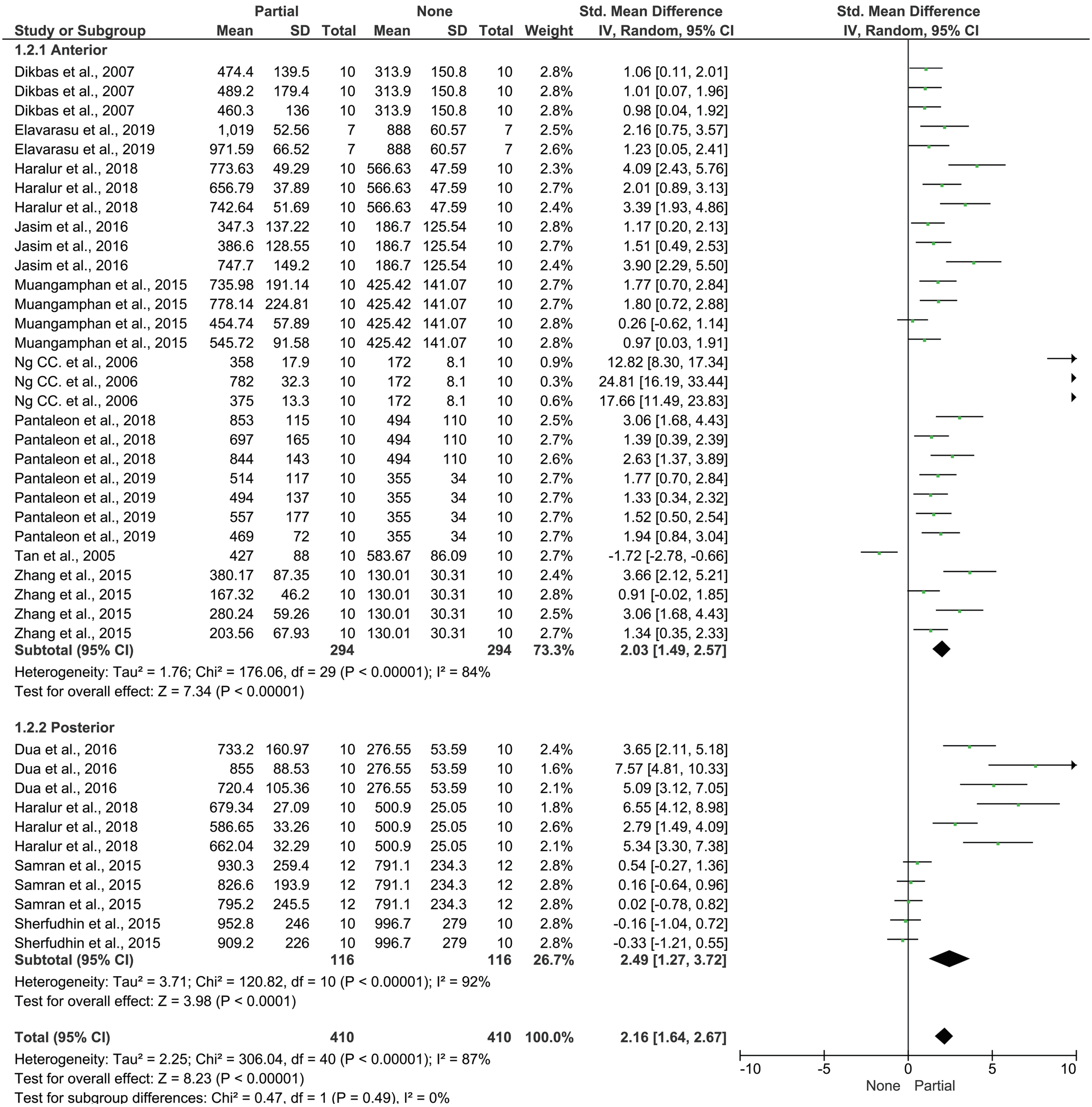


Fig. 4. Forest plot of the included studies for the comparison between no ferrule vs. partial ferrule

this meta-analysis. Moreover, significant publication bias is another factor that should be considered when interpreting and extrapolating results.

To the best of our knowledge, the current meta-analysis is the first to evaluate the effectiveness of PF in ETT fracture resistance. This meta-analysis has many strengths that should be highlighted. This study included a large number of studies (17 studies). In addition,, the effect of the ferrule was tested on both the anterior and premolar teeth. Finally, most of the included studies used both positive and negative control groups, further validating the results. However,, many limitations should be considered when interpreting the results. The main limitation is related to the huge heterogeneity among the studies with respect to the type of teeth being evaluated (anterior teeth, premolar teeth), type of post, as well as using different techniques to ascertain the fracture resistance test. Furthermore, in vitro studies do not simulate intraoral conditions in which teeth are subjected to cyclic loading through mastication. Moreover, the oral cavity has a different testing environment. For example, the presence of temperature changes, water, pH levels, and changes in the oral cavity may considerably affect outcomes. The assumption that all examined groups are comparable in all other aspects to clinical situations may not be valid but may directly influence future research.



Study or Subgroup	Partial Mean	Partial SD	Partial Total	None Mean	None SD	None Total	Weight	Std. Mean Difference IV, Random, 95% CI
1.2.1 Anterior								
Dikbas et al., 2007	474.4	139.5	10	313.9	150.8	10	2.8%	1.06 [0.11, 2.01]
Dikbas et al., 2007	489.2	179.4	10	313.9	150.8	10	2.8%	1.01 [0.07, 1.96]
Dikbas et al., 2007	460.3	136	10	313.9	150.8	10	2.8%	0.98 [0.04, 1.92]
Elavarasu et al., 2019	1,019	52.56	7	888	60.57	7	2.5%	2.16 [0.75, 3.57]
Elavarasu et al., 2019	971.59	66.52	7	888	60.57	7	2.6%	1.23 [0.05, 2.41]
Haralur et al., 2018	773.63	49.29	10	566.63	47.59	10	2.3%	4.09 [2.43, 5.76]
Haralur et al., 2018	656.79	37.89	10	566.63	47.59	10	2.7%	2.01 [0.89, 3.13]
Haralur et al., 2018	742.64	51.69	10	566.63	47.59	10	2.4%	3.39 [1.93, 4.86]
Jasim et al., 2016	347.3	137.22	10	186.7	125.54	10	2.8%	1.17 [0.20, 2.13]
Jasim et al., 2016	386.6	128.55	10	186.7	125.54	10	2.7%	1.51 [0.49, 2.53]
Jasim et al., 2016	747.7	149.2	10	186.7	125.54	10	2.4%	3.90 [2.29, 5.50]
Muangamphan et al., 2015	735.98	191.14	10	425.42	141.07	10	2.7%	1.77 [0.70, 2.84]
Muangamphan et al., 2015	778.14	224.81	10	425.42	141.07	10	2.7%	1.80 [0.72, 2.88]
Muangamphan et al., 2015	454.74	57.89	10	425.42	141.07	10	2.8%	0.26 [-0.62, 1.14]
Muangamphan et al., 2015	545.72	91.58	10	425.42	141.07	10	2.8%	0.97 [0.03, 1.91]
Ng CC. et al., 2006	358	17.9	10	172	8.1	10	0.9%	12.82 [8.30, 17.34]
Ng CC. et al., 2006	782	32.3	10	172	8.1	10	0.3%	24.81 [16.19, 33.44]
Ng CC. et al., 2006	375	13.3	10	172	8.1	10	0.6%	17.66 [11.49, 23.83]
Pantaleon et al., 2018	853	115	10	494	110	10	2.5%	3.06 [1.68, 4.43]
Pantaleon et al., 2018	697	165	10	494	110	10	2.7%	1.39 [0.39, 2.39]
Pantaleon et al., 2018	844	143	10	494	110	10	2.6%	2.63 [1.37, 3.89]
Pantaleon et al., 2019	514	117	10	355	34	10	2.7%	1.77 [0.70, 2.84]
Pantaleon et al., 2019	494	137	10	355	34	10	2.7%	1.33 [0.34, 2.32]
Pantaleon et al., 2019	557	177	10	355	34	10	2.7%	1.52 [0.50, 2.54]
Pantaleon et al., 2019	469	72	10	355	34	10	2.7%	1.94 [0.84, 3.04]
Tan et al., 2005	427	88	10	583.67	86.09	10	2.7%	-1.72 [-2.78, -0.66]
Zhang et al., 2015	380.17	87.35	10	130.01	30.31	10	2.4%	3.66 [2.12, 5.21]
Zhang et al., 2015	167.32	46.2	10	130.01	30.31	10	2.8%	0.91 [-0.02, 1.85]
Zhang et al., 2015	280.24	59.26	10	130.01	30.31	10	2.5%	3.06 [1.68, 4.43]
Zhang et al., 2015	203.56	67.93	10	130.01	30.31	10	2.7%	1.34 [0.35, 2.33]
Subtotal (95% CI)			**294**			**294**	**73.3%**	**2.03 [1.49, 2.57]**
Heterogeneity: Tau² = 1.76; Chi² = 176.06, df = 29 (P < 0.00001); I² = 84%								
Test for overall effect: Z = 7.34 (P < 0.00001)								
1.2.2 Posterior								
Dua et al., 2016	733.2	160.97	10	276.55	53.59	10	2.4%	3.65 [2.11, 5.18]
Dua et al., 2016	855	88.53	10	276.55	53.59	10	1.6%	7.57 [4.81, 10.33]
Dua et al., 2016	720.4	105.36	10	276.55	53.59	10	2.1%	5.09 [3.12, 7.05]
Haralur et al., 2018	679.34	27.09	10	500.9	25.05	10	1.8%	6.55 [4.12, 8.98]
Haralur et al., 2018	586.65	33.26	10	500.9	25.05	10	2.6%	2.79 [1.49, 4.09]
Haralur et al., 2018	662.04	32.29	10	500.9	25.05	10	2.1%	5.34 [3.30, 7.38]
Samran et al., 2015	930.3	259.4	12	791.1	234.3	12	2.8%	0.54 [-0.27, 1.36]
Samran et al., 2015	826.6	193.9	12	791.1	234.3	12	2.8%	0.16 [-0.64, 0.96]
Samran et al., 2015	795.2	245.5	12	791.1	234.3	12	2.8%	0.02 [-0.78, 0.82]
Sherfudhin et al., 2015	952.8	246	10	996.7	279	10	2.8%	-0.16 [-1.04, 0.72]
Sherfudhin et al., 2015	909.2	226	10	996.7	279	10	2.8%	-0.33 [-1.21, 0.55]
Subtotal (95% CI)			**116**			**116**	**26.7%**	**2.49 [1.27, 3.72]**
Heterogeneity: Tau² = 3.71; Chi² = 120.82, df = 10 (P < 0.00001); I² = 92%								
Test for overall effect: Z = 3.98 (P < 0.0001)								
Total (95% CI)			**410**			**410**	**100.0%**	**2.16 [1.64, 2.67]**
Heterogeneity: Tau² = 2.25; Chi² = 306.04, df = 40 (P < 0.00001); I² = 87%								
Test for overall effect: Z = 8.23 (P < 0.00001)								
Test for subgroup differences: Chi² = 0.47, df = 1 (P = 0.49), I² = 0%								

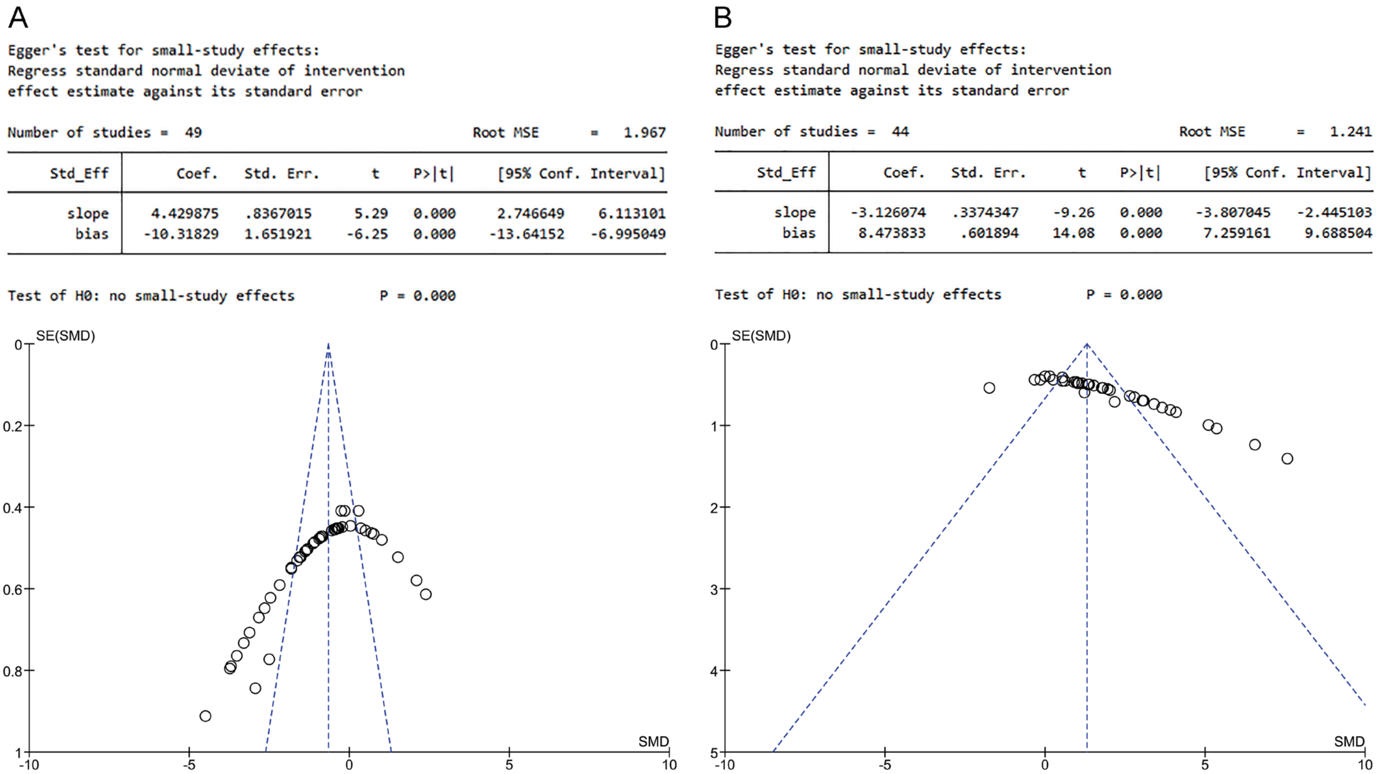
Fig. 5. Forest plot of the included studies for the subgroup analysis of no ferrule vs. partial ferrule

5. Conclusions

The results revealed that in ETT, CF was more effective in reducing the fracture than PF; however, the subgroup analysis found that some PFs were comparable to CF. Additionally, the results revealed that PF significantly increased the fracture resistance as compared to non-ferrule groups. However, given the high risk of bias in some of the included studies, further high-quality studies are required. Additionally, clinical studies are required to assess the effect of PF on the fracture resistance and longevity of ETT.

Protocol registration

The protocol for this meta-analysis was registered by the OSF (DOI 10.17605/OSF.IO/63UHK) and is publicly accessible.



A

```
Egger's test for small-study effects:
Regress standard normal deviate of intervention
effect estimate against its standard error

Number of studies =  49                          Root MSE      =   1.967

     Std_Eff       Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]

       slope    4.429875   .8367015     5.29   0.000     2.746649    6.113101
        bias   -10.31829   1.651921    -6.25   0.000    -13.64152   -6.995049

Test of H0: no small-study effects          P = 0.000
```

B

```
Egger's test for small-study effects:
Regress standard normal deviate of intervention
effect estimate against its standard error

Number of studies =  44                          Root MSE      =   1.241

     Std_Eff       Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]

       slope   -3.126074   .3374347    -9.26   0.000    -3.807045   -2.445103
        bias    8.473833    .601894    14.08   0.000     7.259161    9.688504

Test of H0: no small-study effects          P = 0.000
```

Fig. 6. A- Partial ferrule vs. complete ferrule - Funnel plot and Egger's test. B- Partial ferrule vs. no ferrule - Funnel plot (ALL) and Egger's test .

Funding support

No financial support was received by the authors to conduct this research.

Conflicts of interest

The authors declare no conflict of interest.

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