

Direct pulp capping procedures versus root canal treatment in young permanent vital teeth with pulp exposure due to caries. A systematic review

JOSÉPHINE BRODÉN, DDS, HÅVARD HEIMDAL, DDS, MDSc, OLIVER JOSEFSSON, DDS, MDSc & HELENA FRANSSON, DDS, PhD

ABSTRACT: Purpose: To evaluate the available evidence on pulp capping procedures and root canal treatment in young permanent teeth with vital pulps exposed by caries. **Methods:** The study was conducted as a systematic review of the literature. Three databases, PubMed, Web of Knowledge, and The Cochrane Library were searched. Reference lists of relevant articles were hand searched. The quality of all relevant publications was rated. **Results:** Ten original scientific studies were included in the review. The quality was rated as low in all studies. The search failed to disclose any article directly comparing pulp capping and root canal treatment. The level of evidence was insufficient to draw any conclusions regarding the effectiveness of the two treatment concepts. High success rates are reported for pulp capping procedures in exposure due to caries, though it is not possible to compare them to success rates of root canal treatment. The review confirms the lack of high quality studies on the treatment of young permanent teeth with cariously exposed pulps. (*Am J Dent* 2016;29:201-207).

CLINICAL SIGNIFICANCE: For the treatment of young permanent teeth with pulp exposure due to caries there is currently no evidence to support the assumption on pulp capping being more beneficial than root canal treatment in achieving a symptom free tooth with normal periapical conditions.

✉: Dr. Helena Fransson, Department of Endodontics, Faculty of Odontology, Malmö University, SE-205 06 Malmö, Sweden. E-mail: Helena.Fransson@mah.se

Introduction

In the era of minimal invasive dentistry, it is advised to perform stepwise excavations in teeth with deep carious lesions to avoid exposure of the pulp at all costs. Unfortunately, stepwise excavations do not prevent all exposures of the pulp. In a study on treatment of deep carious lesions in permanent teeth in children by Leksell et al,¹ stepwise excavation resulted in pulp exposures in 18% of the teeth. Bjorndal et al² presented similar numbers for adults where stepwise excavation of deep carious lesions resulted in pulp exposure in 17.5% of the teeth. When the pulp is exposed, two fundamentally different treatment alternatives are available: pulp capping (direct pulp capping or a partial pulpectomy), with the aim of preserving the vitality of the tooth, or pulpectomy, whereby the coronal and radicular pulp tissue is extirpated and the root canals are obturated.

Pulp capping procedures are well-documented vital pulp therapies. Favorable results have been presented in young permanent teeth with traumatic exposures,³⁻⁷ probably because of the healthy state of the pulp tissue. Many pulp exposures are however, due to caries, and in these cases the potential for healing of the inflamed pulp seems to be impaired. The issue of pulp capping in the case of a cariously exposed vital pulp is controversial.⁸ It has been advocated that pulp capping should be reserved only for pulps exposed due to reasons other than caries.⁹ However, young teeth have a rich apical perfusion and the pulp has a high capacity to respond to insults;¹⁰ therefore, the success rate of pulp capping in young patients might be higher than in adult patients.^{5,11}

Root canal treatments are invasive, resource intensive and technically difficult procedures.^{12,13} In adults, the success rates of root canal treatments of teeth with vital pulps range from 92 to 93%.^{14,15} In children, success rates as high as 84% have been reported for traumatized permanent incisors.⁴ Caries is probably

a common cause of root canal treatments in children and adolescents. It was the dominant reason for root canal treatment, accountable for 56%, in a sample of 19-year-olds in Malmö, Sweden.¹⁶ Another study¹⁷ of the same sample reported a frequency of apical periodontitis of 52% of the root-filled teeth.

The present systematic review of the literature evaluated the available evidence on the outcomes of direct pulp capping and root canal treatment of young permanent teeth with cariously exposed vital pulps.

Materials and Methods

The problem was specified according to the PICO framework.¹⁸ The following question defined the problem: In children and adolescents with cariously exposed permanent teeth, is pulp capping more beneficial than root canal treatment in achieving a symptom free tooth with normal periapical conditions?

Database searches were undertaken of PubMed (National Center for Biotechnology Information, U.S. National Library of Medicine), Web of Knowledge (Web of Science, Thompson Reuters) and The Cochrane Library (John Wiley & Sons, Ltd). Different search strategies were used in order to identify publications about the two different treatment concepts: pulp capping procedures and root canal treatments in young permanent vital teeth.

Pulp capping procedures - Dental pulp capping is described in the MeSH (Index Medicus: Medical Subject Headings) browser as “application of a protective agent to an exposed pulp in order to allow the pulp to recover and maintain its normal vitality and function”. This description defines the intervention assessed in this review, but the definition was expanded to include partial pulpotomies, where the pulp tissue immediately underlying the exposure is removed prior to application of the pulp capping agent. However, such procedures as indirect pulp capping, stepwise excavation or full pulpotomy were not addressed.

Table 1 Criteria used for inclusion and exclusion of original scientific studies.

Inclusion criteria	Exclusion criteria
Subjects:	Primary teeth
Human	Avulsed/replanted/transplanted teeth
Aged 20 years or under at the date of intervention	Teeth with root resorption or root fracture pre-intervention
Permanent teeth	Revascularization treatment modalities
Vital teeth	Retrograde root canal therapy
Cariously exposed vital pulps	Endodontic re-treatment
Intervention:	Study addressing only the:
Treated with pulp capping procedure (direct pulp capping or partial pulpotomy) or description of a treatment protocol where the pulp was extirpated and root canals were obturated	<ul style="list-style-type: none"> quality of coronal restorations and/or post-core restoration after endodontic treatment. mechanical properties of the teeth after restoration
Outcome:	Dental trauma as the indication for endodontic treatment
Outcome based on radiographic examination and/or sensitivity testing	Teeth with apical periodontitis
Reported absence/presence of clinical symptoms such as:	In vitro/ex vivo studies
Pain on percussion, associated sinus tract, abscess formation	Non-English language publication
Study:	Case study
Prospective study	
Follow-up: at least 1 year post intervention	

Root canal treatment - The MeSH browser describes root canal therapy as “a treatment modality in endodontics concerned with the therapy of diseases of the dental pulp”. In this review the procedures assessed as control-/comparison interventions were defined as any intervention where the dental pulp was completely extirpated, followed by complete obturation of the root canals. This broad medical subject heading was used in the database searches because a wide variety of terms are used in the literature to describe the procedures of interest in this review.

Compilation and screening of articles - Duplicate checks were run and identified duplicates were removed. The publications obtained from the searches in PubMed, Web of Knowledge and the Cochrane Library were included or excluded according to the predetermined inclusion and exclusion criteria (Table 1). All publications identified by the database searches entered the screening process at the abstract level, except for publications identified by the search strategy for root canal treatment in PubMed. Because of the large number of search results yielded by this search strategy, these publications were first subjected to a selection process at the title level: after reading the title, if at least one of the authors considered a publication might be relevant in terms of the inclusion and exclusion criteria, the abstract was retrieved and was also subjected to the inclusion and exclusion criteria. After this initial screening, publications deemed relevant on the basis of the abstracts were retrieved in full text. Full texts of original scientific studies were read, assessed and subjected to the inclusion and exclusion criteria. Publications meeting the inclusion criteria without infringing any of the exclusion criteria were included. In cases of disagreement, consensus was reached by discussion among the authors. The reference lists of all review articles retrieved in full text and of all included original scientific studies were then hand searched. Original scientific studies deemed relevant were subjected to the inclusion and exclusion criteria, starting at the abstract level of the screening process. The data from original scientific studies included in this review were extracted using a pre-constructed data extraction form.

Original scientific studies included were those with the following: human subjects, aged 20 or under at the date of intervention, permanent teeth with cariously exposed vital pulps

treated by pulp capping (direct pulp capping or partial pulpotomy) or by conventional orthograde root canal therapy. Indirect pulp capping treatments were not addressed. Patients could be either symptom free or have symptoms. Only prospective studies published in English were included. Treatment outcome was based on radiographic examination and/or sensitivity testing for teeth treated by pulp capping procedures and radiographic examination and the presence/absence of clinical symptoms for the root filled teeth. Follow-up to be undertaken at least 1 year post-intervention.

Reviews included were those with at least one of the following terms or any variations thereof to be included in the title or the abstract: ‘pulp capping’, ‘partial pulpotomy’, ‘vital pulp therapy’, ‘root canal treatment’, ‘root canal therapy’, ‘pulpectomy’, ‘endodontic treatment’.

Quality assessment - When the study design of all included studies was defined, the risk of bias and the quality of each study was determined and the quality of evidence for the comparison of the two treatment concepts was rated according to the GRADE guidelines.¹⁹

Results

Systematic literature search - After the database searches, 1887 titles and abstracts were screened, and 584 potentially relevant abstracts were identified. After screening of the abstracts, 82 relevant original scientific studies and review articles were retrieved in full text. Hand searching of the reference lists identified a further 29 relevant articles. In all, 67 original scientific studies were deemed to be relevant. After data extraction, 57 of the 67 publications²⁰⁻⁷⁴ were excluded. The reasons for exclusion at this level are presented in Table 2. Finally, 10 original scientific studies⁷⁵⁻⁸⁴ on pulp capping procedures remained. No relevant study on root canal treatment of cariously exposed permanent teeth was identified.

Risk of bias and interpretation of included studies - The literature search disclosed no study comparing the two treatments “pulp capping” and “root canal treatment” in young permanent teeth with carious exposures. The quality of all included studies was assessed as low.¹⁹ Two of the studies were randomized controlled trials,^{79,84} but not with respect to com-

Table 2. Reasons for exclusion of publications retrieved in full text and number of excluded studies. For several of the excluded articles more than one exclusion criterion may apply.

Exclusion criteria	Excluded studies
Unable to distinguish subjects aged 20 years or under at the date of intervention	Shovelton et al, ²⁰ Haskell et al, ²¹ Goldberg & Gurfinkel, ²² Pekruhn, ²³ Kashiwada & Takagi, ²⁴ Matsuo et al, ²⁵ Friedman et al, ²⁶ Farzaneh et al, ²⁷ Chu et al, ²⁸ Gesi et al, ¹⁵ Marquis et al, ²⁹ Nayar et al, ³⁰ Bjorndal et al, ² Ghoddusi et al, ³¹ Asgary et al ³²
Subjects >20 years of age at the date of intervention.	Sjögren et al, ³³ Hodosh et al, ³⁴ Gagliani et al, ³⁵ Mannocci et al ³⁶
Indirect pulp capping	Orhan et al ³⁷
Full pulpotomy	Waly, ³⁸ Waly, ³⁹ Asgary & Eghbal ⁴⁰
Final follow-up <1 year post intervention	Clarke, ⁴¹ Mulhern et al, ⁴² Fava, ⁴³ Fava ⁴⁴
Retrospective study	Kerekes & Tronstad, ⁴⁵ Odesjo et al, ⁴⁶ Mackie et al, ⁴⁷ Ray & Trope, ⁴⁸ Santucci, ⁴⁹ Benenati & Khajotia, ⁵⁰ Alley et al, ⁵¹ Chen et al, ⁵² Chen et al, ⁵³ Lumley et al, ⁵⁴ Mente et al, ⁵⁵ Lee et al ⁵⁶
Sample already surveyed in another included publication by the same authors	Zilberman et al ⁵⁷
Trauma as indication for treatment	Dominguez Reyes et al, ⁵⁸ Pradhan et al, ⁵⁹ Pace et al, ⁶⁰ Sarris et al, ⁶¹ Damle et al ⁶²
Periapical radiolucency prior to treatment	Roberts & Brilliant, ⁶³ Moazami et al, ⁶⁴ Paredes-Vieyra & Jimenez Enriquez ⁶⁵
Study currently not completed / no results are presented	Beslot-Neveu et al ⁶⁶
No root canal obturation described	Finucane & Kinirons ⁶⁷
Unable to discern periapical status among relevant patients prior to intervention	Barbakow et al, ⁶⁸ Chawla, ⁶⁹ El-Meligy & Avery, ⁷⁰ Ricucci et al ⁷¹
Absence/presence of clinical symptoms not presented	Simon et al ⁷²
Pulp reported as non-vital	Annamalai & Mungara ⁷³
Indication for root canal treatment not reported	Georgieva et al ⁷⁴

paring the methods of interest in this review; direct pulp capping procedures and root canal treatment. Therefore, they were assessed as having a low quality. Moritz et al⁸⁴ randomized patients to one of two groups where one was treated with a direct pulp capping procedure using a pulsed CO₂ laser and the other group treated with a conventional direct pulp capping procedure. Consequently, the intervention group and the control group were treated with the same type of intervention, direct pulp capping, and therefore, for the purposes of this review, the study was not regarded as being a true randomized controlled trial. The same was true in the study by Qudeimat et al⁷⁹ where patients were randomized to partial pulpotomy treatments with either CaOH₂ or with mineral trioxide aggregate (MTA).

The remaining eight studies lacked a control group altogether. No included study presented a power analysis for calculation of the minimum sample size. Three studies either failed to describe the treatment procedure in sufficient detail to allow replication of the trial or failed to present sufficient data on the status of the pulp pre-intervention⁷⁶⁻⁷⁸ (Table 3).

Treatment outcomes of a total of 299 teeth were examined in this review. In six included publications, 201 teeth were treated by a pulp capping procedure which involved removal of some of the pulp tissue prior to capping.^{75-77,79,82,83} In four included publications,^{78,80,81,84} 98 teeth were treated by a pulp capping procedure whereby no pulp tissue was removed prior to capping. The follow-up times for partial pulpotomy were 12-140 months and for pulp capping, 12 months-9 years. When data were extracted from the included publications, some teeth, which did not meet the inclusion criteria for the review, were excluded on the following grounds: the patients were >20 years of age at the date of intervention; the treatment procedure was inadequately described; or the teeth were lost to follow-up

within 12 months post-intervention.^{76,78,81,83,84}

Four of the included studies described a pulp capping procedure whereby no pulp tissue was removed prior to application of a pulp capping agent directly onto the exposure (direct pulp capping). Successful outcomes at follow-up were reported in 38/39 teeth or 97%,⁸¹ 14/18 teeth or 77%,⁸⁴ 28/30 teeth or 93%,⁸⁰ and 6/11 teeth or 64%.⁷⁸ In the six studies where treatment involved partial removal of the pulp tissue prior to application of a pulp capping agent onto the exposure, successful outcomes at follow-up were observed in 28/28 teeth or 100%,⁷⁵ 5/5 teeth or 100%,⁷⁶ 33/37 teeth or 89%,⁷⁷ 47/51 teeth or 92%,⁷⁹ 43/46 teeth or 93.5%,⁸² and 31/34 teeth or 91%.⁸³

Discussion

Since the objective of this systematic review was to evaluate the available evidence on the outcomes of pulp capping procedures compared to root canal treatments undertaken on young permanent teeth with vital pulps exposed by caries, a study would have to compare pulp capping and root canal treatment in this specific group of patients, in order to be assessed as having a high quality. The ideal studies would be randomized controlled trials directly comparing these two procedures, though a well-conducted prospective cohort study could also suit the purpose. The literature search yielded no such studies. A pilot search revealed that it would be difficult to find prospective studies of root canal treatment of vital permanent teeth with carious exposures in children and adolescents.

A broad subject heading was therefore used for the database searches, in order that any relevant studies on root canal treatment would not be overlooked. However, after application of the predetermined inclusion and exclusion criteria, no relevant study on root canal treatment of cariously exposed permanent teeth was identified.

Table 3. Data from each included and study quality.

Author	Study design	Material [(T), No. of teeth; Control (C), No. of teeth; No. of subjects] follow-up	Age (years)	Partial pulpotomy (yes/no)	Reported results	Study quality & comments on risk bias
Barrieshi-Nusair & Qudeimat ⁷⁵	Case series	T: ProRoot Gray MTA, n= 28; Subjects n= 21, 12-26 months	7.2-13.1	Yes	No radiographic indications of root or bone resorption were observed in any teeth. 22 teeth (79%) were responsive to vitality testing (method not specified). 6 teeth were unresponsive to vitality testing had no pain or tenderness to percussion or palpation.	Low. No control.
Nosrat & Nosrat ⁷⁶	Case series	T: Calasept Ca(OH) ₂ , n= 5 Subjects n= 5 14-33 months	10-20	Yes	Periapical, percussion or coronal tenderness tests were negative for all teeth. All teeth were sensitive to electrical stimuli. Periapical status was also assessed on radiographs and no signs of periapical radiolucency were mentioned.	Low. No control. Inadequate description of preoperative pulp status.
Mejare & Cvek ⁷⁷	Case series	T: Calasept Ca(OH) ₂ , n= 37 Subjects n= not specified 24-140 months	6-15	Yes	Group 1 consisted of 31 teeth with no preoperative clinical or radiographic symptoms. Group 2 consisted of 6 teeth with preoperative symptoms. All teeth were examined radiographically and clinically with electrical sense testing. Success was reported for 29 teeth in group one (89%) and for 4 teeth in group 2 (67%).	Low. No control. Inadequate description of preoperative pulp status; inadequate description of treatment procedure.
Olivi et al ⁷⁸	Case series	T: Kerr Life Ca(OH) ₂ , n= 11; Subjects n= 11 4 years	11-18	No	All the teeth in the study were tested for vitality (method not specified) and had intraoral x-rays taken at checkups. Failure was recorded in 4 out of 11 teeth (64% success).	Low. No control. Inadequate description of preoperative pulp status; inadequate description of treatment procedure.
Qudeimat et al ⁷⁹	RCT	T:ProRoot MTA n= 28 C:Dycal Ca(OH) ₂ n= 23 Subjects n=34	25-46 mo	Yes	Patients were examined clinically and had sensitivity (method not specified) and radiographic examinations at the follow-ups. Four teeth were considered failures during the follow-up period, 2 teeth from each of the MTA and Ca(OH) ₂ groups. MTA had a success of 93% and Ca(OH) ₂ had a success of 91%.	Low. Control group and intervention group treated with same intervention.
Farsi et al ⁸⁰	Case series	T: ProRoot MTA, n= 30 Subjects n= 30 2 years	9-12	No	Teeth were examined both clinically and radiographically. Clinical examinations comprised thermal, percussion and palpation tests. 28 teeth were deemed successful and 2 teeth were failures.	Low. No control.
Bogen et al ⁸¹	Case series	T: ProRoot MTA n= 39 Subjects n= 28 9 years	7-18	No	At follow-ups, periapical radiographs were taken and the teeth were tested for vitality with a cold stimulus. At the first year follow-up 39 teeth showed no pathological signs. At the 5-year follow-up 1 tooth was deemed a failure.	Low. No control.
Mass & Zilberman ⁸²	Case series	T:Ca(OH) ₂ n= 46 Subjects n= not discernible 12-48+months	6.9-17.7	Yes	Clinical and radiological follow-ups every 6 months for the first year and then every 12 months thereafter. Mean follow-up was 49 months (12-154 months). Success rate 93.5%.	Low. No control.
Mass & Zilberman ⁸³	Case series	T:Calxyl Ca(OH) ₂ n= 34 Subjects: n= 34 12-48+months	7.5-18	Yes	Clinical and radiographic follow-ups every 3 to 6 months the first year and then once every 1-to 2 years thereafter. Success rate 91%.	Low. No control.
Moritz et al ⁸⁴	RCT	T:Kerr Life Ca(OH) ₂ n= 8 C:Kerr Life Ca(OH) ₂ n= 10; Subjects n= 18 1 week-2 years	9-20	No	Recalls after 1 week and monthly for 18 months, followed by final examination at 2 years. The recall examination comprised thermal tests and measurements of pulpal blood flow using laser Doppler flowmetry. No non-vital pulps were observed in the test group. The 4 control teeth were non-vital at the 2-year examination.	Low. Control group and intervention group treated with same intervention.

The studies included in the review, all on pulp capping procedures, were assessed as having a low quality (Table 3). Consequently, the overall level of evidence on which of the two treatments is the most effective in young permanent teeth with pulp exposure due to caries was assessed as very low according to the GRADE guidelines.⁸⁵ It was decided to include only prospective studies in the review, in order to determine whether the presenting signs or symptoms, or any particular step in the treatment process, would have an effect on the outcome of the interventions. Prospective studies are superior to retrospective studies for studying these effects as they allow the study of

multiple variables. Retrospective studies often have longer follow-up times and study larger populations, but may lack, for example, important data on the subjects, information about the indications for intervention, and detailed descriptions of the intervention procedures.

The heterogeneity among the studies and the low quality precluded a meta-analysis. The highest success rates were for partial pulpotomy, where 92-100% of the teeth were considered successful at follow-up and the lower success rates, 64-92%, were for teeth after direct pulp capping, that is no pulp tissue was removed prior to the pulp being capped. On the basis of the

reported outcomes of these studies, no conclusions could be drawn as to the preferred pulp capping method.

The most accurate outcome of a pulp capping procedure or a root canal treatment would be the retention time: how long the treated tooth remains in function, with no pathology and no spread of infection. A long follow-up period would be preferable, but for practical reasons the criterion for inclusion in this review was a follow-up of at least 1 year. Short follow-ups may show misleading success rates, because later failures can occur. Therefore, a longer follow-up would have given a better indication of the long-term performance of the treated teeth. However, according to data in the literature,²⁵ a pulp capping is most likely to fail soon after treatment; in cariously exposed teeth, similar success rates are reported for 3- and 18-month follow-up times.

With reference to the choice of pulp capping agent, similar outcomes have been reported for calcium hydroxide and mineral trioxide aggregate. One⁷⁹ of the two randomized controlled trials included for review in this study, compared the effect of these two agents on the clinical success rate of partial pulpotomy in permanent molars. The reported outcomes were 91% success for calcium hydroxide and 93% for mineral trioxide aggregate. However, the sample size of 51 patients was far too small to detect a difference in treatment effect. In a systematic review,¹¹ no statistically significant difference could be shown for the success rate of vital pulp therapies using calcium hydroxide or mineral trioxide aggregate as the pulp capping agents. However, the review was not restricted to studies on young permanent teeth and according to the authors the subjects could not be stratified into different age groups for analysis. The authors suggested that the lack of significant difference between the two materials could be due to the small sample size, or to the fact that there was no clinical difference.

There are no reports on the prevalence of deep carious lesions in young permanent teeth in the literature. In epidemiological data,⁸⁶ 22% of a cohort of 15-year-olds in Sweden had one or more deep restorations, extending into the inner half of the dentin. Moreover, complete excavation of deep carious lesions could result in pulp exposure in 40% of cases.¹ Thus, clinicians are regularly called upon to make decisions about the treatment of cariously exposed teeth.

In future clinical trials, all details of the treatment procedures, preoperative conditions and of the sample should be described. This would facilitate the inclusion of the trial in a meta-analysis. Comparison of trials could also be simplified if there was consensus on the materials, methods and treatment routines to be used. For instance, instead of using a wide variety of medicaments with slight differences in formula, the choice of control material for vital pulp therapies could be simplified by using calcium hydroxide mixed with water. We also suggest that the success of a pulp capping procedure or a root canal treatment should be measured in retention time. Root-filled teeth are more often extracted than vital teeth which affect the long-term prognosis. Reports^{51,87} have shown that 10-19% of teeth treated with a root canal treatment are extracted within 5 years. This may apply in particular to children and adolescents, where root formation may not be fully complete. The walls of the roots of young permanent teeth are immature, implying increased risk of root fracture after root canal treatment.⁸⁸

It could be questionable from an ethical point of view to conduct a randomized controlled trial where the young subjects would be randomized to a pulp capping procedure or root canal treatment. We believe it is of great importance to conduct minimal invasive dentistry and to keep the vitality of the young tooth and avoid root canal treatment if possible. A more ethical way of studying pulp capping compared to root canal treatment of young permanent teeth with cariously exposed pulps could be by analytic modelling. In analytic modelling evidence is drawn from a range of sources including already published studies.

Conclusions

1. Overall, the findings of the review highlight the lack of high quality studies on the treatment of young permanent teeth with carious exposures;
2. The literature search identified no study on root canal treatment of young permanent vital teeth with carious exposures;
3. Based on the included studies, the level of evidence on pulp capping procedures versus root canal treatment in young permanent teeth with pulp exposure due to caries, was assessed as very low.

Disclosure statement: The authors declared no conflict of interest.

Dr. Brodén is a former Endodontics resident of the Malmö University School of Dentistry; Dr. Heimdal and Dr. Josefsson are former students of the Malmö University School of Dentistry and Graduate students of the Department of Endodontics; and Dr. Fransson is Assistant Professor, Department of Endodontics, Faculty of Odontology, Malmö University, Malmö, Sweden.

References

1. Leksell E, Ridell K, Cvek M, Mejare I. Pulp exposure after stepwise versus direct complete excavation of deep carious lesions in young posterior permanent teeth. *Endod Dent Traumatol* 1996;12:192-196.
2. Bjørndal L, Reit C, Bruun G, Markvart M, Kjaeldgaard M, Näsman P, et al. Treatment of deep caries lesions in adults: Randomized clinical trials comparing stepwise vs. direct complete excavation, and direct pulp capping vs. partial pulpotomy. *Eur J Oral Sci* 2010;118:290-297.
3. Cvek M. A clinical report on partial pulpotomy and capping with calcium hydroxide in permanent incisors with complicated crown fracture. *J Endod* 1978;4:232-237.
4. Ravn JJ. Follow-up study of permanent incisors with complicated crown fractures after acute trauma. *Scand J Dent Res* 1982;90:363-372.
5. Horsted P, Sandergaard B, Thylstrup A, El Attar K, Fejerskov O. A retrospective study of direct pulp capping with calcium hydroxide compounds. *Endod Dent Traumatol* 1985;1:29-34.
6. Fuks AB, Gavra S, Chosack A. Long-term follow up of traumatized incisors treated by partial pulpotomy. *Pediatr Dent* 1993;15:334-336.
7. Iwamoto CE, Adachi E, Pameijer CH, Barnes D, Romberg EE, Jefferies S. Clinical and histological evaluation of white ProRoot MTA in direct pulp capping. *Am J Dent* 2006;19:85-90.
8. Bergenholtz G, Spangberg L. Controversies in endodontics. *Crit Rev Oral Biol Med* 2004;15:99-114.
9. Baume LJ, Holz J. Long term clinical assessment of direct pulp capping. *Int Dent J* 1981;31:251-260.
10. Massler M. Therapy conducive to healing of the human pulp. *Oral Surg Oral Med Oral Pathol* 1972;34:122-130.
11. Aguilar P, Linsuwanont P. Vital pulp therapy in vital permanent teeth with cariously exposed pulp: A systematic review. *J Endod* 2011;37:581-587.
12. Kirkevang LL, Orstavik D, Horsted-Bindslev P, Wenzel A. Periapical status and quality of root fillings and coronal restorations in a Danish population. *Int Endod J* 2000;33:509-515.
13. Fransson H. On the repair of the dentine barrier. *Swed Dent J Suppl* 2012;226:9-84.
14. Petersson K, Hasselgren G, Petersson A, Tronstad L. Clinical experience with the use of dentine chips in pulpectomies. *Int Endod J* 1982;15:161-167.
15. Gesi A, Hakeberg M, Warfvinge J, Bergenholtz G. Incidence of periapical lesions and clinical symptoms after pulpectomy - A clinical and radiographic evaluation of 1- versus 2-session treatment. *Oral Surg Oral*

- Med Oral Pathol Oral Radiol* 2006;101:379-388.
16. Ridell K, Sundin B, Matsson L. Endodontic treatment during childhood and adolescence. A survey of 19-year-olds living in the city of Malmö, Sweden. *Swed Dent J* 2003;27:83-89.
 17. Ridell K, Petersson A, Matsson L, Mejare I. Periapical status and technical quality of root-filled teeth in Swedish adolescents and young adults. A retrospective study. *Acta Odontol Scand* 2006;64:104-110.
 18. Straus SE, Glasziou P, Richardson WS, Haynes RB. *Evidence-based medicine: How to practice and teach it*. 4th ed. New York, NY, USA: Churchill Livingstone 2011;213-215.
 19. Guyatt GH, Oxman AD, Vist G, Kunz R, Brozek J, Alonso-Coello P, Montori V, Akl EA, Djulbegovic B, Falck-Ytter Y, Norris SL, Williams JW Jr, Atkins D, Meerpohl J, Schünemann HJ. GRADE guidelines: 4. Rating the quality of evidence - study limitations (risk of bias). *J Clin Epidemiol* 2011;64:407-415.
 20. Shovelton DS, Friend LA, Kirk EE, Rowe AH. The efficacy of pulp capping materials. A comparative trial. *Br Dent J* 1971;130:385-391.
 21. Haskell EW, Stanley HR, Chellemi J, Stringfellow H. Direct pulp capping treatment: A long-term follow-up. *J Am Dent Assoc* 1978;97:607-612.
 22. Goldberg F, Gurfinkel J. Analysis of the use of Dycal with gutta-percha points as an endodontic filling technique. *Oral Surg Oral Med Oral Pathol Oral Radiol* 1979;47:78-82.
 23. Pekruhn RB. The incidence of failure following single-visit endodontic therapy. *J Endod* 1986;12:68-72.
 24. Kashiwada T, Takagi M. New restoration and direct pulp capping systems using adhesive composite resin. *Bull Tokyo Med Dent Univ* 1991;38:45-52.
 25. Matsuo T, Nakanishi T, Shimizu H, Ebisu S. A clinical study of direct pulp capping applied to carious-exposed pulps. *J Endod* 1996;22:551-556.
 26. Friedman S, Abitbol S, Lawrence HP. Treatment outcome in endodontics: The Toronto Study. Phase I: Initial treatment. *J Endod* 2003;29:787-793.
 27. Farzaneh M, Abitbol S, Lawrence HP, Friedman S, Toronto Study. Treatment outcome in endodontics-the Toronto Study. Phase II: Initial treatment. *J Endod* 2004;30:302-309.
 28. Chu CH, Lo EC, Cheung GS. Outcome of root canal treatment using Thermanfil and cold lateral condensation filling techniques. *Int Endod J* 2005;38:179-185.
 29. Marquis VL, Dao T, Farzaneh M, Abitbol S, Friedman S. Treatment outcome in endodontics: The Toronto Study. Phase III: Initial treatment. *J Endod* 2006;32:299-306.
 30. Nayar S, Bishop K, Alani A. A report on the clinical and radiographic outcomes of 38 cases of apexification with mineral trioxide aggregate. *Eur J Prosthodont Restor Dent* 2009;17:150-156.
 31. Ghodusi J, Shahrami F, Alizadeh M, Kianoush K, Forghani M. Clinical and radiographic evaluation of vital pulp therapy in open apex teeth with MTA and ZOE. *N Y State Dent J* 2012;78:34-38.
 32. 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;71:130-136.
 33. Sjogren U, Hagglund B, Sundqvist G, Wing K. Factors affecting the long-term results of endodontic treatment. *J Endod* 1990;16:498-504.
 34. Hodosh M, Hodosh SH, Hodosh AJ. Capping carious exposed pulps with potassium nitrate, dimethyl isosorbide, polycarboxylate cement. *Dent Today* 2003;22:46-51.
 35. Gagliani MA, Cerutti A, Bondesan A, Colombo M, Godio E, Giacomelli G. A 24-month survey on root canal treatment performed by NiTi engine driven files and warm gutta-percha filling associated system. *Minerva Stomatol* 2004;53:543-554.
 36. Mannocci F, Qualtrough AJ, Worthington HV, Watson TF, Pitt Ford TR. Randomized clinical comparison of endodontically treated teeth restored with amalgam or with fiber posts and resin composite: Five-year results. *Oper Dent* 2005;30: 9-15.
 37. Orhan AI, Oz FT, Orhan K. Pulp exposure occurrence and outcomes after 1- or 2-visit indirect pulp therapy vs complete caries removal in primary and permanent molars. *Pediatr Dent* 2010;32: 347-355.
 38. Waly NG. A five-year comparative study of calcium hydroxide-glutaraldehyde pulpotomies versus calcium hydroxide pulpotomies in young permanent molars. *Egypt Dent J* 1995;41: 993-1000.
 39. Waly NG. Long-term follow-up of glutaraldehyde pulpotomies in young permanent molars. *Egypt Dent J* 1994;40: 927-932.
 40. Asgary S, Eghbal MJ, Ghodusi J, Yazdani S. One-year results of vital pulp therapy in permanent molars with irreversible pulpitis: an ongoing multicenter, randomized, non-inferiority clinical trial. *Clin Oral Investig* 2013;17: 431-439.
 41. Clarke NG. The corticosteroid-antibiotic dressing as a capping for inflamed dental pulps. *Aust Dent J* 1971;16: 71-76.
 42. Mulhern JM, Patterson SS, Newton CW, Ringel AM. Incidence of postoperative pain after one-appointment endodontic treatment of asymptomatic pulpal necrosis in single-rooted teeth. *J Endod* 1982;8: 370-375.
 43. Fava LR. A comparison of one versus two appointment endodontic therapy in teeth with non-vital pulps. *Int Endod J* 1989;22: 179-183.
 44. Fava LR. A clinical evaluation of one and two-appointment root canal therapy using calcium hydroxide. *Int Endod J* 1994;27: 47-51.
 45. Kerekes K, Tronstad L. Long-term results of endodontic treatment performed with a standardized technique. *J Endod* 1979;5: 83-90.
 46. Odesjo B, Hellden L, Salonen L, Langeland K. Prevalence of previous endodontic treatment, technical standard and occurrence of periapical lesions in a randomly selected adult, general population. *Endod Dent Traumatol* 1990;6: 265-272.
 47. Mackie IC, Worthington HV, Hill FJ. A follow-up study of incisor teeth which had been treated by apical closure and root filling. *Br Dent J* 1993;175: 99-101.
 48. Ray HA, Trope M. Periapical status of endodontically treated teeth in relation to the technical quality of the root filling and the coronal restoration. *Int Endod J* 1995;28: 12-18.
 49. Santucci PJ. Dycal versus Nd:YAG laser and Vitrebond for direct pulp capping in permanent teeth. *J Clin Laser Med Surg* 1999;17: 69-75.
 50. Benenati FW, Khajotia SS. A radiographic recall evaluation of 894 endodontic cases treated in a dental school setting. *J Endod* 2002;28:391-395.
 51. Alley BS, Kitchens GG, Alley LW, Eleazer PD. A comparison of survival of teeth following endodontic treatment performed by general dentists or by specialists. *Oral Surg Oral Med Oral Pathol Oral Radiol* 2004;98: 115-118.
 52. Chen SC, Chueh LH, Hsiao CK, Tsai MY, Ho SC, Chiang CP. An epidemiologic study of tooth retention after nonsurgical endodontic treatment in a large population in Taiwan. *J Endod* 2007;33:226-229.
 53. Chen SC, Chueh LH, Hsiao CK, Wu HP, Chiang CP. First untoward events and reasons for tooth extraction after nonsurgical endodontic treatment in Taiwan. *J Endod* 2008;34:671-674.
 54. Lumley PJ, Lucarotti PS, Burke FJ. Ten-year outcome of root fillings in the General Dental Services in England and Wales. *Int Endod J* 2008; 41:577-585.
 55. Mente J, Geletneký B, Ohle M, Koch MJ, Friedrich Ding PG, et al. Mineral trioxide aggregate or calcium hydroxide direct pulp capping: An analysis of the clinical treatment outcome. *J Endod* 2010;36:806-813.
 56. Lee AH, Cheung GS, Wong MC. Long-term outcome of primary nonsurgical root canal treatment. *Clin Oral Investig* 2012;16:1607-1617.
 57. Zilberman U, Mass E, Sarnat H. Partial pulpotomy in carious permanent molars. *Am J Dent* 1989;2:147-150.
 58. Dominguez Reyes A, Muñoz Muñoz L, Aznar Martin T. Study of calcium hydroxide apexification in 26 young permanent incisors. *Dent Traumatol* 2005;21:141-145.
 59. Pradhan DP, Chawla HS, Gauba K, Goyal A. Comparative evaluation of endodontic management of teeth with unformed apices with mineral trioxide aggregate and calcium hydroxide. *J Dent Child (Chic)* 2006; 73:79-85.
 60. Pace R, Giuliani V, Pini Prato L, Baccetti T, Pagavino G. Apical plug technique using mineral trioxide aggregate: Results from a case series. *Int Endod J* 2007;40:478-484.
 61. Sarris S, Tahmassebi JF, Duggal MS, Cross IA. A clinical evaluation of mineral trioxide aggregate for root-end closure of non-vital immature permanent incisors in children-a pilot study. *Dent Traumatol* 2008;24:79-85.
 62. Damle SG, Bhattal H, Loomba A. Apexification of anterior teeth: A comparative evaluation of mineral trioxide aggregate and calcium hydroxide paste. *J Clin Pediatr Dent* 2012;36:263-268.
 63. Roberts SC Jr, Brilliant JD. Tricalcium phosphate as an adjunct to apical closure in pulpless permanent teeth. *J Endod* 1975;1:263-269.
 64. Moazami F, Sahebi S, Sobhnamayan F, Alipour A. Success rate of nonsurgical endodontic treatment of nonvital teeth with variable periradicular lesions. *Iran Endod J* 2011;6:119-124.
 65. Paredes-Vieyra J, Jimenez Enriquez FJ. Success rate of single- versus two-visit root canal treatment of teeth with apical periodontitis: A randomized controlled trial. *J Endod* 2012;38:1164-1169.
 66. Beslot-Neveu A, Bonte E, Baune B, Serreau R, Aissat F, Quinquin L, Grabar S, Lasfargues JJ. Mineral trioxide aggregate versus calcium hydroxide in apexification of non vital immature teeth: Study protocol for a randomized controlled trial. *Trials* 2011;12:174.
 67. Finucane D, Kinirons MJ. Non-vital immature permanent incisors: Factors that may influence treatment outcome. *End Dent Traumatol* 1999;15:273-277.
 68. Barbakow FH, Cleaton-Jones P, Friedman D. An evaluation of 566 cases of root canal therapy in general dental practice. 1. Diagnostic criteria and treatment details. *J Endod* 1980;6:456-460.

69. Chawla HS. Apical closure in a nonvital permanent tooth using one Ca(OH)₂ dressing. *ASDC J Dent Child* 1986;53:44-47.
70. El-Meligy OA, Avery DR. Comparison of apexification with mineral trioxide aggregate and calcium hydroxide. *Pediatr Dent* 2006;28:248-253.
71. Ricucci D, Russo J, Rutberg M, Burleson JA, Spangberg LS. A prospective cohort study of endodontic treatments of 1,369 root canals: Results after 5 years. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2011;112:825-842.
72. Simon S, Rilliard F, Berdal A, Machtou P. The use of mineral trioxide aggregate in one-visit apexification treatment: A prospective study. *Int Endod J* 2007;40:186-197.
73. Annamalai S, Mungara J. Efficacy of mineral trioxide aggregate as an apical plug in non-vital young permanent teeth: Preliminary results. *J Clin Pediatric Dent* 2010;35:149-155.
74. Georgieva MG, Indjova KN, Indjov SI. Endodontic treatment of permanent teeth in children with a new calcium-carbamide-formaldehyde paste. *Folia Medica* 2002;44:35-38.
75. Barrieshi-Nusair KM, Qudeimat MA. A prospective clinical study of mineral trioxide aggregate for partial pulpotomy in cariously exposed permanent teeth. *J Endod* 2006;32:731-735.
76. Nosrat IV, Nosrat CA. Reparative hard tissue formation following calcium hydroxide application after partial pulpotomy in cariously exposed pulps of permanent teeth. *Int Endod J* 1998;31:221-226.
77. Mejare I, Cvek M. Partial pulpotomy in young permanent teeth with deep carious lesions. *Endod Dent Traumatol* 1993;9:238-242.
78. Olivi G, Genovese MD, Maturo P, Docimo R. Pulp capping: Advantages of using laser technology. *Eur J Paediatric Dent* 2007;8:89-95.
79. Qudeimat MA, Barrieshi-Nusair KM, Owais AI. Calcium hydroxide vs mineral trioxide aggregates for partial pulpotomy of permanent molars with deep caries. *Eur Arch Paediatr Dent* 2007;8:99-104.
80. Farsi N, Alamoudi N, Balto K, Al Mushayt A. Clinical assessment of mineral trioxide aggregate (MTA) as direct pulp capping in young permanent teeth. *J Clin Pediatric Dent* 2006;31:72-76.
81. Bogen G, Kim JS, Bakland LK. Direct pulp capping with mineral trioxide aggregate: An observational study. *J Am Dent Assoc* 2008;139:305-315.
82. Mass E, Zilberman U. Long-term radiologic pulp evaluation after partial pulpotomy in young permanent molars. *Quintessence Int* 2011;42:547-554.
83. Mass E, Zilberman U. Clinical and radiographic evaluation of partial pulpotomy in carious exposure of permanent molars. *Pediatr Dent* 1993;15:257-259.
84. Moritz A, Schoop U, Goharkhay K, Sperr W. Advantages of a pulsed CO₂ laser in direct pulp capping: A long-term in vivo study. *Lasers Surg Med* 1998;22:288-293.
85. Balshem H1, Helfand M, Schünemann HJ, Oxman AD, Kunz R, Brozek J, Vist GE, Falck-Ytter Y, Meerpohl J, Norris S, Guyatt GH. GRADE guidelines: 3. Rating the quality of evidence. *J Clin Epidemiol* 2011;4:401-406.
86. Ridell K, Olsson H, Mejare I. Unrestored dentin caries and deep dentin restorations in Swedish adolescents. *Caries Res* 2008;42:164-170.
87. Caplan DJ, Cai J, Yin G, White BA. Root canal filled versus non-root canal filled teeth: A retrospective comparison of survival times. *J Public Health Dent* 2005; 65:90-96.
88. 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; 8:45-55.