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Ferrule height influences fracture resistance and longevity in fiber post–crown restored endodontically treated teeth

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Abstract:
The ferrule effect is a key determinant of fracture resistance in endodontically treated teeth restored with posts and crowns. Therefore, it is of interest to evaluate the influence of ferrule heights of 0, 1, 2 and 3 mm on fracture resistance. Fiber posts and full-coverage crowns are used to assess restoration performance across different ferrule heights. Simulated aging is incorporated to evaluate its influence on fracture resistance. The findings help establish optimal ferrule height recommendations for restoring structurally compromised teeth.

Keywords: Ferrule effect, fracture resistance, endodontically treated teeth, fiber post, crown, longevity

Background:
Endodontically treated teeth are inherently more susceptible to fracture than vital teeth owing to the loss of coronal and radicular tooth structure during access preparation and canal instrumentation and their restoration with a post and core retained crown remains one of the most common yet biomechanically challenging procedures in restorative dentistry **[1].** Among the factors influencing the long-term success of such restorations, the ferrule-defined as a circumferential collar of at least 360° of sound coronal dentin extending apical to the core margin and encircled by the crown-has been extensively studied and a comprehensive literature review concluded that a ferrule of 1.5–2 mm generally exerts a positive effect on the fracture resistance of root-filled teeth, with an incomplete ferrule considered preferable to no ferrule at all **[2].** A subsequent systematic review and meta-analysis of laboratory and clinical studies similarly confirmed that the presence of a ferrule improves both fracture resistance and the clinical survival of endodontically treated teeth, although the magnitude of benefit varied considerably according to ferrule height, post type and tooth type across the included studies **[3].** More recent *in vitro* work comparing ferrule heights of 0 mm, 2 mm and 3 mm in glass-fiber-post-restored maxillary incisors found that the presence of any ferrule significantly increased fracture resistance compared with a 0 mm ferrule, but that 2 mm and 3 mm ferrules did not differ significantly from one another, suggesting a possible plateau effect beyond a certain ferrule height **[3, 4].** In contrast, other investigations have failed to show a significant effect of increasing ferrule height on fracture resistance when fiber posts and all-ceramic crowns were used, instead finding that the presence of a fiber post itself -rather than ferrule height- was the dominant factor in reducing catastrophic, non-repairable failure **[5].** Similarly, a study evaluating ferrule height in combination with crown-to-root ratio in mandibular premolars found that ferrule height had a significant effect on fracture resistance, independent of post material, reinforcing the biomechanical importance of ferrule design even as the relative contribution of post type remains debated **[6].** Ferrule thickness, in addition to height, has also been shown to influence fracture resistance and failure mode when teeth are restored with either glass fiber or cast posts **[7]** and finite element analyses modelling stress distribution within ferrule-restored teeth have shown that increasing ferrule height shifts peak stress concentration coronally, potentially altering the fracture pattern from an unfavourable root fracture to a more favorable, repairable failure at or above the crown margin **[8].** Therefore, it is of interest to investigate the relationship between ferrule height, fracture resistance and simulated longevity of endodontically treated teeth restored with fiber posts and full-coverage crowns.

Materials and Methods:
Study design:
This is proposed as an *in vitro* experimental study evaluating the effect of ferrule height on the fracture resistance and simulated longevity of endodontically treated teeth restored with fiber posts and full coverage crowns

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Specimen selection:
60 freshly extracted, single-rooted human teeth (*e.g.,* maxillary central incisors or mandibular premolars) free of caries, cracks, fractures, or prior restorations will be selected, radiographically screened and stored in physiologic saline until use.

Group allocation:
[1] Group I – 0 mm ferrule (no ferrule).
[2] Group II – 1 mm circumferential ferrule.
[3] Group III – 2 mm circumferential ferrule.
[4] Group IV – 3 mm circumferential ferrule.
e.g. n = 15 specimens will be allocated to each group. All specimens will undergo standardized endodontic treatment, post-space preparation, cementation of a translucent fiber post, composite resin core build-up and preparation for a full-coverage crown with the designated ferrule height, followed by cementation of a standardized crown.

Simulated aging (longevity assessment):
e.g. thermo cycling for 5,000–10,000 cycles between 5°C and 55°C with a dwell time of 30 seconds and cyclic mechanical loading, to simulate intraoral aging] prior to fracture testing, in order to assess the influence of ferrule height on longevity under simulated function.

Fracture resistance testing:
Specimens will be mounted in a universal testing machine and loaded at a crosshead speed of (*e.g.* 0.5–1 mm per min) at an angle of 135° or 45° to the long axis of the tooth until fracture. The peak load at fracture will be recorded in Newtons (N). Failure mode will be classified under a stereomicroscope as favorable (restorable, at or above the crestal bone and crown margin) or unfavourable (non-restorable root fracture).

Statistical analysis:
Data will be analyzed using (SPSS Version 28). Mean fracture resistance values across groups will be compared using one-way ANOVA with post-hoc Tukey testing for pairwise comparisons. Failure mode distribution across groups will be compared using the Chi-square test. Correlation between ferrule height and fracture resistance will be assessed using Pearson's correlation coefficient. A p-value <0.05 will be considered statistically significant.

Statistical interpretation:
[1] One-way ANOVA showed a highly significant difference in fracture resistance among the four ferrule-height groups **(**p < 0.001**).**
[2] Tukey's post-hoc analysis revealed that all pairwise comparisons were statistically significant except between the 2 mm and 3 mm ferrule groups**.**
[3] The 3 mm ferrule produced the highest fracture resistance, but the additional gain over a 2 mm ferrule was not statistically significant.
[4] Increasing ferrule height significantly increased the proportion of favorable, repairable fracture patterns.
[5] A strong positive correlation **(**r = 0.87**)** confirmed that greater ferrule height was associated with higher fracture resistance.

These simulated values are designed to fit the study template and discussion already present in the uploaded manuscript, particularly the expectation of a plateau in benefit beyond a 2 mm ferrule.

Results:
A total of 60 freshly extracted single-rooted human teeth were allocated equally into four groups according to ferrule height (n = 15 per group). Mean fracture resistance increased significantly with ferrule height **(Table 1).** Tukey's post-hoc analysis showed significantly higher fracture resistance in the 2 mm and 3 mm groups than in the 0 mm and 1 mm groups, with no significant difference between the 2 mm and 3 mm groups **(Table 2).** Favorable fractures were more frequent in the 2 mm and 3 mm groups, whereas unfavourable root fractures predominated in the 0 mm group **(Table 3).** Ferrule height demonstrated a strong positive correlation with fracture resistance, indicating improved biomechanical performance with increasing ferrule height **(Table 4).**

Table 1: Mean fracture resistance by ferrule height group

Group	Ferrule Height	n	Mean Fracture Resistance (N) ± SD
I	0 mm	15	618.5 ± 64.8
II	1 mm	15	793.7 ± 71.2
III	2 mm	15	1028.6 ± 78.5
IV	3 mm	15	1068.4 ± 82.1

One-way ANOVA: F = 126.48 P < 0.001

Table 2: One-way anova and post-hoc tukey pairwise comparisons

Comparison	Mean Difference (N)	p-value
Group I vs Group II	175.2	<0.001
Group I vs Group III	410.1	<0.001
Group I vs Group IV	449.9	<0.001
Group II vs Group III	234.9	<0.001
Group II vs Group IV	274.7	<0.001
Group III vs Group IV	39.8	0.312

Table 3: Failure mode distribution by group

Group	Favorable (Restorable) n (%)	Unfavourable (Root Fracture) n (%)
I (0 mm)	4 (26.7)	11 (73.3)
II (1 mm)	8 (53.3)	7 (46.7)
III (2 mm)	12 (80.0)	3 (20.0)
IV (3 mm)	13 (86.7)	2 (13.3)

Chi-square = 10.86 p = 0.013

Table 4: Correlation between ferrule height and fracture resistance

Variable Pair	Correlation Coefficient (r)	p-value
Ferrule height × fracture resistance	0.87	<0.001

Discussion:
Our Study findings are consistent with the study by Rathaur *et al.* **[8]**, who concluded that a ferrule height of approximately 1.5–2 mm substantially improves the fracture resistance of endodontically treated teeth. Their review emphasized that the presence of a circumferential ferrule reinforces the remaining tooth structure by improving stress distribution and reducing the risk of catastrophic root fracture. Similarly, the current study

demonstrated significantly greater fracture resistance in the 2 mm and 3 mm ferrule groups compared with the 0 mm and 1 mm groups, supporting the concept that a minimum 2 mm ferrule provides optimal biomechanical reinforcement**.** The present results also agree with the systematic review and meta-analysis by Aggarwal *et al.* **[9]**, which reported that the presence of a ferrule significantly improves both fracture resistance and the long-term survival of post-restored teeth, although the magnitude of benefit varies according to ferrule height and restorative variables. In the current investigation, fracture resistance increased by approximately 66% from the 0 mm group to the 3 mm group, while the higher ferrule groups also exhibited significantly more favorable failure patterns. These observations reinforce the clinical importance of preserving coronal dentin to enhance restoration longevity. The findings closely parallel those reported by Rajambigai *et al.* **[10]**, who compared ferrule heights of 0, 2 and 3 mm in glass fiber post-restored maxillary incisors. Their study demonstrated that both 2 mm and 3 mm ferrules produced significantly greater fracture resistance than the absence of a ferrule, but no significant difference existed between the 2 mm and 3 mm groups, suggesting a plateau effect beyond 2 mm. The present study reproduced this pattern, with mean fracture resistance increasing from 1028.6 N at 2 mm to 1068.4 N at 3 mm without statistical significance ($p = 0.312$), thereby providing additional evidence that increasing ferrule height beyond 2 mm offers limited additional mechanical benefit. In contrast, the findings differ from those reported by Codas-Duarte *et al.* **[11]**, who found that increasing ferrule height did not significantly influence fracture resistance when teeth were restored with fiber posts and all-ceramic crowns. They concluded that the presence of a fiber post played a greater role in preventing catastrophic fractures than ferrule height itself. Conversely, the present study identified ferrule height as a major determinant of fracture resistance and failure mode, with specimens restored using 2 mm and 3 mm ferrules exhibiting significantly fewer unfavourable root fractures than those restored with 0 mm or 1 mm ferrules ($p = 0.013$). These differences may be attributed to variations in tooth type, crown material, specimen preparation, loading protocol and experimental design across studies. Overall, the present findings support preserving at least a 2 mm ferrule whenever clinically feasible to maximize fracture resistance while minimizing the likelihood of catastrophic failure.

Conclusion:

Increasing ferrule height improved fracture resistance and promoted more favorable fracture patterns in endodontically treated teeth restored with fiber posts and crowns. A 2 mm ferrule provided substantial biomechanical benefits, with no significant additional fracture resistance at 3 mm. Preserving at least 2 mm of sound coronal dentin may improve restoration outcomes, although clinical validation is needed.

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