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ORIGINAL ARTICLE

Influence of Different Post-endodontic Restorations on the Survival Rate Against Fracture of Endodontically Treated Anterior Teeth Affected by Cervical Lesions with Pulpal Involvement: A Retrospective Clinical Study

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ABSTRACT

Objective: To compare the survival rate against fracture of endodontically treated anterior teeth (ETT) affected by cervical (class V) lesions with pulpal involvement restored with resin composite or a post/core and crown, and to identify the prognostic factors for fracture.

Methods: Dental records and radiographs of ETT affected by cervical lesions with pulpal involvement restored with resin composite or a post/core and crown during a recall period from 2009–2022 were selected according to the inclusion and exclusion criteria. The number of tooth fracture, the restorability after fracture and any possible risk factors were identified. The survival rate against ETT fracture were analyzed and compared between the two restoration groups by Kaplan-Meier survival analysis and the Tarone-Ware test. Non-proportional hazard models were used to identify the prognostic factors. The sub-analysis in each restoration group was also performed.

Results: The study comprised 175 ETT restored with resin composite (n=125) or a crown (n=50). With a mean recall period of 32.9±15.8 months, the survival rate against ETT fracture with resin composite (85.6%) was not significantly different from those with a crown (88%) ($p \geq 0.05$). The most frequent mode of fracture was crown-root fracture, which accounted for 78% and 83.30% of the fractures in the resin composite and crown groups, respectively. A significant prognostic factor for ETT fracture affected by cervical lesions with pulpal involvement was additional tooth structure loss from a class III, class IV or another class V lesion on the opposite side ($p<0.05$). The ETT affected by cervical lesions with pulpal involvement combined with additional tooth structure loss had a 7.25-fold higher risk of fracture than those with single-surface affected by cervical lesions with pulpal involvement (hazard ratio [HR] = 7.25; 95% confidence interval [CI], 1.68–31.30). The sub-analysis in the crown and resin composite groups revealed that the survival rates of ETT with single-surface affected by cervical lesions with pulpal involvement was 100% and 96.15%, respectively, which were significantly higher than those of ETT with additional tooth loss at 80.65% and 78.08%, respectively ($p<0.05$).

Conclusion: With a mean 33-month recall period, the survival rate against ETT fracture affected by cervical lesions with pulpal involvement restored with resin composite or crown were not significantly different. Additional tooth structure loss was a significant prognostic factor for fracture.

Keywords: Cervical lesion, dental crown, endodontically treated teeth, resin composite, survival rate

HIGHLIGHTS

- This is the first clinical study to compare the effects of different post-endodontic restorations (resin composite or crown) on the survival rate against fracture of the endodontically treated anterior teeth affected by cervical lesions with pulpal involvement.

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HIGHLIGHTS

- Endodontically treated anterior teeth affected by a single-surface cervical lesions with pulpal involvement can be simply restored by resin composites with a fracture survival rate similar to full-coverage crowns.
- Endodontically treated anterior teeth with additional tooth structure loss (i.e. class III, IV or another class V cavity) demonstrated significantly decreased survival against fracture, including when a full-coverage crown is placed. Thus, any excessive functional force should be avoided on the restored teeth.

INTRODUCTION

The significant reduction in the fracture resistance of endodontically treated teeth (ETT) compared with vital teeth is primarily caused by substantial tooth structure loss (1). Large dental caries or existing restorations, especially involving the marginal ridge(s), markedly decrease the strength of the tooth and increase the risk of fracture (2, 3). A cuspal-coverage coronal restoration is the main factor in achieving long-term success by reducing the likelihood of tooth fracture, especially in posterior ETT (4, 5).

The loss of cervical tooth structure (class V cavity) is categorized into carious and non-carious cervical lesions (6, 7). Untreated, deep cervical lesions may result in pulpal exposure. The substantial loss of cervical tooth structure significantly reduces the fracture resistance of the tooth, especially to lateral loading force (8). Higher stress accumulation in the cervical region is associated with increased cavity depth (9), which may induce tooth fracture in ETT possessing a cervical lesion with or without a pulpal exposure. The loss of cervical tooth structure from carious or non-carious causes affects the biomechanical properties of the tooth by weakening the cervical area and increasing the risk of tooth fracture (10, 11). Furthermore, the location of the cervical lesion is another important factor in decreasing fracture resistance. Maxillary anterior ETT that have lost their palatal cervical structure have a lower fracture strength than ETT with an intact palatal cervical structure (12).

Laboratory studies suggested that a resin composite restoration is likely to sufficiently reinforce anterior ETT affected by cervical lesions with pulpal involvement by restoring their biomechanical characteristics and fracture resistance similar to that of the intact tooth (10, 13), either with or without placing a prefabricated fibre post (8). In a retrospective cohort study, placing a crown restoration decreased the incidence of an unrestorable fracture in the anterior ETT from approximately 1% to 18% when the cervical structure was lost (including exposure and non-exposure) on more than two surfaces (12). However, these results cannot be generalized to the anterior ETT affected by cervical lesions with pulpal involvement, especially on one surface. A retrospective study demonstrated that premolar ETT with cervical exposure (mostly on the buccal surface) were successfully restored with resin composite, and fracture survival was similar to those restored with a crown (14). However, the tooth structure and loading force of the anterior teeth and premolars are completely different. Furthermore, there is no clinical study on the survival of fractured anterior ETT affected by cervical lesions with pulpal involvement.

The clinical recommendation for post-endodontic restoration (i.e. resin composite vs. crown) for anterior ETT affected by cervical lesions with pulpal involvement is unresolved due to the lack of clinical evidence and is mainly based on laboratory results. Hence, the aim of this retrospective cohort study was to evaluate the survival rate against fracture of endodontically treated anterior teeth affected by cervical lesions with pulpal involvement that were restored with either a resin composite or crown. In addition, the factors associated with an increased survival rate against fracture were identified.

MATERIALS AND METHODS

The protocol of this retrospective cohort study was approved by the Institutional Review Board, Faculty of Dentistry and Faculty of Pharmacy, Mahidol University, Bangkok, Thailand (MU-DT/PY-IRB 2020/DT011). The study was conducted in accordance with the Declaration of Helsinki.

Sample Size Calculation

The result of a previous study in endodontically treated teeth affected by cervical lesions with pulpal involvement was used to calculate the sample size (14) by STATA software version 14.0 (Stata Corp LP, College Station, TX, USA) with a level of significance at 0.05, a statistical power of 80% and the hazard ratio (HR) (resin composite and crown) was 2.07. The sample sizes between the resin composite and the crown groups were set with an unbalanced ratio (~2:1) due to the unequal numbers of the cases with a resin composite or crown in the database. The calculated sample sizes were 94 and 47 for the resin composite group and the crown group, respectively.

Inclusion and exclusion criteria

The anterior ETT data were collected from the dental records of patients who received non-surgical endodontic treatment/retreatment and post-endodontic restoration with either resin composite or a post/core and crown at the endodontic clinic (Faculty of Dentistry, Mahidol University, Bangkok, Thailand) and attended recall(s) during January 2009-January 2022. For the restorative treatment, the operators were undergraduates, postgraduates (under the supervision of clinical instructors) and restorative dentists. The teeth were included in the study based on the following inclusion criteria:

1. Teeth affected by either carious or non-carious cervical lesions with pulpal involvement at the labial or palatal/lingual side.
2. Teeth with or without additional tooth loss on the other surface(s) (e.g. proximal [class III], inciso-proximal cavity [class IV] or a non-exposure class V on the opposite side).
3. Teeth with complete root formation.
4. Teeth with occlusal function with the opposing natural tooth or fixed prosthesis.
5. The recall period was at least 12 months. However, any teeth that fractured prior to the first-year recall were included and recorded as a fractured case.

The ETT were excluded if any of these conditions was present:

1. Teeth affected by cervical lesions without pulpal involvement.
2. Inadequate dental and/or radiographic records.
3. History of procedural error(s) that compromised the strength of the tooth structure (e.g. excessive coronal access, separated instrument removal, root perforation or a misdirected post-space preparation).
4. External root resorption.
5. History of a preoperative crack or suspected root fracture.
6. Ongoing orthodontic treatment.

The teeth extracted for other reasons not related to fracture, i.e. endodontic or periodontal causes, were included. For these teeth, the last recall period before tooth extraction was set as the survival endpoint.

Endodontic and Restorative Procedures

The endodontic and restorative procedures were performed following the standard protocols at our institute. In brief, the endodontic treatment was performed by undergraduates, postgraduates or endodontists under rubber dam isolation before caries removal (if any), pre-endodontic cervical restoration with resin composite and conventional access preparation. The working length was determined using an electronic apex locator in combination with periapical radiographs. Root canal preparation was performed with stainless steel hand files (Dentsply Maillefer, Ballaigues, Switzerland) and/or nickel-titanium rotary files (e.g. ProTaper Next, Dentsply Maillefer) using the crown-down technique under irrigation with 2.5% sodium hypochlorite and 17% EDTA. Root canal final-size preparation depended on several factors, such as initial root canal size or root dentine thickness. In this study, the final preparation size typically ranged from 30–40. In most cases, the root canals were medicated with calcium hydroxide paste for at least one week before obturation with gutta-percha/root canal sealer [zinc oxide eugenol (MU Sealer, M-Dent, Bangkok, Thailand) or epoxy resin-based sealer (AH Plus, Dentsply-Maillefer, Tulsa, OK, USA)], using the cold lateral or warm vertical compaction technique. The gutta-percha was cut by a heat-carrier tip at 1–2 mm apical to the gingival margin of the cervical lesion.

The post-endodontic restoration was a direct resin composite or crown per the operators' decision and preference, which was typically determined by the remaining tooth structure and functional force (15). When using resin composite, most of the restorations were placed as a permanent restoration, however, a few of the restorations were an intermediate restoration before crown placement. The gutta-percha was covered with a 1–2 mm thick glass-ionomer lining cement (Vitrebond, 3M ESPE, St. Paul, MN, USA; or Fuji VII, GC corp., Tokyo, Japan) as a barrier. The access cavity was bonded with a resin-based adhesive using an etch-and-rinse (Adper Single Bond 2, 3M ESPE) or self-etch adhesive (Clearfil SE Bond, Kuraray, Osaka, Japan), and then incrementally filled with resin composite (Z350XT, 3M ESPE; or Estelite Sigma Quick, Tokuyama, Tokyo, Japan).

In the crown group, a prefabricated fibre post (DT LIGHT-POST, BISCO Inc., Schaumburg, IL, USA; or FRC Postec® Plus, Ivoclar Vivadent AG, Schaan, Liechtenstein) was placed into the root canal leaving 4–5 mm of gutta-percha remaining. The prefabricated post was cemented with a resin-based cement (e.g. Rely-X U200, 3M ESPE), or a core build-up material (e.g. MultiCore Flow, Ivoclar Vivadent AG; or LuxaCore Z, DMG, Hamburg, Germany). After tooth preparation, an all-ceramic crown (e.g. Empress e.max, Ivoclar Vivadent AG) or a porcelain-fused-to-metal crown was fabricated and cemented with a resin-based cement (e.g. Variolink-N, Ivoclar Vivadent AG; or Rely-X U200).

Data acquisition

The data was acquired from dental charts and radiographs. General information comprising sex, age (years) and recall period (months) were collected. The following clinical and radiographic information were identified: (a) tooth type, (b) tooth location, (c) cavity (single-surface class V with pulpal involvement or class V with pulpal involvement combined with additional tooth structure loss), (d) restoration type; (e) presence of a post, (f) ratio of the cervical root dentine (mesial and distal dentine wall width) and the root canal width at 2 mm apical to the CEJ (ratio <1:1 or ≥1:1), (g) incidence of fracture, (h) fracture pattern, (i) restorability after fracture, (j) abutment for a prosthesis, (k) posterior support, (l) proximal contact, (m) parafunctional habits and (n) crestal bone level in relation to the root length. Furthermore, the degree of additional tooth structure loss was divided into three subgroups according to the extension of the restored cavity in the radiographs: small– the dentine outer-third or less, moderate– the dentine middle-third and large– the dentine inner-third or close to the pulp.

Outcome Assessment

The number of tooth fracture was determined, and the fracture pattern was recorded as a crown, crown-root or root fracture. The outcome was categorized as not survived from fracture if any tooth fracture was detected or survived from fracture if no fracture was recorded. The restorability after fracture was identified as restorable if the fractured tooth could be re-restored or non-restorable if tooth extraction was indicated.

TABLE 1. Data distribution of the anterior ETT affected by class V lesions with pulpal involvement restored with either resin composite or a full-coverage crown

Factors	Resin composite (n=125)		Crown (n=50)		Total (n=175)	
	n	%	n	%	n	%
Sex						
Male	57	45.6	24	48	81	46.3
Female	68	54.4	26	52	94	53.7
Age (years)						
Less than 60	50	40	14	28	64	36.6
≥60	75	60	36	72	111	63.4
Tooth location						
Maxillary teeth	92	73.6	35	70	127	72.6
Mandibular teeth	33	26.4	15	30	48	27.4
Tooth type						
Incisor (central/lateral)	60	48	17	34	77	44
Canine	65	52	33	66	98	56
Cavity type						
Single-surface class V	52	41.6	19	38	71	40.6
Class V and other additional tooth loss	73	58.4	31	62	104	59.4
Abutment						
No	90	72	29	58	119	68
Yes	35	28	21	42	56	32
Posterior support						
2 sides	53	42.4	19	38	72	41.1
0–1 side	72	57.6	31	62	103	58.9
Proximal contact						
2 sides	80	64	29	58	109	62.3
0–1 side	45	36	21	42	66	37.7
Parafunctional habits						
No	97	77.6	38	76	135	77.1
Yes	28	22.4	12	24	40	22.9
Cervical root dentine (ratio)						
≥1:1	116	92.8	46	93	162	92.6
<1:1	9	7.2	4	8	13	7.4
Crestal bone level						
Coronal	108	86.4	49	98	157	89.7
Middle	17	13.6	1	2	89	10.3

No significant differences in the data distribution were found between the two restoration groups (Fisher's exact test; p-value ≥0.05), except for the crestal bone level (p-value =0.025). ETT: Endodontically treated anterior teeth

Statistical Analysis

The data were statistically analyzed using SPSS v.22 for Mac (SPSS Inc., Chicago, IL, USA) and STATA v.17 for Mac (Stata Corp., College Station, TX, USA) with a significance level of p-value <0.05. Descriptive statistics were used to describe the data distribution. Fisher's exact test was used to compare the data distribution between the resin composite and crown groups. The survival rate against fracture of the anterior ETT with resin composite and crown restorations were compared using Kaplan-Meier survival analysis and the Tarone-Ware test.

When analysing the possible prognostic factors, the hazard ratios were non-proportional. Hence, a multivariable, non-proportional hazard model was used in a full model and a predictive model to explain and predict any prognostic factors with a p-value of <0.05 in the Tarone-Ware test.

For the subgroup analysis in the resin composite group and the crown group, the Kaplan-Meier survival analysis and the Tarone-Ware test were used to analyze the survival rates and possible prognostic factors.

RESULTS

Overall, 175 anterior ETT out of 246 teeth were included in this study. Of the 155 patients [70 males (45.16%) and 85 females (54.84%)], 140 cases had one included tooth, and 15 cases had two or more included teeth. The patients' ages ranged from 21–89 years old (mean 62±12.7 years old). The recall rate in this study was 71.14% (175/246), which was 66.49% (125/188) and 86.21% (50/58) for the resin composite group and the crown group, respectively. The ETT affected by cervical lesions with pulpal involvement were restored with resin composite (n=125) or full-coverage crowns (n=50). The distribution of the ETT data based on the possible prognostic factors is presented in Table 1.

TABLE 2. The bivariate (Tarone-Ware) analysis of the survival rate against fracture of the anterior ETT affected by class V lesions with pulpal involvement (n=175)

Factors	Number of teeth	Survived from fracture		Not survived from fracture		p
		n	%	n	%	
Restoration type						
Resin composite	125	107	85.6	18	14.4	0.361
Crown	50	44	88	6	12	
Sex						
Male	81	71	87.7	10	12.3	0.427
Female	94	80	85.1	14	14.9	
Age (years)						
Less than 60	64	57	89.1	7	10.9	0.442
≥60	111	94	84.68	17	15.32	
Tooth location						
Maxillary teeth	127	108	85.04	19	14.96	0.297
Mandibular teeth	48	43	89.58	5	10.42	
Tooth type						
Incisor (central/lateral)	44	65	84.42	12	15.58	0.588
Canine	56	86	87.76	12	12.24	
Cavity type						
Single-surface class V	71	69	97.18	2	2.82	0.001
Class V and other additional tooth loss	104	82	78.75	22	21.15	
Abutment						
No	119	103	86.55	16	13.45	0.567
Yes	56	48	85.71	8	14.29	
Posterior support						
2 sides	72	64	88.89	8	11.11	0.169
0–1 side	103	87	84.47	16	15.53	
Proximal contact						
2 sides	109	95	87.16	14	12.84	0.233
0–1 side	66	56	84.85	10	15.15	
Parafunctional habits						
No	135	116	85.93	19	14.07	0.946
Yes	40	35	87.50	5	12.50	
Cervical root dentine (ratio)						
≥1:1	162	142	87.70	20	12.30	0.091
<1:1	13	9	69.20	4	30.80	
Crestal bone level						
Coronal	157	137	87.30	20	12.70	0.244
Middle	18	14	77.80	4	22.20	

Fracture Survival Rates

With recall periods ranging from 12–60 (32.9±15.8) months, the overall survival rate against fracture of ETT affected by cervical lesions with pulpal involvement was 86.30% (151/175 teeth). The survival rates of the resin composite group (mean recall period of 32.8±16.9 months) and the crown group (mean recall period of 33.2±12.8 months) were 85.60% (107/125 teeth) and 88% (44/50 teeth), respectively. There was no significant difference in the survival rate against fracture of ETT affected by cervical lesions with pulpal involvement between the resin composite and the crown groups (Table 2, p-value =0.361).

The fracture patterns in the resin composite group were crown-root (77.80%, 14 teeth), crown (11.11%, 2 teeth) and root fracture (11.11%, 2 teeth). The fracture patterns in the crown group were crown-root (83.30%, 5 teeth) and crown fracture (16.67%, 1 tooth) with no root fracture. The most frequent mode of fracture was crown-root fracture, which accounted for 78% and 83.30% of the fractures in the resin composite and crown groups, respectively.

The 5-year survival rates of the ETT affected by cervical lesions with pulpal involvement and restored with the two restoration types are presented as cumulative survival rates (%) and compared using Kaplan-Meier survival analysis (Fig. 1). The cumulative survival rate in the resin composite group was 91.51% at 24 months and gradually decreased to 82.42% and 80.41% at 36 and 60 months, respectively. The cumulative survival rate in the crown group was 95.35% at 24 and 36 months and markedly dropped to 66% at 54 and 60 months. The numbers of recalled teeth and fractured teeth of anterior ETT affected by cervical lesions with pulpal involvement as well as the calculated cumulative non-fracture and fracture at each recall time interval are presented in Table 3.

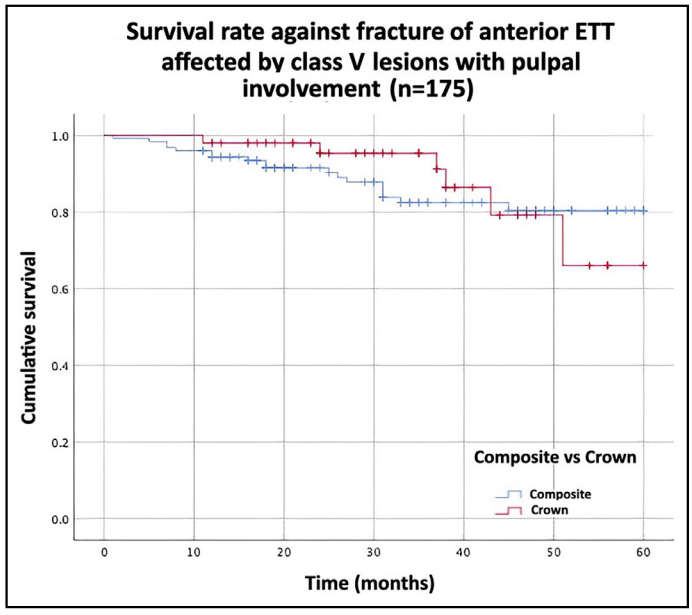

Figure 1. The Kaplan-Meier cumulative survival curves of the anterior ETT affected by class V lesions with pulpal involvement restored with resin composite and full-coverage crown.

No significant difference in fracture survival was detected between the resin composite and full-coverage crown groups (p-value ≥0.05). ETT: Endodontically treated anterior teeth

Prognostic Factors to Fracture

The non-proportional hazard full model reported that cavity type was a significant prognostic factor to fracture (Table 4, p-value =0.01). The non-proportional hazard predictive model confirmed that cavity type was a significant prognostic factor to fracture (Table 5, p-value =0.008). The ETT affected by cervical lesion with pulpal involvement combined with other additional tooth structure loss from class III, IV or another class V on the opposite side of the tooth had a 7.25-fold higher risk of fracture than those affected by only a cervical lesion with pulpal involvement (hazard ratio [HR] = 7.25; 95% confidence interval [CI], 1.68–31.30; p-value <0.05).

Effect of Additional Tooth Structure Loss on Survival Against Fracture

The survival rate against fracture of the ETT affected by a single-surface class V with pulpal involvement were 100% and 96.15% for the crown and resin composite groups, respectively. The ETT affected by class V lesions with pulpal involvement and additional tooth structure loss had survival rate against fracture at 80.65% in the crown group and 78.08% in the resin composite group. The survival rates in the single-surface class V with pulpal involvement group were significantly higher than those in the ETT affected by class V lesions with pulpal involvement and additional tooth structure loss group for both resin composite and crown restorations (p-value <0.05).

The Kaplan-Meier survival analysis indicated that the ETT affected by a single-surface class V with pulpal involvement had a 100% cumulative survival rate at 12–24 months in the resin composite and crown groups. The survival rate in the resin composite group slightly decreased to 97.18% at 36–60 months (Fig. 2a). For the ETT affected by class V lesions with pulpal involvement and additional tooth structure loss, the cumulative survival rate at 12–36 months of the crown group (96.67% to 92.57%) was higher than the resin composite group (90.33% to 73.59%). At 36–60 months, the survival rates in the resin composite group were stable (73.59% to 70.24%), while those in the crown group dramatically decreased (92.57% to 45.58%) (Fig. 2b).

Sub-Analysis of Prognostic Factors in the Resin Composite and Crown Groups

No significant prognostic factor was identified in the crown group (Table 6). In contrast, in the resin composite group, cavity type was a significant prognostic factor for ETT affected by class V lesions with pulpal involvement fracture (p-value =0.002) (Table 7).

Effect of Different Additional Tooth Structure Loss Types in the Resin Composite Group

The ETT affected by class V lesions with pulpal involvement and restored with resin composite (125 teeth) were further

TABLE 3. The numbers of recalled teeth and fractured teeth of anterior ETT affected by cervical lesions with pulpal involvement as well as the calculated cumulative non-fracture and fracture at each recall time interval

Recall time (months)	Recalled teeth (N)	Fractured teeth (N)	Cumulative non-fracture*	Cumulative fracture
Resin composite group (n=125)				
12	119	7	0.9436	0.0564
24	80	3	0.9150	0.0850
36	55	7	0.8242	0.1758
48	38	1	0.8041	0.1959
60	16	0	0.8041	0.1959
Crown group (n=50)				
12	50	1	0.9800	0.0002
24	39	1	0.9535	0.0465
36	23	0	0.9535	0.0465
48	9	3	0.7920	0.2080
60	4	1	0.6600	0.3400

*: Cumulative non-fracture is calculated: proportion non-fracture on this day x cumulative non-fracture over the previous period

TABLE 4. The multivariable, non-proportional hazard model (full model) for six possible prognostic factors of the survival rate against fracture of the anterior ETT affected by cervical lesions with pulpal involvement

Factors	Hazard ratio (95% CI)	p
Tooth location		
Maxillary vs. Mandibular	2.12 (0.76-5.93)	0.152
Cavity type		
Class V and other additional tooth loss vs. Single-surface class V	6.88 (1.58–29.99)	**0.010**
Posterior support		
0–1 side vs. 2 sides	1.35 (0.53–3.46)	0.528
Proximal contact		
0–1 side vs. 2 sides	0.93 (0.37–2.33)	0.875
Cervical root dentine (ratio)		
<1:1 vs. ≥1:1	2.06 (0.65–6.52)	0.217
Crestal bone level		
Middle vs. Coronal	1.77 (0.56–5.61)	0.330

CI: Confidence interval

TABLE 5. The multivariable, non-proportional hazard model (predictive model) using the backward elimination approach on the four factors with a p-value ≤0.35

Factors	Hazard ratio (95% CI)	p
Tooth location		
Maxillary vs. Mandibular	2.07 (0.74-5.75)	0.163
Cavity type		
Class V and other additional tooth loss vs. Single-surface class V	7.25 (1.68-31.30)	**0.008***
Cervical root dentine (ratio)		
<1:1 vs. ≥1:1	1.93 (0.63-5.91)	0.251
Crestal bone level		
Middle vs. Coronal	1.76 (0.58-5.34)	0.317

*: Class V and other additional tooth loss was a significant predictor of the survival rate against fracture of the anterior ETT affected by class V lesions with pulpal involvement

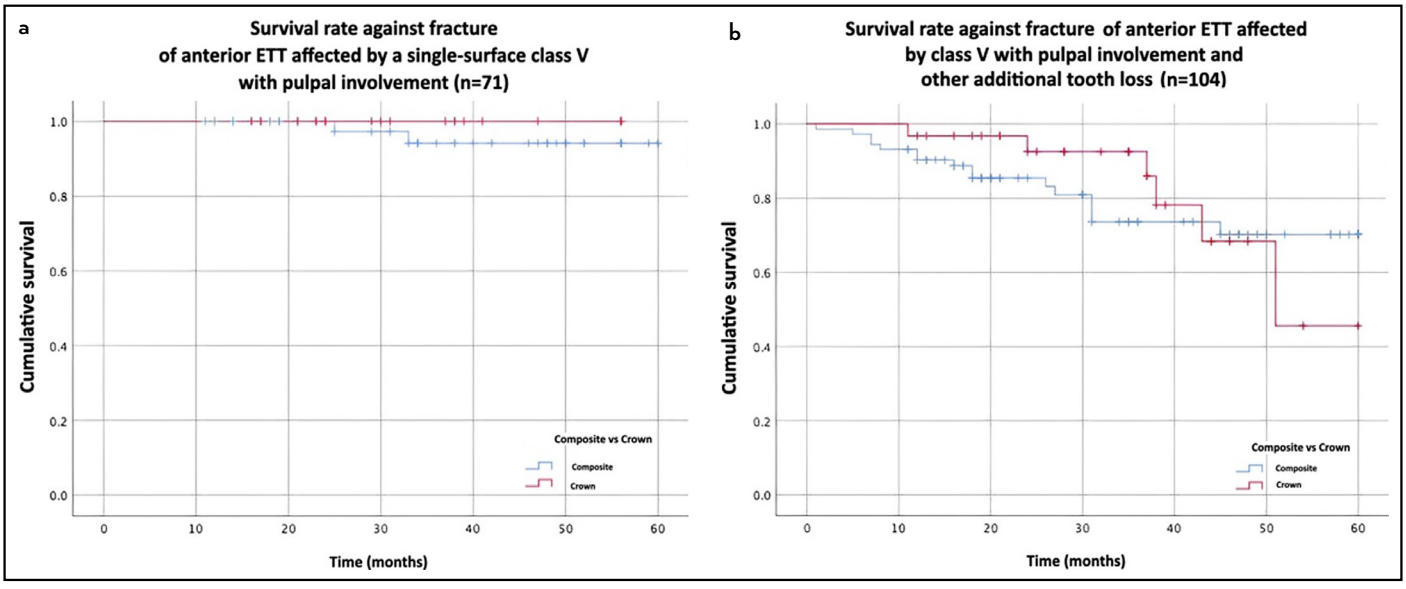

Figure 2. (a) The Kaplan-Meier cumulative survival curves of anterior ETT affected by a single-surface class V with pulpal involvement restored with a resin composite or crown. (b) The Kaplan-Meier cumulative survival curves of the anterior ETT affected by class V with pulpal involvement and other additional tooth loss (class III, IV or another class V on the opposite side) restored with resin composite or crown

No significant difference was found between the resin composite and crown groups (p-value ≥0.05)

TABLE 6. Sub-analysis of the factors for the survival rate against fracture of the anterior ETT affected by cervical lesions with pulpal involvement in the crown group (n=50) (Tarone-Ware test)

Factors	Number of teeth	Survived from fracture		Not survived from fracture		p
		n	%	n	%	
Sex						
Male	24	20	83.33	4	16.67	0.230
Female	26	24	92.31	2	7.69	
Age (years)						
Less than 60	14	13	92.86	1	7.14	0.308
≥60	36	31	86.11	5	13.89	
Tooth location						
Maxillary teeth	15	14	93.33	1	6.67	0.690
Mandibular teeth	35	30	85.71	5	14.29	
Tooth type						
Incisor (central/lateral)	17	15	88.24	2	11.76	0.540
Canine	33	29	87.88	4	12.12	
Cavity type						
Single-surface class V	19	19	100	0	0	N/A*
Class V and other additional tooth loss	31	25	80.65	6	19.35	
Abutment						
No	29	25	86.21	4	13.79	0.554
Yes	21	19	90.44	2	9.52	
Posterior support						
2 sides	19	16	84.21	3	15.79	0.636
0–1 side	31	28	90.32	3	9.68	
Proximal contact						
2 sides	29	25	86.21	4	13.79	0.423
0–1 side	21	19	90.48	2	9.52	
Parafunctional habits						
No	38	33	86.84	5	13.16	0.980
Yes	12	11	91.67	1	8.33	
Cervical root dentine (ratio)						
≥1:1	46	41	89.13	5	10.87	0.878
<1:1	4	3	75	1	25	

*: No fracture case in the group of Class V only. No significant prognostic factor for fracture was found. N/A: Not applicable

categorized into three subgroups based on the different additional tooth structure loss types; group A: ETT affected by a single-surface class V with pulpal involvement (labial or palatal/lingual), group B: ETT affected by class V lesions with pulpal involvement and additional tooth structure loss as class III or IV and group C: ETT affected by class V lesions with pulpal involvement and additional tooth structure loss as another class V on the opposite side. The overall survival rate against fracture in group A, B and C was 96.15% (50/52), 83.33% (40/48) and 68% (17/25), respectively. The survival rate against fracture in group A was significantly higher than in the other groups (p-value<0.05).

The Kaplan-Meier survival curves of the ETT with additional tooth structure loss (groups B and C) compared with those affected by a single-surface class V with pulpal involvement (group A) are presented in Figure 3. The survival rate in group B gradually decreased to approximately 80% at 24–36 months. The survival rate in group C markedly decreased to less than 80% at the early, i.e., 12 and 24 months, follow-ups and then slightly decreased thereafter.

Representative non-fracture and fracture cases of anterior ETT affected by cervical lesions with pulpal involvement restored with resin composite or a crown are presented in Figure 4 and 5.

DISCUSSION

To the best of knowledge, this is the first clinical study to compare the effect of different post-endodontic restorations on the survival rate against fracture of the anterior ETT affected by cervical lesions with pulpal involvement. There was no significant difference between the teeth restored with resin composite (85.60%) and those restored with full-coverage crowns (88%). Therefore, the authors recommend that anterior ETT affected by cervical lesions with pulpal involvement can be restored with resin composite and do not require a crown restoration. However, in addition to a class V lesion with pulpal involvement, additional tooth structure loss from a class III, IV cavity or another class V cavity on the opposite tooth side significantly decreased the survival against fracture of the anterior ETT, regardless of the post-endodontic restoration type.

TABLE 7. The sub-analysis of the factors for the survival rate against fracture of the anterior ETT affected by cervical lesions with pulpal involvement in the resin composite group (n=125) (Tarone-Ware test)

Factors	Number of teeth	Survived from fracture		Not survived from fracture		p
		n	%	n	%	
Sex						
Male	57	51	89.47	6	10.53	0.147
Female	68	56	82.35	12	17.65	
Age (years)						
Less than 60	50	44	88	6	12	0.566
≥60	75	63	84	12	16	
Tooth location						
Maxillary teeth	92	78	84.78	14	15.22	0.364
Mandibular teeth	33	29	87.88	4	12.12	
Tooth type						
Incisor (central/lateral)	60	50	83.33	10	16.67	0.468
Canine	65	57	87.69	8	12.31	
Cavity type						
Single-surface class V	52	50	96.15	2	3.85	**0.002***
Class V and other additional tooth loss	73	57	78.08	16	21.92	
Abutment						
No	90	78	86.67	12	13.33	0.276
Yes	35	29	82.86	6	17.14	
Posterior support						
2 sides	53	48	90.57	5	9.43	0.086
0–1 side	72	59	81.94	13	18.06	
Proximal contact						
2 sides	80	70	87.50	10	12.50	0.283
0–1 side	45	37	82.22	8	17.78	
Parafunctional habits						
No	97	83	85.57	14	14.43	0.933
Yes	28	24	85.71	4	14.29	
Cervical root dentine (ratio)						
≥1:1	116	101	87.07	15	12.93	0.089
<1:1	9	6	66.67	3	33.33	
Crestal bone level						
Coronal	108	94	87.04	14	12.96	0.308
Middle	17	13	76.47	4	23.53	

*: Class V and other additional tooth loss was a significant factor for the fracture of anterior ETT affected by cervical lesions with pulpal involvement

In this study, the resin composite group had a similar survival rate against fracture compared with the crown group. The teeth restored with resin composite generally demonstrated a lower *in vitro* fracture resistance than those with crowns (16); however, the higher fracture strength of the crowned teeth may not be clinically meaningful. In another clinical study, anterior ETT with direct restorations generally had a fracture survival rate similar to those with crowns (17), which is consistent with our results in anterior ETT affected by cervical lesions with pulpal involvement. The present study found that the survival rate against fracture of ETT did not depend on the restoration type, but rather on the amount of lost tooth structure.

This study had a retrospective design, however, in the absence of established guidelines, selection bias in the post-endodontic restorations may have occurred based on individual clinician's decision-making and preference. For the ETT with moderate–severe tooth structure loss, a crown was typically selected. Out of 31 teeth that received crowns, most of the crowns were placed in 28 teeth with moderate to large additional tooth structure loss (90.30%). In comparison, resin composite restorations were placed in 63 teeth with small–moderate additional tooth structure loss out of 73 teeth that were restored using resin composite (86.30%). Clinically, a full-coverage crown should be considered for anterior ETT with substantial tooth structure loss and may be beneficial compared with a direct restoration (12).

The only significant prognostic factor for fracture was additional tooth structure loss combined with a cervical lesion with pulpal involvement. The survival rate against fracture of the ETT with this prognostic factor were 78.08% in the resin composite group and 80.65% in the crown group compared with 96.15% and 100%, respectively, of the teeth with only

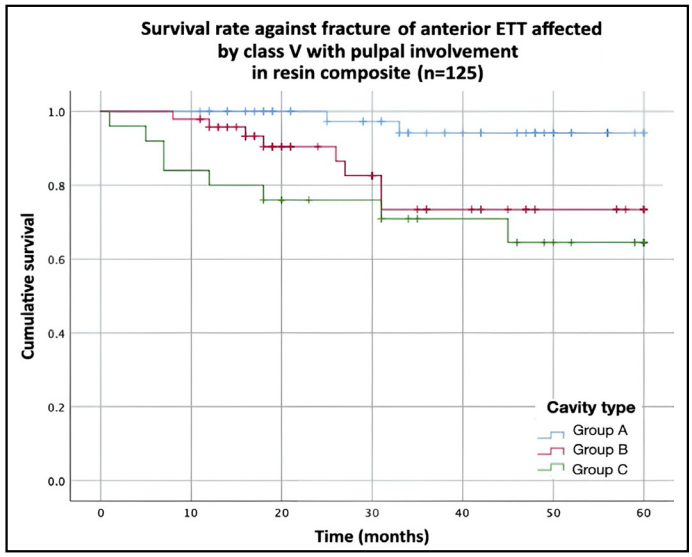

Figure 3. The Kaplan-Meier cumulative survival curves of anterior ETT affected by class V with pulpal involvement restored with resin composite divided by the cavity type. Group A: ETT affected by a single-surface class V with pulpal involvement (labial or palatal/lingual) were significantly different from the other groups (p-value <0.05). Group B: ETT affected by class V lesions with pulpal involvement and additional tooth loss- class III or IV, and Group C: ETT affected by class V lesions with pulpal involvement and additional tooth loss (another class V on the opposite side with/without class III or IV)

a cervical lesion with pulpal involvement. The lower survival rate against fracture of the ETT with additional tooth structure loss can be explained by the fact that greater tooth structure loss results in reduced tooth strength (2, 18). When cervical tooth structure is lost, the high-stress accumulation in the cervical region from occlusal forces may increase the risk of tooth fracture (9–11); however, the fracture resistance tends to recover after restoration (10, 11, 13). Additional tooth structure loss (e.g. class III cavity) tends to further weaken the ETT affected by a cervical lesion with pulpal involvement because the loss of one or two marginal ridges significantly reduces the fracture resistance of anterior ETT (19). Moreover, the teeth with a higher amount of lost tooth structure, such as a class IV cavity, had a two-fold increase in clinical failure compared with the teeth with a lower amount of lost tooth structure, such as a class III cavity (20). The ability to withstand lateral functional forces also markedly decreases in ETT with cervical lesions on the labial and palatal sides (21).

In this study, the fractures in the resin composite and crown groups were mostly cervical fractures with retained roots. Hence, the fracture was usually defined as non-restorable, resulting in tooth extraction due to the absence of a ferrule and an inadequate crown-root ratio (22–24). ETT with a cervical defect have a greater risk of crown-root fracture than those without the defect (14, 25). This fracture phenomenon can be ex-

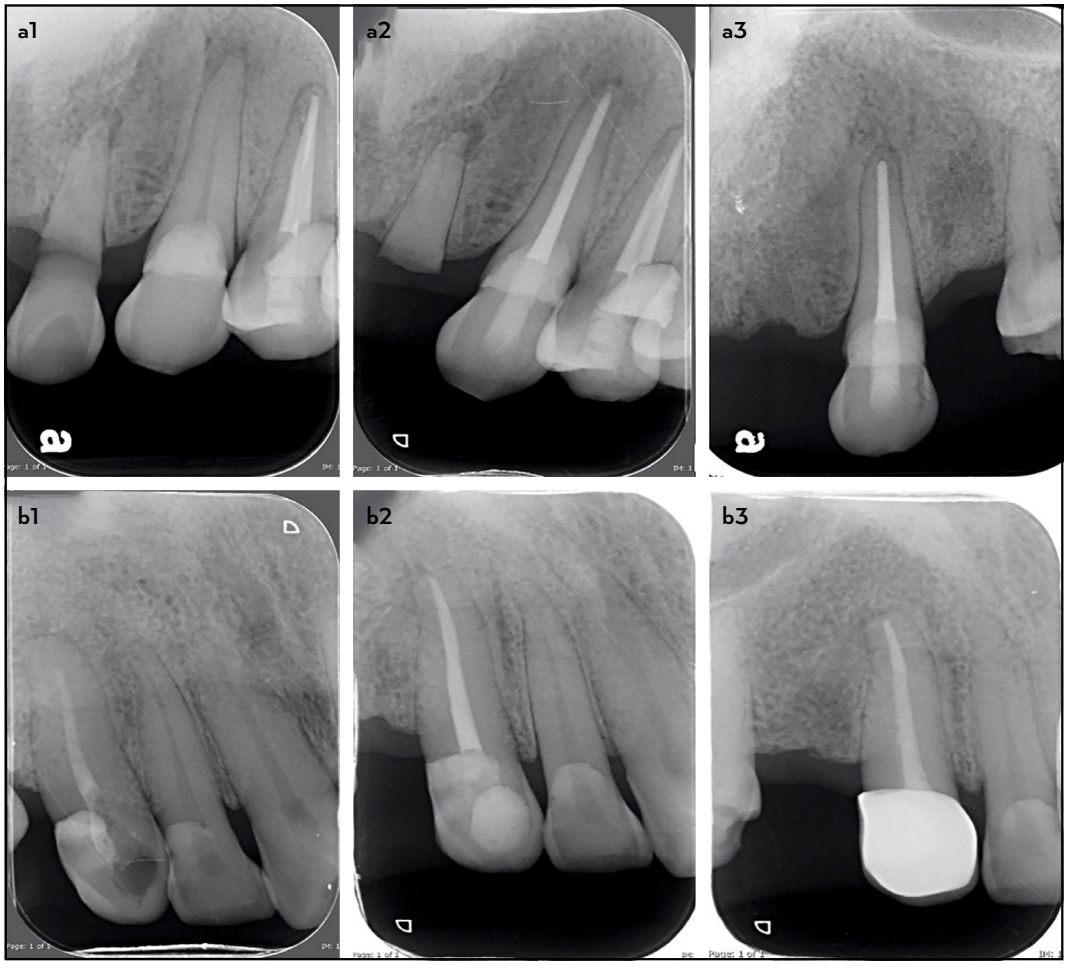

Figure 4. Non-fracture cases of an anterior ETT in the resin composite group (a1-a3; pre-operative, post-operative, follow-up radiographs) and the crown group (b1-b3)

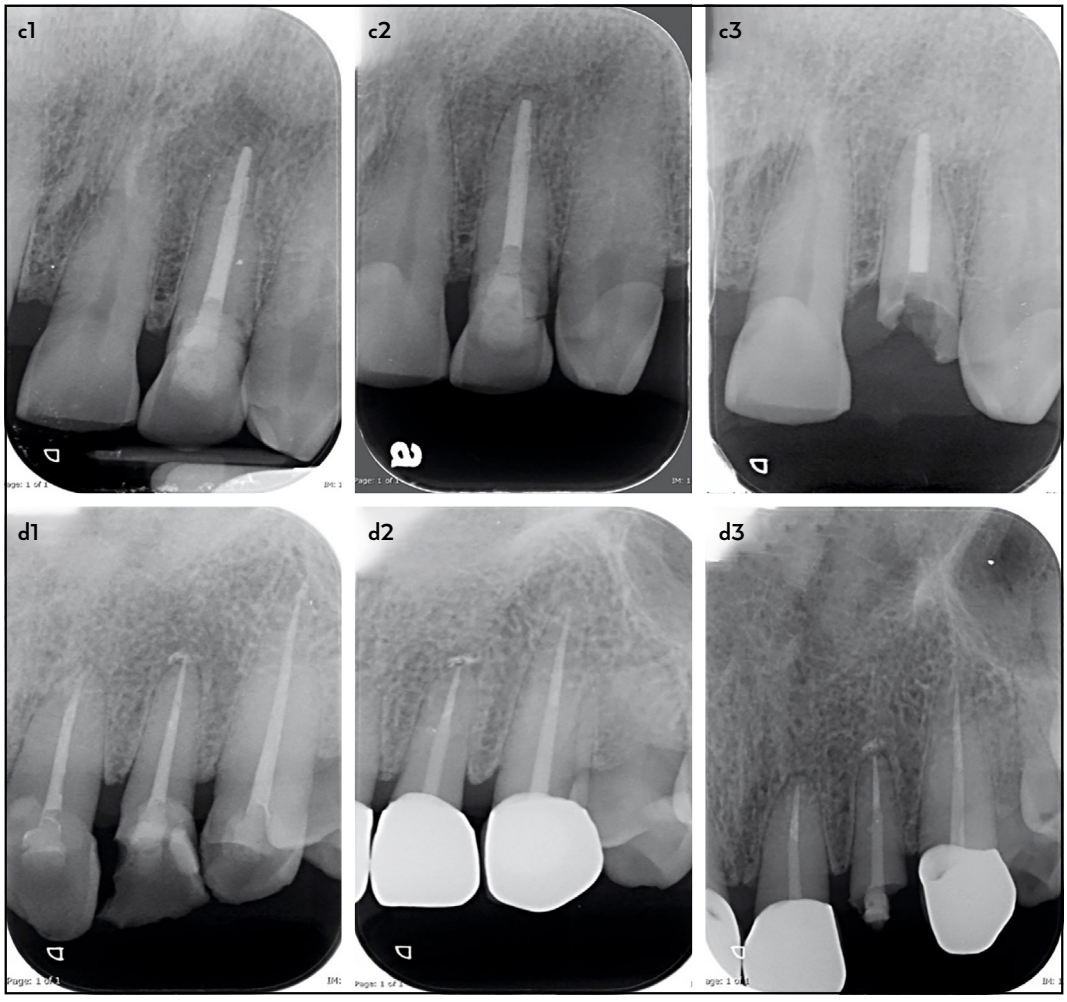

Figure 5. Fracture cases of an anterior ETT in the resin composite group (c1-c3; pre-operative, post-operative, follow-up radiographs) and the crown group (d1-d3)

plained by the changes in the stress-strain pattern that induces high-stress accumulation in the cervical region (9–11, 25, 26).

A fibre post was typically placed in the crown group because the remaining coronal structure after tooth preparation was usually insufficient to provide retention for a core build-up/crown. Moreover, the results from an *in vitro* study indicated that the anterior ETT with a glass fibre post had a higher fracture resistance than those without a post (27). It has been reported that anterior ETT with a fibre post had a higher survival and success rates than those without a post, whether the coronal restoration was a direct resin composite or a single-unit crown (28). From the systematic reviews of the *in vitro* studies, it has been suggested that fibre posts may be beneficial to the long-term survival of anterior ETT; however, the results of the *in vivo* studies are still inconclusive (8, 29). For our protocol in the direct restoration of ETT, a post is not typically indicated, which differs from other recommendations (4). Hence, a post was not used in the resin composite group in this study.

For the ETT restored with resin composite, the restoration protocol in this study was specific; the restorative material was placed 1–2 mm apical to the margin of the cervical lesion in the coronal-third of the root canal. This intraradicular extension was performed to provide an internal seal to prevent bacterial leakage if the cervical restoration leaked or was lost. Furthermore, the intraradicular extension simultaneously reinforces the cervical region and enhances the ETT's fracture resistance (13, 26). Hence, this specific restorative protocol might have enhanced the survival rate against fracture of the anterior ETT restored with resin composite in this study.

For the ETT restored with a crown, a prefabricated post was usually used, however, no post was placed in the resin composite group. A prefabricated fibre post is likely to reinforce the ETT cervical area to resist lateral functional forces (8, 30, 31). However, the results indicated that fractures still occurred in the crown group with a fibre post when the tooth structure was lost from the cervical exposure in combination with an additional cavity. In this situation, an increase in the fracture resistance from the fibre post placement tended to be insufficient to completely prevent a cervical fracture. Naumann et al. proposed that the remaining cervical tooth structure (as a ferrule) is more important than placing a post in resisting functional forces (32).

A limitation of the present study is that due to its retrospective cohort study design, selection bias in post-endodontic restoration (resin composite or crown) may have been affected by the remaining tooth structure and/or dental practitioners' preference, which were confounding factors.

Moreover, the outcome may be affected by the attrition bias. Therefore, a randomized controlled clinical trial that compares the two restoration groups in the anterior ETT affected by cervical lesions with pulpal involvement and additional tooth structure loss, should be performed. In addition, in this study, the remaining tooth structure was subjectively estimated by the restorative dentist. Currently, the use of digital intraoral scanning provides the opportunity for a precise volumetric evaluation of the remaining tooth structure, which may affect the definitive restoration selection. A future study of post-endodontic restorations using digital intraoral scanning to evaluate residual tooth structure should be performed.

CONCLUSION

The survival rate against fracture of endodontically treated anterior teeth affected by cervical lesions with pulpal involvement restored with resin composite and a crown were not significantly different at a mean recall period of 33 months. Additional tooth structure loss in combination with a cervical lesion with pulpal involvement was a significant prognostic factor for post-endodontic fracture.

Disclosures

Conflict of interest: The authors deny any conflict of interest.

Ethics Committee Approval: This study was approved by The Institutional Review Board, Faculty of Dentistry and Faculty of Pharmacy, Mahidol University, Bangkok, Thailand (Date: 28/02/2022, Number: MU-DT/PY-IRB 2020/DT011).

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