EUROPEAN ENDODONTIC JOURNAL

ORIGINAL ARTICLE

Tooth Fracture and Associated Risk Factors in Permanent Molars Treated with Vital Pulp Therapy and Restored with Direct Resin Composites: A Retrospective Survival Analysis in Young Patients

Nattakan CHAIPATTANAWAN,[1] Papimon CHOMPU-INWAI,[1] Chanika MANMONTRI,[1] Piriya CHERDSATIRAKUL,[2] Areerat NIRUNSITTIRAT,[3] Phichayut PHINYO[4,5,6]

[1]Division of Pediatric Dentistry, Department of Orthodontics and Pediatric Dentistry, Chiang Mai University, Faculty of Dentistry, Chiang Mai, Thailand
[2]Division of Operative Dentistry, Department of Restorative Dentistry and Periodontology, Chiang Mai University, Faculty of Dentistry, Chiang Mai, Thailand
[3]Division of Community Dentistry, Department of Family and Community Dentistry, Chiang Mai University, Faculty of Dentistry, Chiang Mai, Thailand
[4]Department of Family Medicine, Faculty of Medicine, Chiang Mai University, Chiang Mai, Thailand
[5]Center for Clinical Epidemiology and Clinical Statistics, Faculty of Medicine, Chiang Mai University, Chiang Mai, Thailand
[6]Musculoskeletal Science and Translational Research (MSTR) Cluster, Chiang Mai University, Chiang Mai, Thailand

ABSTRACT

Objective: This study aimed to evaluate the survival from fractures and risk factors of VPT-treated permanent molars restored with direct resin composites in young patients.

Methods: The dental records of patients aged 6 to 18 years with VPT-treated permanent molars restored with resin composites were retrospectively evaluated for the presence of fractures on these teeth. Kaplan-Meier methods were used to estimate the survival probabilities. The potential risk factors were assessed using the multivariable Cox proportional hazard model.

Results: A total of 234 treated molars from 189 patients were included. An overall average follow-up time was 33.34±20.54 months (ranging from 6 to 83 months). At the end of the study, 21.8% of molars had fractures with the majority of them (92.2%) were restorable. Radiographically, only 3.9% of the fractured molars had periapical lesions and considered VPT failures. The percentages of the fracture types are as follows: 54.9% natural tooth structure fracture, 27.5% restoration fracture, and 17.6% combination fracture. The most common fracture location among the 37 molars with natural tooth fracture (either alone or in combination with restoration fracture) was at the marginal ridge (59.5%), followed by the marginal ridge extending to cusp (21.6%), and the cusp itself (18.9%). The cumulative survival probabilities of these teeth decreased over time, reaching 66.02% (95% CI: 55.89–74.36) after 5 years. VPT-treated molars in the mandible had a 2.1 times higher risk of fracture than those in the maxilla. Furthermore, the molars treated with partial and coronal pulpotomy had 2.4 times and 4.6 times higher risks of fracture when compared to those with indirect pulp capping, respectively.

Conclusion: In VPT-treated permanent molars in young patients, more fractures were seen in mandibular teeth and in teeth with pulp roof removal (partial and coronal pulpotomy). Clinicians should plan for proper restoration on these teeth.

Keywords: Direct resin composite restorations, permanent molars, risk factors, survival from fracture, vital pulp therapy

HIGHLIGHTS

- Clinicians performing VPT in permanent molars of young patients should be aware that the teeth will be more prone for fractures
- Permanent molars restored with resin composites following VPT in young patients especially those in mandibles and those with pulp roof removal (partial and coronal pulpotomy), showed higher a number of fractures.
- The results of our study may be useful for the development of specific guidelines for restoration in VPT-treated permanent teeth in young patients.

Please cite this article as:
Chaipattanawan N, Chompu-inwai P, Manmontri C, Cherdsatirakul P, Nirunsittirat A, Phinyo P. Tooth Fracture and Associated Risk Factors in Permanent Molars Treated with Vital Pulp Therapy and Restored with Direct Resin Composites: A Retrospective Survival Analysis in Young Patients. Eur Endod J 2023; 8: 37-46

Address for correspondence:
Papimon Chompu-inwai
Division of Pediatric Dentistry, Department of Orthodontics and Pediatric Dentistry, Chiang Mai University, Faculty of Dentistry, Chiang Mai, Thailand
E-mail: papimonin@hotmail.com

Received August 06, 2022,
Revised October 13, 2022,
Accepted December 13, 2022

Published online: January 13, 2023
DOI 10.14744/eej.2022.18894

INTRODUCTION

Vital pulp therapy (VPT) is currently considered the viable option for management of vital permanent teeth with deep caries (1–3). According to the European Society of Endodontology (ESE), types of VPT procedures, based on the concept of non-selective carious-tissue removal to hard dentine, include indirect pulp capping, direct pulp capping, partial pulpotomy, and coronal pulpotomy (4). Previous clinical studies regarding VPT in permanent teeth of young patients reported high success rates, ranging approximately from 90% to 95% (5, 6). Although the high pulp healing capacity of permanent teeth in young patients makes the major contribution to promising results of VPT (5, 6), other unique features of these teeth may make them more susceptible to fractures, jeopardizing their long-term survival (7).

Fractures of endodontically treated teeth are usually associated with loss of coronal tooth structure from extensive caries lesions and endodontic procedures (8, 9). Because of their incomplete mineralized dentine and enamel, deep caries of permanent teeth in young patients often results in extensive loss of coronal tooth structure (7, 10). Furthermore, the thin dentine wall and large pulp chamber in these teeth can make them even more susceptible to tooth fracture (7). The devastating results of fractures in these teeth can range from compromising the success of endodontic treatment (11) to losing the treated tooth, if fractures are extensive and cause the tooth to be unrestorable (12).

To protect the tooth from fracture, a permanent full coverage crown is traditionally recommended (13). Nevertheless, the survival from fracture of root canal-treated molars restored with either direct resin composites or crowns in patients older than 18 years old, were shown to be comparable in the treated molars with only occlusal surface loss (14). This finding supports the results of previous studies that the preservation of marginal ridge plays a significant role in maintaining the integrity of the tooth structure (15, 16). In addition, the placement of permanent crowns in young patients can be difficult due to the level of their cooperation. Moreover, the unique features of permanent teeth in young patients, such as short clinical crowns, thin dentine wall, large pulp chambers, immature proximal contact and occlusion, and subgingival crown margins, can further complicate the permanent crown procedure in these teeth (17). For these reasons, VPT-treated permanent molars in young patients have been commonly restored with direct resin composite in several clinical studies (5, 6).

When compared to root canal treatment (RCT), VPT is considered less invasive, however the degree of invasiveness is variable. Indirect pulp capping and direct pulp capping do not involve removal of roof chamber and pulp tissue. Conversely, partial and coronal pulpotomy relate with different degree of removal, ranging from partial to complete removal of both structures. Thus, risk factors affecting the survival from fracture of VPT-treated teeth are possibly different from those of root canal-treated teeth and have not yet been determined. Therefore, the aims of this retrospective cohort study were to evaluate the survival probabilities from fractures and to identify the associated risk factors in VPT-treated permanent molars of 6- to 18-year-old patients.

MATERIALS AND METHODS

Study Design and Ethic Approval

This study was designed as a retrospective cohort university-based study and was approved by the Human Experimentation Committee, Faculty of Dentistry, Chiang Mai University, Chiang Mai , Thailand (No 47/2018). Informed consent or assent were waived as the data was collected retrospectively by chart review. Reporting follows the STROBE guidelines (18).

Sample Size Calculation

The sample size of this retrospective cohort study was calculated by using the Power analysis for the Cox proportional hazards model, with a significance level of 0.05 and a statistical power of 0.8. Based on the result of a previous 5-year retrospective cohort study by Nagasiri and Chitmongkolsuk (19), the probability of event was 0.45 (45%, 101/220 of teeth had fractures). With the effect size (anticipated Hazard ratio) of 2.1 and proportional of withdrawals of 0.4, the total sample size needed for this 5-year retrospective cohort study was 212 teeth.

Study Participants and Inclusion Criteria

All data were collected from dental records of patients aged between 6 and 18 years old at the time of treatment, whose permanent molars received VPT at the Pediatric Dentistry Clinic, Faculty of Dentistry, Chiang Mai University between September 2012 and March 2019. Teeth were initially included in this study if: 1) They were treated with non-selective carious-tissue removal to hard dentine, followed by one of the VPT procedures according to the ESE position statement (4): indirect pulp capping, direct pulp capping, partial pulpotomy, or coronal pulpotomy; 2) They were restored with direct resin composites; 3) They had at least one opposing tooth with occlusal contact; 4) They had participated in at least one recall; 5) They had all required data documented in the dental record. The exclusion criterion was teeth reinforced with metal bands.

Vital Pulp Therapy and Direct Resin Composite Restorative Procedures

The VPT procedure and direct resin composite restorations were performed under rubber dam isolation by postgraduate dental students in pediatric dentistry, with at least 2 years of clinical experience as a general dental practitioner. All students were orientated for the protocol used before performing these procedures. Moreover, every step was supervised by one experienced instructor (PC), specialist in pediatric dentistry. The magnification was not used in any procedures.

The protocol for each VPT procedure, including irrigant and pulp dressing material used, is shown in Figure 1. For restorative procedure, the base material and surrounding dentine wall were etched with 37% phosphoric acid (ScotchbondTM etchant; 3M ESPE, St. Paul, MN) for 15 seconds and rinsed thoroughly for 20 seconds. Later, two-step total-etch adhesive (AdperTM Single Bond; 3M ESPE) was applied, according to the manufacturer's instructions. Finally, the cavity was filled with

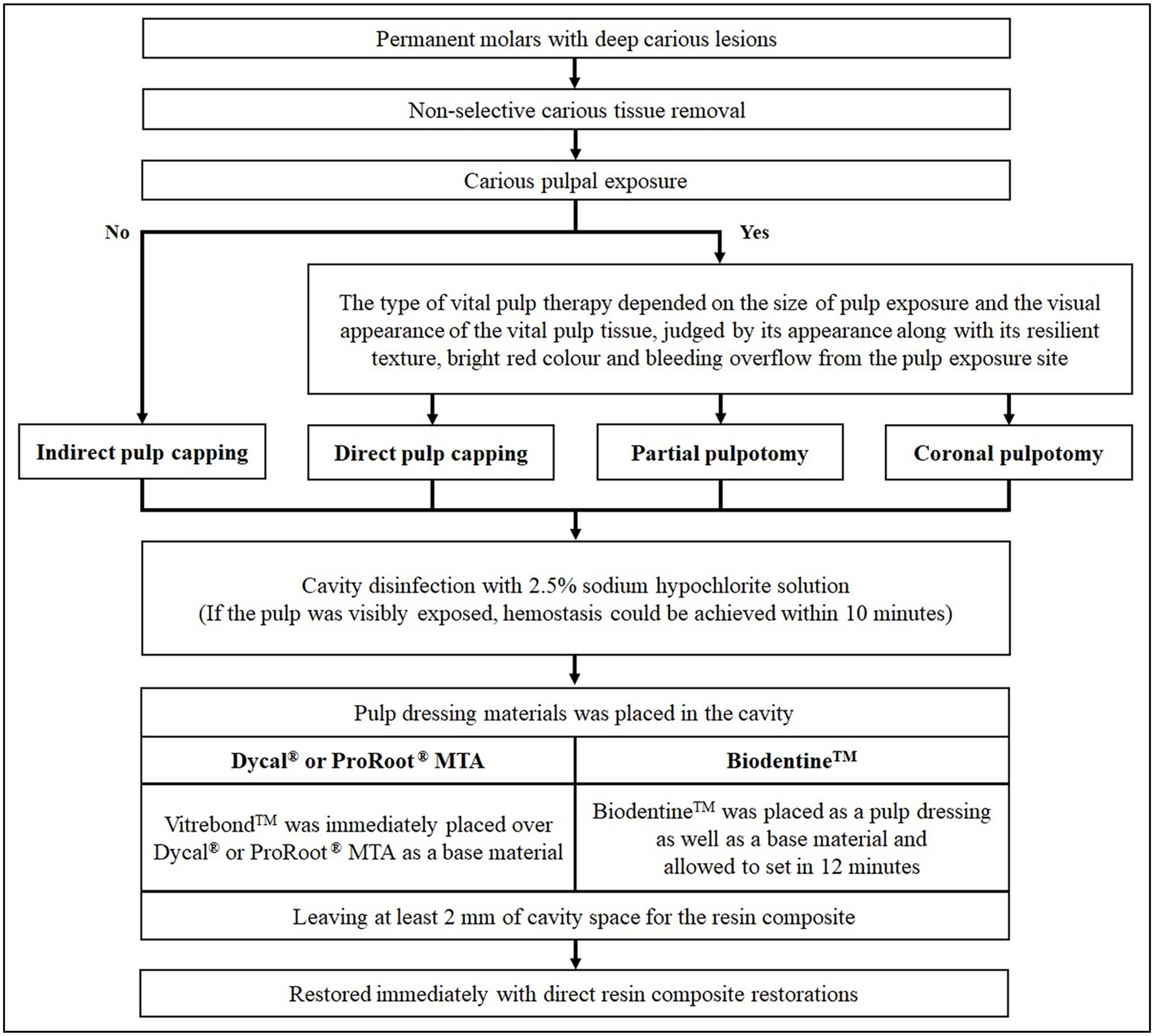

Figure 1. Flow diagram of vital pulp therapy

MTA: Mineral trioxide aggregate

a universal nanohybrid resin composite (FiltekTM Z350 XT; 3M ESPE) using the incremental technique, and each layer was light cured for 40 seconds. The occlusion and proximal contact were checked.

Afterward, all treated teeth were clinically and radiographically followed up approximately every 6 months by undergraduate and postgraduate dental students, under the supervision of two instructors (PC and CM).

Data Collection

Patients' records from September 2012 to September 2019 were retrospectively evaluated to gather the baseline data and presence of the events of interest (failure), which were fractures of the VPT-treated teeth. If any fracture had not occurred during the observation period, the treated tooth was described as "survival". The fracture assessment criteria, described in previous clinical studies (20, 21), were used in this study. Fracture restorability was classified into a restorable fracture (can be repaired or replaced; with either a direct resin composite or stainless steel crown) and an unrestorable fracture (the fracture extends considerably subgingivally necessitating extraction of the tooth). Moreover, the fractures were classified into 3 types, including a natural tooth structure fracture, a restoration fracture, and a combination of a natural tooth and a restoration fracture. The fracture location on the remaining tooth structure was also documented as being at the marginal ridge, at the cusp, or at the marginal ridge extending to the cusp.

The survival time to failure was set as the time between the date of treatment and the date of fracture. If the date of fracture could not be definitely indicated, the survival time was estimated as halfway between the last recall visit at which the treated tooth was considered as survival, and the date at which the fracture was seen, the method described by Kopperud et al. (22) However, some participants were considered as censored survival data when information on survival time was unavailable. In other words, censored teeth were those for which we could not verify whether or not the event occurred, making it impossible to determine the survival time of those teeth. In this study, censored survival data were determined if teeth: 1) were lost to follow-up for at least 6 months after the last recall visit; 2) were subsequently treated with RCT or extracted due to VPT failure without any fracture; and 3) were extracted for orthodontic treatment. The survival time of the censors was set as the time between the date of treatment and the last recall visit at which the treated tooth was considered as survival.

Moreover, the potential risk factors including sex, tooth location, stage of root development, number of marginal ridge losses, type of VPT procedure, and pulp dressing and base materials used, were also investigated.

Statistical Methods for Data Analysis

The descriptive analysis provides the distribution summary according to the potential risk factors affecting fractures. The Kaplan-Meier survival analysis was used to calculate the cumulative survival probabilities from fractures. This method involves calculating of probabilities of event occurrence at a certain point of time and a log-rank test is used to determine whether significant differences exist for each variable and survival outcome (23). Moreover, the multivariable Cox proportional-hazards regression was used to evaluate the risk factors affecting fractures. This regression model is the statistical technique used for exploring the relationship between the survival outcome and potential risk variables (24). Hazard ratios (HR) and their 95% confidence intervals (95% CI) were obtained. All statistical analyses were performed using the SPSS 24.0 software (SPSS Science, IBM Corp., Armonk, NY, US). All P-values less than 0.05 were considered as statistically significant.

RESULTS

A total of 218 patient records were screened. Of these, a total of 270 VPT-treated molars restored with direct resin composites were initially included, but 20 of these teeth had never taken part in the recall program, resulting in 250 teeth that met the inclusion criteria. Among them, 16 teeth were excluded due to the presence of a reinforced metal band. Consequently, 234 teeth from 189 patients (80 male and 109 female, average age 9.8±2.0 years old) were analyzed in the study (Fig. 2). An overall average follow-up time was 33.34±20.54 months (ranging from 6 to 83 months), whereas median (interquartile range) follow-up was 26.5 (16, 50) months.

Survival Probabilities from Fractures of Vital Pulp Therapy-Treated Permanent Molars

The distribution of fractured molars is presented in Table 1. At the end of the study, 21.8% (51/234) of molars had fractures with the majority of them (92.2%, 47 out of 51 teeth) were restorable. Radiographically, only 2 out of 51 (3.9%) fractured molars had periapical lesion and considered VPT failures. The percentages of the fracture types are as follows: 54.9% (28/51) natural tooth structure fracture, 27.5% (14/51) restoration fracture, and 17.6% (9/51) combination fracture. The most common fracture location among the 37 molars with natural tooth fracture (either alone or in combination with restoration fracture) was at the marginal ridge (59.5%), followed by the marginal ridge extending to cusp (21.6%), and the cusp itself (18.9%).The Kaplan-Meier cumulative survival curve against time for VPT-treated molars restored with direct resin composite is presented in Figure 3. The cumulative survival probabilities decreased over the first 5 years of observation (Fig. 3), with 1-, 2-, 3-, 4-, and 5-year cumulative survival probabilities of 90.38%, 82.32%, 78.43%, 72.68%, and 66.02%, respectively (Table 2). However, after 5 years, the cumulative survival probabilities remained constant.

Potential Risk Factors Associated with Fractures

The data distribution of the included molars according to the potential risk factors affecting fractures is shown in Table 3. Using the Cox proportional hazards regression in both non-adjusted and adjusted models, potential risk factors affecting the survival from fractures of the treated teeth are presented in Table 4. Two significant potential risk factors affecting the survival from fractures in our study were tooth location and type of VPT procedure ($P<0.05$). Other variables were considered not significant risk factors ($P\geq0.05$).

In the multivariable analysis, adjusted by sex, tooth location, stage of root development, number of marginal ridge losses, type of VPT procedure, and pulp dressing and base material used (Table 4), VPT-treated molars in the mandible had a 2 times higher risk of fracture than those in the maxilla (adjusted HR: 2.057; 95% CI: 1.047–4.038, P=0.036). Furthermore, the teeth treated with partial and coronal pulpotomy had 2.4 times (adjusted HR: 2.395; 95% CI: 1.136–5.051, P=0.022) and 4 times (adjusted HR: 4.568; 95% CI: 1.820–11.466, P=0.001) higher risks of fracture when compared to those with indirect pulp capping, respectively. However, there was no significant difference between the teeth treated with indirect pulp capping and direct pulp capping (adjusted HR: 0.510; 95% CI: 0.154–1.686, P=0.270).

The Kaplan-Meier cumulative survival probabilities from fracture curves, against follow-up periods for the VPT-treated teeth categorized by tooth locations and type of VPT procedures, are presented in Figure 4 and 5, respectively.

DISCUSSION

VPT has shown very promising successful outcomes in permanent molars in young patients (5, 6). However, the unique features of these teeth make them highly susceptible to fractures, which may further affect their survival. To the best of our knowledge, this is the first study that has investigated the survival from fracture and associated risk factors of VPT-treated permanent molars restored with direct resin composite in young patients. The results of this study will be beneficial to clinicians for designing and selecting the appropriate type of restoration to ultimately minimize fracture following VPT.

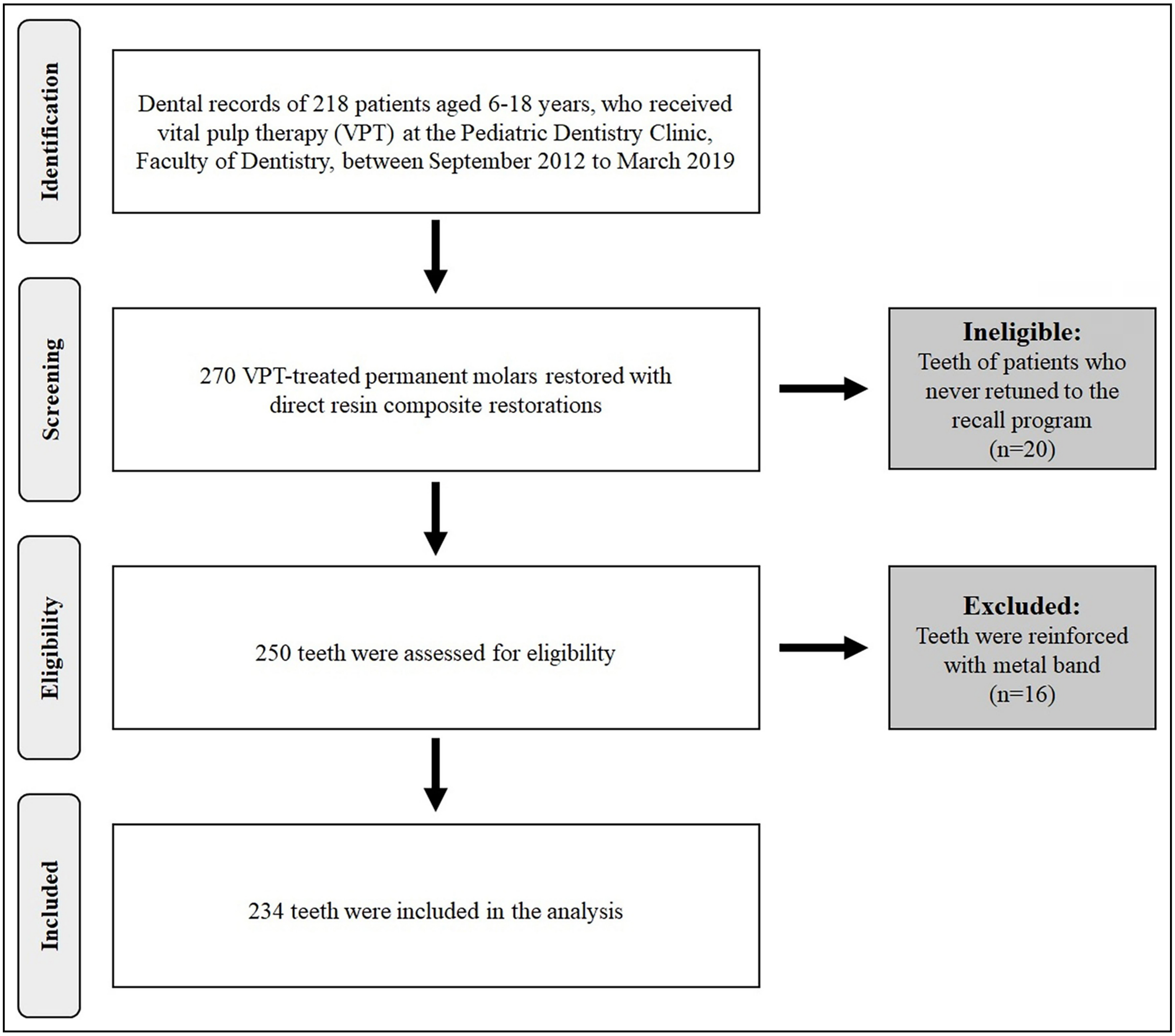

Figure 2. Flow diagram of this retrospective study

For survival analyses, the Kaplan-Meier estimator was used in our study. The survival probability from fracture of VPT-treated permanent molars in young patients restored with direct resin composite decreased from 100% to 66.02% in the first 5-year observation period. After 5 years, the cumulative survival probabilities remained constant. However, the result of this survival analysis should be interpreted with caution because there was a small number of VPT-treated teeth reaching more than 5 years follow-up. The 5-year cumulative survival probability (66.02 %) of VPT-treated teeth in our study is higher than that of root canal-treated teeth in one study (approximately 45%) (19) but is lower than those of root canal-treated teeth (approximately 80%) in two studies (14, 21). Although the data from different studies could not be directly compared because they differ in several aspects, it may be speculated that not only the type of endodontic treatment performed (VPT versus RCT), but the existing features of the treated teeth (thin versus thick dentine wall) may also have contributed to number of fractures. In general, VPT is considered to provide greater preservation of tooth structure than RCT. However, the low number of survival of VPT-treated teeth in our study may prompt researchers to further investigate proper management of permanent molars in children specifically. Moreover, future studies that directly compare the survival from fracture of VPT-treated posterior teeth between young and adult patients, and the survival from fracture of teeth following VPT and RCT in both young and adult patients may add more information to this issue.

When looking closely to the detail of fractures, approximately one-fifth (21.8%) of all treated teeth had fractures. There were 27.5% of restoration fractures, often presenting at or above the gingival area. This type of fracture is usually restorable and can be repaired or replaced easily (20). On

TABLE 1. Data distribution of vital pulp therapy-treated permanent molars with fracture according to fracture restorability, type, and fracture location on the remaining tooth structure

Fracture characteristics	n/N	%
Restorability (N=51)		
Restorable fracture	47/51	92.2
Unrestorable fracture	4/51	7.8
Radiographic sign of periapical lesion (N=51)		
Absence	49/51	96.1
Presence	2/51	3.9
Fracture type (N=51)		
Tooth structure fracture	28/51	54.9
Restoration fracture	14/51	27.5
Combination fracture	9/51	17.6
Fracture location on the remaining tooth structure (N=37*)		
Marginal ridge	22/37	59.5
Marginal ridge extending to cusp	8/37	21.6
Cusp	7/37	18.9

*: The tooth with restoration fracture were not counted

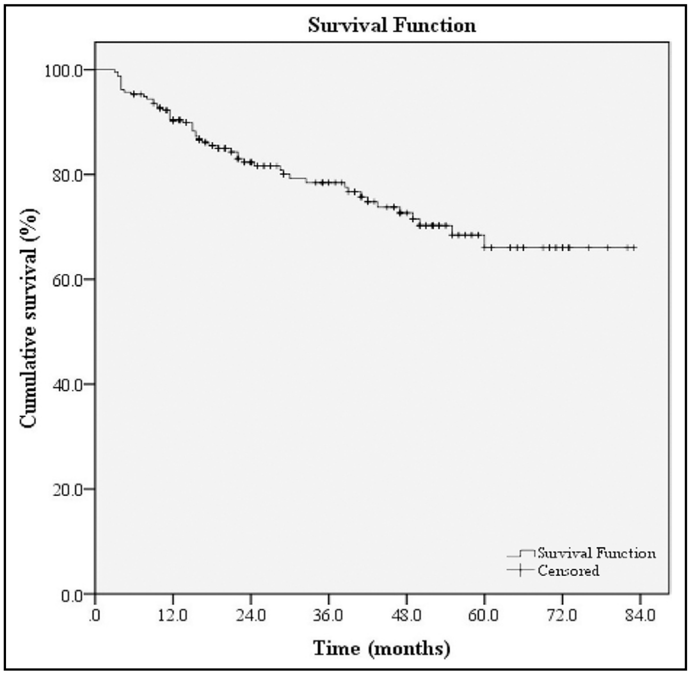

Figure 3. The Kaplan-Meier cumulative survival probability from fracture curve of vital pulp therapy-treated permanent molars restored with direct resin composite restorations

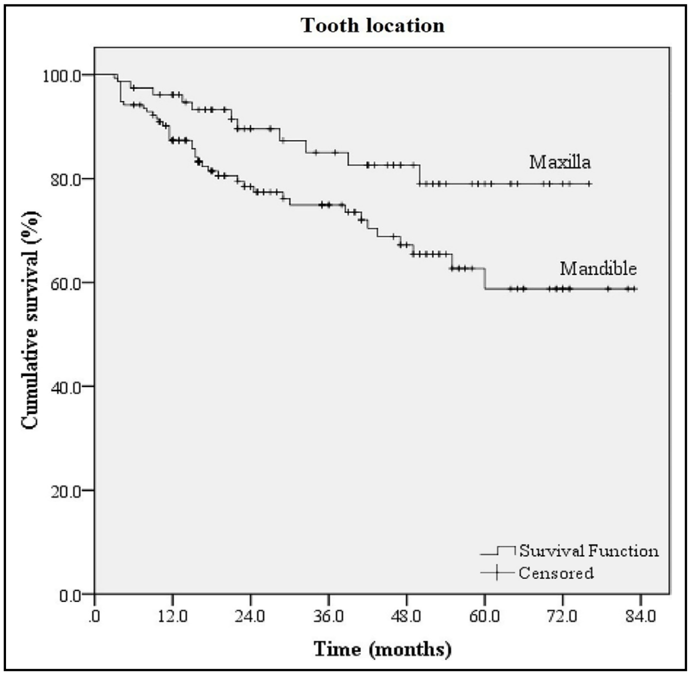

Figure 4. The Kaplan-Meier cumulative survival probabilities from fracture curves of vital pulp therapy-treated permanent molars according to tooth location (maxilla and mandible)

the other hand, there was a high incidence of fractures on tooth structure (54.9%), which were probably the results of the pre-existing thin dentine wall, extensive destruction from caries, and VPT procedure itself. Moreover, the most common fracture locations on the remaining tooth structure were at the marginal ridge (59.5%), followed by the marginal ridge extending to cusp (21.6%). The loss of marginal ridges was strongly associated with the loss of flexural strength in posterior teeth, resulting in cuspal deflection or leading to an unrestorable condition (15, 16). In this study, 7.8% of fractured teeth were unrestorable, and thus were extracted, despite their successful VPT outcome. In-depth knowledge regarding factors specifically contributing to the unrestorability of the fractures will definitively aid in the development of appropriate treatment plans for these teeth.

For all types of fracture, there are two significant potential risk factors: tooth location and type of VPT procedure. Regarding the tooth location, most fractures in our study were observed in the mandibular molars, with approximately 2 times lower survival compared to those in the maxillary molars. The reason may have been that the protruding palatal cusps of the maxillary molars occluded forcefully into the central fossa of the mandibular molars, leading to the greater risk of tooth fracture in the mandibular molars (25). However, the occlusion status of each patient was not recorded, and thus may be considered as a limitation of this study.

Another risk factor affecting fractures in our study was the type of VPT procedure. When compared to those with indirect pulp capping, molars treated with partial and coronal pulpotomy had an approximately 2.4 times and 4 times lower survival, respectively. Previously, it has been demonstrated that the removal of pulpal roof under greater occlusal loads can affect the fracture strength of the root canal-treated posterior teeth (26). Likewise, both partial and coronal pulpotomy were the types of VPT procedure that involved the removal of pulpal roof. Thus, they can result in a more extensive destruction and greater susceptibility to tooth fracture than those teeth with indirect pulp capping and direct pulp capping, which are the VPT procedures not involving the removal of pulpal roof.

It appears that coronal pulpotomy is the most destructive form of VPT procedure because the entire pulpal roof and coronal

TABLE 2. The cumulative survival probabilities at each follow-up time point of vital pulp therapy-treated permanent molars restored with direct resin composite restorations

Follow-up time* (months)	Number of teeth at beginning	Number of teeth survived from fracture	Number of teeth that had fracture	Estimated cumulative survival probability % (Standard error)	95% confidence interval	
					Lower limit	Upper limit
0	234	234	0	100.0 (0)	Not applicable	
6	223	212	11	95.03 (1.38)	91.67	97.37
12	197	186	11	90.38 (1.95)	85.76	93.56
18	150	141	9	85.57 (2.42)	80.06	89.66
24	119	114	5	82.32 (2.73)	76.21	87.00
30	100	96	4	79.23 (3.03)	72.51	84.48
36	93	92	1	78.43 (3.11)	71.57	83.82
42	79	75	4	74.79 (3.46)	67.24	80.84
48	63	61	2	72.68 (3.67)	64.72	79.13
54	41	39	2	70.27 (3.92)	61.81	77.20
60	28	26	2	66.02 (4.72)	55.89	74.36
66	19	19	0	66.02 (4.72)	55.89	74.36
72	11	11	0	66.02 (4.72)	55.89	74.36
78	4	4	0	66.02 (4.72)	55.89	74.36
83	1	1	0	66.02 (4.72)	55.89	74.36

*: Observation time limited to 83 months

TABLE 3. Data distribution of the included 234 vital pulp therapy-treated permanent molars restored with direct resin composite restorations according to the potential risk factors affecting fractures

Potential risk factors	Number of teeth N	Number of teeth surviving from fracture		Number of teeth that had fracture	
		n/N	%	n/N	%
All vital pulp therapy-treated teeth	234	183/234	78.2	51/234	21.8
Sex					
Male	100	78/100	78.0	22/100	22.0
Female	134	105/134	78.4	29/134	21.6
Tooth location					
Maxilla	79	68/79	86.1	11/79	13.9
Mandible	155	115/155	74.2	40/155	25.8
Stage of root development					
Mature root	132	108/132	81.8	24/132	18.2
Immature root	102	75/102	73.5	27/102	26.5
Number of marginal ridge losses					
None	205	163/205	79.5	42/205	20.5
One marginal ridge (mesial or distal)	29	20/29	69.0	9/29	31.0
Two marginal ridges (both mesial and distal)	0	0/0	0	0/0	0
Type of vital pulp therapy procedures					
Indirect pulp capping	68	59/68	86.8	9/68	13.2
Direct pulp capping	53	49/53	92.4	4/53	7.6
Partial pulpotomy	83	57/83	68.7	26/83	31.3
Coronal pulpotomy	30	18/30	60.0	12/30	40.0
Pulp dressing and base material used					
Dycal® or ProRoot® MTA+Vitrebond™	149	117/149	78.5	32/149	21.5
Biodentine™	85	66/85	77.7	19/85	22.3

MTA: Mineral trioxide aggregate

pulp tissue are removed. Moreover, coronal cavity preparation for coronal pulpotomy procedures that had a longer remaining part of the marginal ridge than its width can lead to a greater risk of fracture from occlusal forces (27). For these reasons, previous studies have already recommended prosthetic crowns for coronal restoration following coronal pulpotomy (28, 29). Moreover, Yong and Cathro (30) have suggested that if coronal pulpotomy-treated teeth present favourable

TABLE 4. Multivariable Cox proportional hazards regression model analysis of vital pulp therapy-treated permanent molars restored with direct resin composite restorations

Potential risk factors	Unadjusted model		Adjusted model	
	HR (95% CI)	P	HR (95% CI)	P
Sex				
Male	1.00	–	1.00	–
Female	1.010 (0.570–1.790)	0.973	1.100 (0.586–2.060)	0.769
Tooth location				
Maxilla	1.00	–	1.00	–
Mandible	2.142 (1.083–4.237)	0.029*	2.057 (1.047–4.038)	0.036*
Stage of root development				
Mature root	1.00	–	1.00	–
Immature root	1.700 (0.975–2.965)	0.061	1.800 (0.984–3.282)	0.057
Number of marginal ridge losses				
No	1.00	–	1.00	–
One marginal ridge	1.360 (0.713–2.594)	0.351	1.734 (0.872–3.448)	0.117
Two marginal ridges	N/A	N/A	N/A	N/A
Type of vital pulp therapy procedure				
Indirect pulp capping	1.00	–	1.00	–
Direct pulp capping	0.558 (0.171–1.820)	0.334	0.510 (0.154–1.686)	0.270
Partial pulpotomy	2.579 (1.259–5.286)	0.010*	2.395 (1.136–5.051)	0.022*
Coronal pulpotomy	4.442 (1.885–10.466)	0.001*	4.568 (1.820–11.466)	0.001*
Pulp dressing and base material used				
Dycal® or ProRoot® MTA+Vitrebond™	1.00	–	1.00	–
Biodentine™	0.778 (0.445–1.361)	0.379	0.783 (0.428–1.433)	0.428

P-values with asterisk (*) were considered as statistically significant (P<0.05). HR: Hazard ratio, CI: Confidence interval, N/A: Not applicable, MTA: Mineral trioxide aggregate

outcomes 12 months postoperatively, the placement of full coverage restorations should be considered.

For teeth with partial pulpotomy, it has been reported previously that the preservation of pulpal roof may distribute the occlusal forces, thus resulting in the reduced risk of fracture (31, 32). Although partial pulpotomy is less invasive than coronal pulpotomy because the procedure involves only partial removal of pulp roof and pulp tissue, there was a marked decrease in survival over time. Therefore, caution should be applied not only to coronal pulpotomy, but also to partial pulpotomy; the permanent molars treated with partial pulpotomy in young patients should also be regularly and closely followed, and interim full coverage crowns, such as stainless steel crowns, may be considered when necessary.

Besides tooth location and type of VPT procedure, the loss of marginal ridge integrity may also have a detrimental effect on survival. Chotvorrarak et al. (14) demonstrated in their clinical study, regarding the survival from fracture of the root canal-treated molars restored with direct resin composites in patients aged 18 to 78 years old, that the treated molars with tooth structure loss limited to the occlusal surface had a lower incidence of fracture than teeth with loss of marginal ridge. Conversely, the loss of marginal ridge integrity was not a significant factor affecting fracture in our study. The reason for differences between the present and previous studies may lie in the fact that most VPT-treated molars in young patients in this study had a deep destructive occlusal cavity with thin dentine walls. Even though the remaining thin dentine wall exists, they are still at high risk of tooth fracture, thus resulting in no difference in number of fractures between teeth with different numbers of tooth surface loss. Previous *in vitro* studies have reported a reduction in tooth resistance to fracture when a marginal ridge thickness was less than 2 mm in root canal-treated posterior teeth (33, 34). However, the re-

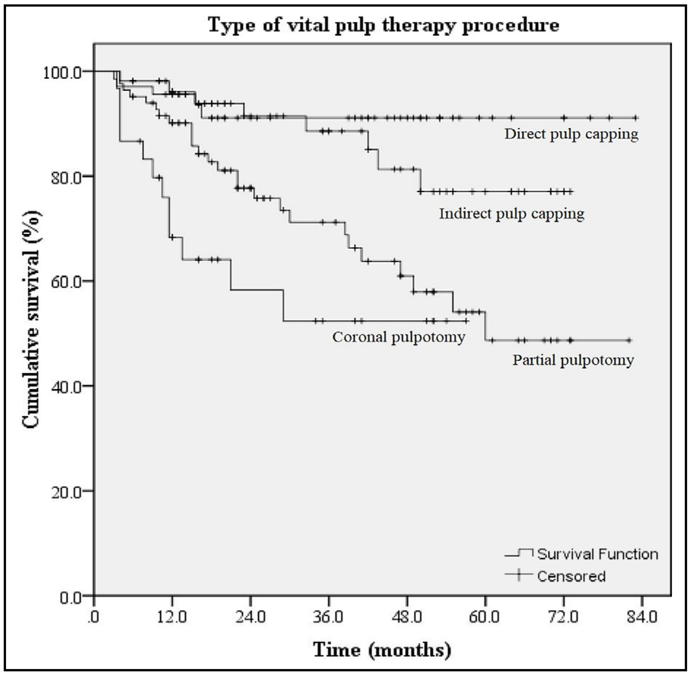

Figure 5. The Kaplan-Meier cumulative survival probabilities from fracture curves of vital pulp therapy-treated permanent molars according to type of vital pulp therapy procedure (indirect pulp capping, direct pulp capping, partial pulpotomy, and coronal pulpotomy)

maining wall thicknesses were not recorded at the time of treatment, which is considered a limitation of this retrospective study. Moreover, the VPT-treated molars restored with resin composites in this study were apparently only teeth with less than two marginal ridge losses. The reason behind this trend is the fact that severely destroyed molars in young patients with more than two marginal ridge losses have often been restored with interim preformed metal crowns or sometimes been extracted (35, 36).

Although the stage of root development was not a significant factor affecting fracture in our study, there was a trend toward the significant level in the adjusted model of the multivariable Cox proportional hazards regression analysis. The stage of root development (immature versus mature root) has been previously demonstrated to affect the risk of fracture in anterior teeth. Thin dentine walls of immature roots make them prone to fracture with reported fracture incidences in incisors from 28% to 77% (37). In a finite element evaluation analysis, it was confirmed that the pattern of stress distribution in mature and immature incisors is different. Cervical area of the buccal surface in immature incisors had the high rate of fracture because it is one of the stress concentration areas (38). However, studies on fracture in immature versus mature posterior teeth with VPT should be further investigated.

Owing to the retrospective nature of this study, some limitations could not be avoided. First, there was a high number of subjects categorized as censors (41.9%), which can lead to underestimation of survival probabilities. Second, some other potential risk factors that may have affected the survival from fracture such as severity of enamel hypomineralization, occlusal stress risk, dentine wall thickness, proximal contact of adjacent teeth, patients' oral hygiene and caries risk factors, have not been recorded nor evaluated. Last, VPT procedure was performed by several postgraduate dental students in Pediatric Dentistry with different clinical skills and experiences. However, one experienced pediatric dentist supervised all of the procedures. Future prospective randomized clinical trials with long-term follow-up should be performed to address these limitations.

The recent emerging evidence on success of VPT has encouraged advocacy of this conservative pulp therapy as one of the reliable alternatives for pulpally-involved teeth (4). However, it could not be overemphasized that minimizing fractures in these teeth are as important as keeping their pulp alive. Prospective future studies designed for collecting other possible risk factors for fracture can probably give us more specific information regarding this matter. Moreover, the methods in minimizing fractures, including cavity design, type of adhesive and restorative materials, and type of interim full coverage crowns appropriate for VPT-treated permanent teeth in young patients, should be further studied.

CONCLUSION

Because more fractures were seen in VPT-treated young permanent mandibular molars with pulp roof removal, clinicians should plan for proper restoration on these teeth.

Disclosures

Acknowledgments: The authors thank Mr. Martin Clutterbuck, for his assistance in the preparation of the manuscript.

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

Ethics Committee Approval: This study was approved by The Chiang Mai University, Faculty of Dentistry Human Experimentation Ethics Committee (Date: 18/09/2018, Number: 47/2018).

Peer-review: Externally peer-reviewed.

Financial Disclosure: This research was supported by the Research Fund for Postgraduate Students of the Faculty of Dentistry, Chiang Mai University, Chiang Mai, Thailand.

Authorship contributions: Concept – N.C., P.C., C.M.; Design – N.C., P.C., C.M., A.N.; Supervision – N.C., P.C., C.M.; Funding - None; Materials - N.C., P.C., C.M.; Data collection and/or processing – N.C., P.C., C.M.; Analysis and/or interpretation – N.C., P.C., C.M., A.N., P.P.; Literature search – N.C., P.Che., C.M., P.C.; Writing – N.C., P.C., C.M., P.Che. A.N., P.P.; Critical Review – N.C., P.C., C.M., P.Che. A.N., P.P.

REFERENCES

1. Asgary S, Eghbal MJ. Treatment outcomes of pulpotomy in permanent molars with irreversible pulpitis using biomaterials: a multi-center randomized controlled trial. Acta Odontol Scand 2013; 71(1):130–6.
2. Brodén J, Davidson T, Fransson H. Cost-effectiveness of pulp capping and root canal treatment of young permanent teeth. Acta Odontol Scand 2019; 77(4):275–81. [CrossRef]
3. Taha NA, Khazali MA. Partial pulpotomy in mature permanent teeth with clinical signs indicative of irreversible pulpitis: a randomized clinical trial. J Endod 2017; 43(9):1417–21. [CrossRef]
4. Duncan HF, Galler KM, Tomson PL, Simon S, El-Karim I, Kundzina R, et al; European Society of Endodontology (ESE). European Society of Endodontology position statement: management of deep caries and the exposed pulp. Int Endod J 2019; 52(7):923–34. [CrossRef]
5. Parinyaprom N, Nirunsittirat A, Chuveera P, Na Lampang S, Srisuwan T, Sastraruji T, et al. Outcomes of direct pulp capping by using either proroot mineral trioxide aggregate or biodentine in permanent teeth with carious pulp exposure in 6- to 18-year-old patients: a randomized controlled trial. J Endod 2018; 44(3):341–8. [CrossRef]
6. Uesrichai N, Nirunsittirat A, Chuveera P, Srisuwan T, Sastraruji T, Chompu-Inwai P. Partial pulpotomy with two bioactive cements in permanent teeth of 6- to 18-year-old patients with signs and symptoms indicative of irreversible pulpitis: a noninferiority randomized controlled trial. Int Endod J 2019; 52(6):749–59. [CrossRef]
7. Baba NZ, White SN, Bogen G. Restoration of endodontically treated teeth. In: Chugal N, Lin LM, editors. Endodontic Prognosis. 1st ed. Switzerland: Springer International Publishing; 2017. p.161–92. [CrossRef]
8. Ferrari M, Vichi A, Fadda GM, Cagidiaco MC, Tay FR, Breschi L, et al. A randomized controlled trial of endodontically treated and restored premolars. J Dent Res 2012; 91(Suppl 7):S72–8. [CrossRef]
9. Dammaschke T, Nykiel K, Sagheri D, Schäfer E. Influence of coronal restorations on the fracture resistance of root canal-treated premolar and molar teeth: a retrospective study. Aust Endod J 2013; 39(2):48–56.
10. Lynch RJ. The primary and mixed dentition, post-eruptive enamel maturation and dental caries: a review. Int Dent J 2013; 63(Suppl 2):S3–13.
11. Mandke L. Importance of coronal seal: preventing coronal leakage in endodontics. J Restor Dent 2016; 4(3):71. [CrossRef]
12. Touré B, Faye B, Kane AW, Lo CM, Niang B, Boucher Y. Analysis of reasons for extraction of endodontically treated teeth: a prospective study. J Endod 2011; 37(11):1512–5. [CrossRef]
13. Ng YL, Mann V, Gulabivala K. Tooth survival following non-surgical root canal treatment: a systematic review of the literature. Int Endod J 2010; 43(3):171–89. [CrossRef]
14. Chotvorrarak K, Suksaphar W, Banomyong D. Retrospective study of fracture survival in endodontically treated molars: the effect of single-unit crowns versus direct-resin composite restorations. Restor Dent Endod 2021; 46(2):e29. [CrossRef]
15. Reeh ES, Messer HH, Douglas WH. Reduction in tooth stiffness as a result of endodontic and restorative procedures. J Endod 1989; 15(11):512–6.

16. Panitvisai P, Messer HH. Cuspal deflection in molars in relation to endodontic and restorative procedures. J Endod 1995; 21(2):57–61.
17. Koch MJ, García-Godoy F. The clinical performance of laboratory-fabricated crowns placed on first permanent molars with developmental defects. J Am Dent Assoc 2000; 131(9):1285–90. [CrossRef]
18. von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP; STROBE Initiative. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement: guidelines for reporting observational studies. Int J Surg 2014; 12(12):1495–9. [CrossRef]
19. Suksaphar W, Banomyong D, Jirathanyanatt T, Ngoenwiwatkul Y. Survival rates from fracture of endodontically treated premolars restored with full-coverage crowns or direct resin composite restorations: a retrospective study. J Endod 2018; 44(2):233–8. [CrossRef]
20. Jirathanyanatt T, Suksaphar W, Banomyong D, Ngoenwiwatkul Y. Endodontically treated posterior teeth restored with or without crown restorations: a 5-year retrospective study of survival rates from fracture. J Investig Clin Dent 2019; 10(4):e12426. [CrossRef]
21. Nagasiri R, Chitmongkolsuk S. Long-term survival of endodontically treated molars without crown coverage: a retrospective cohort study. J Prosthet Dent 2005; 93(2):164–70. [CrossRef]
22. Kopperud SE, Tveit AB, Gaarden T, Sandvik L, Espelid I. Longevity of posterior dental restorations and reasons for failure. Eur J Oral Sci 2012; 120(6):539–48. [CrossRef]
23. Barakat A, Mittal A, Ricketts D, Rogers BA. Understanding survival analysis: actuarial life tables and the Kaplan-Meier plot. Br J Hosp Med (Lond) 2019; 80(11):642–6. [CrossRef]
24. Bradburn MJ, Clark TG, Love SB, Altman DG. Survival analysis part II: multivariate data analysis--an introduction to concepts and methods. Br J Cancer 2003; 89(3):431–6. [CrossRef]
25. Mamoun JS, Napoletano D. Cracked tooth diagnosis and treatment: an alternative paradigm. Eur J Dent 2015; 9(2):293–303. [CrossRef]
26. González-López S, De Haro-Gasquet F, Vílchez-Díaz MA, Ceballos L, Bravo M. Effect of restorative procedures and occlusal loading on cuspal deflec-tion. Oper Dent 2006; 31(1):33–8. [CrossRef]
27. Marzouk MA, Simonton AL, Gross RD. Operative Dentistry: Modern Theory and Practice. 1st ed. St. Louis: Ishiyaku EuroAmerica; 1985.
28. Kunert GG, Kunert IR, da Costa Filho LC, de Figueiredo JAP. Permanent teeth pulpotomy survival analysis: retrospective follow-up. J Dent 2015; 43(9):1125–31. [CrossRef]
29. Zanini M, Hennequin M, Cousson PY. Which procedures and materials could be applied for full pulpotomy in permanent mature teeth? A systematic review. Acta Odontol Scand 2019; 77(7):541–51. [CrossRef]
30. Yong D, Cathro P. Conservative pulp therapy in the management of reversible and irreversible pulpitis. Aust Dent J 2021; 66(Suppl 1):S4–14.
31. Jiang W, Bo H, Yongchun G, LongXing N. Stress distribution in molars restored with inlays or onlays with or without endodontic treatment: a three-dimensional finite element analysis. J Prosthet Dent 2010; 103(1): 6–12.
32. Özyürek T, Ülker Ö, Demiryürek EÖ, Yılmaz F. The effects of endodontic access cavity preparation design on the fracture strength of endodontically treated teeth: traditional versus conservative preparation. J Endod 2018; 44(5):800–5. [CrossRef]
33. Scotti N, Rota R, Scansetti M, Paolino DS, Chiandussi G, Pasqualini D, et al. Influence of adhesive techniques on fracture resistance of endodontically treated premolars with various residual wall thicknesses. J Prosthet Dent 2013; 110(5):376–82. [CrossRef]
34. Abu-Awwad M. Dentists' decisions regarding the need for cuspal coverage for endodontically treated and vital posterior teeth. Clin Exp Dent Res 2019; 5(4):326–35. [CrossRef]
35. Ong DC, Bleakley JE. Compromised first permanent molars: an orthodontic perspective. Aust Dent J 2010; 55(1):2–14. [CrossRef]
36. Seale NS, Randall R. The use of stainless steel crowns: a systematic literature review. Pediatr Dent 2015; 37(2):145–60.
37. Cvek M. Prognosis of luxated non-vital maxillary incisors treated with calcium hydroxide and filled with gutta-percha. a retrospective clinical study. Endod Dent Traumatol 1992; 8(2):45–55. [CrossRef]
38. Talati A, Disfani R, Afshar A, Fallah Rastegar A. Finite element evaluation of stress distribution in mature and immature teeth. Iran Endod J 2007; 2(2):47–53.