Pulp Therapy for Primary and Immature Permanent Teeth

Latest Revision

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Purpose

The American Academy of Pediatric Dentistry (**AAPD**) intends these recommendations to aid in the diagnosis of pulp health versus pathosis and to set forth the indications, objectives, and therapeutic interventions for pulp therapy in primary and immature permanent teeth.

Methods

Recommendations on pulp therapy for primary and immature permanent teeth were developed by the Clinical Affairs Committee – Pulp Therapy Subcommittee and adopted in 1991. This document by the Council of Clinical Affairs is a revision of the previous version, last revised in 2009. This revision included a new systematic literature search of the PubMed®/MEDLINE database using the terms: pulpotomy, pulpectomy, indirect pulp treatment, stepwise excavation, pulp therapy, pulp capping, pulp exposure, bases, liners, calcium hydroxide, formocresol, ferric sulfate, glass ionomer, mineral trioxide aggregate (**MTA**), bacterial microleakage under restorations, dentin bonding agents, resin modified glass ionomers, and endodontic irrigants; fields: all. Papers for review were chosen from the resultant lists and from hand searches. When data did not appear sufficient or were inconclusive, recommendations were based upon expert and/or consensus opinion including those from the 2007 joint symposium of the AAPD and the American Association of Endodontists (**AAE**) titled *Emerging Science in Pulp Therapy: New Insights into Dilemmas and Controversies* (Chicago, Ill.)

Background

The primary objective of pulp therapy is to maintain the integrity and health of the teeth and their supporting tissues. It is a treatment objective to maintain the vitality of the pulp of a tooth affected by caries, traumatic injury, or other causes. Especially in young permanent teeth with immature roots, the pulp is integral to continue apexogenesis. Long term retention of a permanent tooth requires a root with a favorable crown/root ratio and dentinal walls that are thick enough to withstand normal function. Therefore, pulp preservation is a primary goal for treatment of the young permanent dentition. A tooth without a vital pulp, however, can remain clinically functional.[1]

The indications, objectives, and type of pulpal therapy depend on whether the pulp is vital or nonvital, based on the clinical diagnosis of normal pulp (symptom free and normally responsive to vitality testing), reversible pulpitis (pulp is capable of healing), symptomatic or asymptomatic irreversible pulpitis (vital inflamed pulp is incapable of healing), or necrotic pulp.[2] The clinical diagnosis[3] is derived from:

1. a comprehensive medical history.
2. a review of past and present dental history and treatment, including current symptoms and chief complaint.
3. a subjective evaluation of the area associated with the current symptoms/chief complaint by questioning the child and parent on the location, intensity, duration, stimulus, relief, and spontaneity.
4. a objective extraoral examination as well as examination of the intraoral soft and hard tissues.
5. if obtainable, radiograph(s) to diagnose pulpitis or necrosis showing the involved tooth, furcation, periapical area, and the surrounding bone.
6. clinical tests such as palpation, percussion, and mobility.[1,4]

In permanent teeth, electric pulp tests and thermal tests may be helpful.[3] Teeth exhibiting signs or symptoms such as a history of spontaneous unprovoked toothache, a sinus tract, soft tissue inflammation not resulting from gingivitis or periodontitis, excessive mobility not associated with trauma or exfoliation, furcation/apical radiolucency, or radiographic evidence of internal/external resorption have a clinical diagnosis of irreversible pulpitis or necrosis. These teeth are candidates for nonvital pulp treatment.[5,6]

Teeth exhibiting provoked pain of short duration relieved with over-the-counter analgesics, by brushing, or upon the

* *In 2017, the AAPD published a separate document, clinical practice guideline: Dhar V, Marghalani AA, Crystal YO, et al. Use of Vital Pulp Therapies in Primary Teeth with Deep Caries Lesions. Pediatr Dent 2017;39(5):E146-E159. (Available at: http://www.aapd.org/media/Policies_Recommendations/G_VitalPulpTherapies). The clinical guidance in that publication supersedes any conflicting recommendations which may be found in this document.*

ABBREVIATIONS

AAE: American Association of Endodontists. **AAPD:** American Academy of Pediatric Dentistry. **ITR:** Interim therapeutic restoration. **MTA:** Mineral trioxide aggregate.

removal of the stimulus and without signs or symptoms of irreversible pulpitis, have a clinical diagnosis of reversible pulpitis and are candidates for vital pulp therapy. Teeth diagnosed with a normal pulp requiring pulp therapy or with reversible pulpitis should be treated with vital pulp procedures.[7-10]

Recommendations

All relevant diagnostic information, treatment, and treatment follow-up shall be documented in the patient's record.

Any planned treatment should include consideration of:

1. the patient's medical history;
2. the value of each involved tooth in relation to the child's overall development;
3. alternatives to pulp treatment; and
4. restorability of the tooth.

When the infectious process cannot be arrested by the treatment methods included in this section, bony support cannot be regained, inadequate tooth structure remains for a restoration, or excessive pathologic root resorption exists, extraction should be considered.[1,5,6]

It is recommended that all pulp therapy be performed with rubber-dam or other equally effective isolation to minimize bacterial contamination of the treatment site.

This guideline is intended to recommend the best currently-available clinical care for pulp treatment, but the AAPD encourages additional research for consistently successful and predictable techniques using biologically-compatible medicaments for vital and nonvital primary and immature permanent teeth. Pulp therapy requires periodic clinical and radiographic assessment of the treated tooth and the supporting structures. Post-operative clinical assessment generally should be performed every six months and could occur as part of a patient's periodic comprehensive oral examination. Patients treated for an acute dental infection initially may require more frequent clinical reevaluation. A radiograph of a primary tooth pulpectomy should be obtained immediately following the procedure to document the quality of the fill and to help determine the tooth's prognosis. This image also would serve as a comparative baseline for future films (the type and frequency of which are at the clinician's discretion). Radiographic evaluation of primary tooth pulpotomies should occur at least annually because the success rate of pulpotomies diminishes over time.[11] Bitewing radiographs obtained as part of the patient's periodic comprehensive examinations may suffice. If a bitewing radiograph does not display the interradicular area, a periapical image is indicated. Pulp therapy for immature permanent teeth should be reevaluated radiographically six and 12 months after treatment and then periodically at the discretion of the clinician. For any tooth that has undergone pulpal therapy, clinical signs or symptoms may prompt a clinician to select a more frequent periodicity of reassessment.

Apexification, reimplantation of avulsions, and placement of prefabricated post and cores are not indicated for primary teeth. For endodontic procedures not included in this section, the AAPD supports the AAE's *Guide to Clinical Endodontics*.[12]

Primary teeth

Vital pulp therapy for primary teeth diagnosed with a normal pulp or reversible pulpitis

Protective liner. A protective liner is a thinly-applied liquid placed on the pulpal surface of a deep cavity preparation, covering exposed dentin tubules, to act as a protective barrier between the restorative material or cement and the pulp. Placement of a thin protective liner such as calcium hydroxide, dentin bonding agent, or glass ionomer cement is at the discretion of the clinician.[13,14]

- Indications: In a tooth with a normal pulp, when all caries is removed for a restoration, a protective liner may be placed in the deep areas of the preparation to minimize injury to the pulp, promote pulp tissue healing, and/or minimize post-operative sensitivity.[15,16]
- Objectives: The placement of a liner in a deep area of the preparation is utilized to preserve the tooth's vitality, promote pulp tissue healing and tertiary dentin formation, and minimize bacterial microleakage.[17,18] Adverse post-treatment clinical signs or symptoms such as sensitivity, pain, or swelling should not occur.

Indirect pulp treatment. Indirect pulp treatment is a procedure performed in a tooth with a deep carious lesion approximating the pulp but without signs or symptoms of pulp degeneration.[1] The caries surrounding the pulp is left in place to avoid pulp exposure and is covered with a biocompatible material.[19] A radiopaque liner such as a dentin bonding agent,[20] resin modified glass ionomer,[21,22] calcium hydroxide,[23,24] zinc oxide/eugenol,[24] or glass ionomer cement[7,9,25-27] is placed over the remaining carious dentin to stimulate healing and repair. If calcium hydroxide is used, a glass ionomer or reinforced zinc oxide/eugenol material should be placed over it to provide a seal against microleakage since calcium hydroxide has a high solubility, poor seal, and low compressive strength.[28-31] The use of glass ionomer cements or reinforced zinc oxide/eugenol restorative materials has the additional advantage of inhibitory activity against cariogenic bacteria.[32,33] The tooth then is restored with a material that seals the tooth from microleakage. Interim therapeutic restorations (**ITR**) with glass ionomers may be used for caries control in teeth with carious lesions that exhibit signs of reversible pulpitis. The ITR can be removed once the pulp's vitality is determined and, if the pulp is vital, an indirect pulp cap can be performed.[34,35] Current literature indicates that there is no conclusive evidence that it is necessary to reenter the tooth to remove the residual caries.[36,37] As long as the tooth remains sealed from bacterial contamination, the prognosis is good for caries to arrest and reparative dentin to form to protect the pulp.[32,33,36-40] Indirect pulp capping has been shown to have a higher success rate than pulpotomy in long term studies.[7,9,20,22-27,35] It also allows for a normal exfoliation time.

Therefore, indirect pulp treatment is preferable to a pulpotomy when the pulp is normal or has a diagnosis of reversible pulpitis.

- Indications: Indirect pulp treatment is indicated in a primary tooth with no pulpitis[18] or with reversible pulpitis when the deepest carious dentin is not removed to avoid a pulp exposure.[8] The pulp is judged by clinical and radiographic criteria to be vital and able to heal from the carious insult.[8,9]
- Objectives: The restorative material should seal completely the involved dentin from the oral environment. The tooth's vitality should be preserved. No post-treatment signs or symptoms such as sensitivity, pain, or swelling should be evident. There should be no radiographic evidence of pathologic external or internal root resorption or other pathologic changes. There should be no harm to the succedaneous tooth.

Direct pulp cap. When a pinpoint mechanical exposure of the pulp is encountered during cavity preparation or following a traumatic injury, a biocompatible radiopaque base such as MTA[41-44] or calcium hydroxide[45] may be placed in contact with the exposed pulp tissue. The tooth is restored with a material that seals the tooth from microleakage.[7]

- Indications: This procedure is indicated in a primary tooth with a normal pulp following a small mechanical or traumatic exposure when conditions for a favorable response are optimal.[41-45] Direct pulp capping of a carious pulp exposure in a primary tooth is not recommended.[1]
- Objectives: The tooth's vitality should be maintained. No post-treatment signs or symptoms such as sensitivity, pain, or swelling should be evident. Pulp healing and reparative dentin formation should result. There should be no radiographic signs of pathologic external or progressive internal root resorption or furcation/apical radiolucency. There should be no harm to the succedaneous tooth.

Pulpotomy. A pulpotomy is performed in a primary tooth with extensive caries but without evidence of radicular pathology when caries removal results in a carious or mechanical pulp exposure. The coronal pulp is amputated, and the remaining vital radicular pulp tissue surface is treated with a long-term clinically-successful medicament such as Buckley's Solution of formocresol or ferric sulfate.[46-52] Several studies have utilized sodium hypochlorite with comparable results to formocresol and ferric sulfite.[53-55] Calcium hydroxide has been used, but with less long term success.[56] MTA is a more recent material used for pulpotomies with a high rate of success. Clinical trials show that MTA performs equal to or better than formocresol or ferric sulfate[8,11,57-61] and may be the preferred pulpotomy agent in the future.[62,63] Electrosurgery also has demonstrated success.[64] After the coronal pulp chamber is filled with zinc/oxide eugenol or other suitable base, the tooth is restored with a restoration that seals the tooth from microleakage. The most effective long-term restoration has been shown to be a stainless steel crown. However, if there is sufficient supporting enamel remaining, amalgam or composite resin can provide a functional alternative when the primary tooth has a life span of two years or less.[65-67]

- Indications: The pulpotomy procedure is indicated when caries removal results in pulp exposure in a primary tooth with a normal pulp or reversible pulpitis or after a traumatic pulp exposure.[6] The coronal tissue is amputated, and the remaining radicular tissue is judged to be vital without suppuration, purulence, necrosis, or excessive hemorrhage that cannot be controlled by a damp cotton pellet after several minutes, and there are no radiographic signs of infection or pathologic resorption.
- Objectives: The radicular pulp should remain asymptomatic without adverse clinical signs or symptoms such as sensitivity, pain, or swelling. There should be no postoperative radiographic evidence of pathologic external root resorption. Internal root resorption may be self-limiting and stable. The clinician should monitor the internal resorption, removing the affected tooth if perforation causes loss of supportive bone and/or clinical signs of infection and inflammation.[52,68-70] There should be no harm to the succedaneous tooth.

Nonvital pulp treatment for primary teeth diagnosed with irreversible pulpitis or necrotic pulp

Pulpectomy. Pulpectomy is a root canal procedure for pulp tissue that is irreversibly infected or necrotic due to caries or trauma. The root canals are debrided and shaped with hand or rotary files.[21] Since instrumentation and irrigation with an inert solution alone cannot adequately reduce the microbial population in a root canal system, disinfection with irrigants such as one percent sodium hypochlorite and/or chlorhexidine is an important step in assuring optimal bacterial decontamination of the canals.[70-72] Because it is a potent tissue irritant, sodium hypochlorite must not be extruded beyond the apex.[73] After the canals are dried, a resorbable material such as non-reinforced zinc/oxide eugenol,[5,74] iodoform-based paste (KRI),[75] or a combination paste of iodoform and calcium hydroxide (Vitapex®, Endoflax®)[76-78] is used to fill the canals. The tooth then is restored with a restoration that seals the tooth from microleakage.

- Indications: A pulpectomy is indicated in a primary tooth with irreversible pulpitis or necrosis or a tooth treatment planned for pulpotomy in which the radicular pulp exhibits clinical signs of irreversible pulpitis (e.g., excessive hemorrhage that is not controlled with a damp cotton pellet applied for several minutes) or pulp necrosis (e.g., suppuration, purulence). The roots should exhibit minimal or no resorption.
- Objectives: Following treatment, the radiographic infectious process should resolve in six months, as evidenced by bone deposition in the pretreatment radiolucent areas, and pretreatment clinical signs and symptoms should resolve within a few weeks. There should be radiographic evidence of successful filling without gross overextension or underfilling.[74,76,78] The treatment should permit resorption of the primary

tooth root and filling material to permit normal eruption of the succedaneous tooth. There should be no pathologic root resorption or furcation/apical radiolucency.

Young permanent teeth

Vital pulp therapy for teeth diagnosed with a normal pulp or reversible pulpitis

Protective liner. A protective liner is a thinly-applied liquid placed on the pulpal surface of a deep cavity preparation, covering exposed dentin tubules, to act as a protective barrier between the restorative material or cement and the pulp. Placement of a thin protective liner such as calcium hydroxide, dentin bonding agent, or glass ionomer cement is at the discretion of the clinician.[13,14] The liner must be followed by a well-sealed restoration to minimize bacterial leakage from the restoration-dentin interface.[17,18]

- Indications: In a tooth with a normal pulp, when caries is removed for a restoration, a protective liner may be placed in the deep areas of the preparation to minimize pulp injury, promote pulp tissue healing, and/or minimize postoperative sensitivity.
- Objectives: The placement of a liner in a deep area of the preparation is utilized to preserve the tooth's vitality, promote pulp tissue healing, and facilitate tertiary dentin formation. This liner must be followed by a well-sealed restoration to minimize bacterial leakage from the restoration-dentin interface.[17,18] Adverse post-treatment signs or symptoms such as sensitivity, pain, or swelling should not occur.

Apexogenesis (root formation). Apexogenesis is a histological term used to describe the continued physiologic development and formation of the root's apex. Formation of the apex in vital, young, permanent teeth can be accomplished by implementing the appropriate vital pulp therapy described in this section (i.e., indirect pulp treatment, direct pulp capping, partial pulpotomy for carious exposures and traumatic exposures).

Indirect pulp treatment. Indirect pulp treatment is a procedure performed in a tooth with a diagnosis of reversible pulpitis and deep caries that might otherwise need endodontic therapy if the decay was completely removed.[6] In recent years, rather than complete the caries removal in two appointments, the focus has been to excavate as close as possible to the pulp, place a protective liner, and restore the tooth without a subsequent reentry to remove any remaining affected dentin.[79-83] The risk of this approach is either an unintentional pulp exposure or irreversible pulpitis.[80] More recently, the step-wise excavation of deep caries has been revisited[72-84] and shown to be successful in managing reversible pulpitis without pulpal perforation and/or endodontic therapy.[85] This approach involves a two-step process. The first step is the removal of carious dentin along the dentin-enamel junction (DEJ) and excavation of only the outermost infected dentin, leaving a carious mass over the pulp. The objective is to change the cariogenic environment in order to decrease the number of bacteria, close the remaining caries from the biofilm of the oral cavity, and slow or arrest the caries development.[85-87] The second step is the removal of the remaining caries and placement of a final restoration. The most common recommendation for the interval between steps is three to six months, allowing sufficient time for the formation of tertiary dentin and a definitive pulpal diagnosis. Critical to both steps of excavation is the placement of a well-sealed restoration.[17,18] The decision to use a one-appointment caries excavation or a step-wise technique should be based on the individual patient circumstances since the research available is inconclusive on which approach is the most successful over time.[36,37]

- Indications: Indirect pulp treatment is indicated in a permanent tooth diagnosed with a normal pulp with no symptoms of pulpitis or with a diagnosis of reversible pulpitis. The pulp is judged by clinical and radiographic criteria to be vital and able to heal from the carious insult.
- Objectives: The intermediate and/or final restoration should seal completely the involved dentin from the oral environment. The vitality of the tooth should be preserved. No post-treatment signs or symptoms such as sensitivity, pain, or swelling should be evident. There should be no radiographic evidence of internal or external root resorption or other pathologic changes. Teeth with immature roots should show continued root development and apexogenesis.

Direct pulp cap. When a small exposure of the pulp is encountered during cavity preparation and after hemorrhage control is obtained, the exposed pulp is capped with a material such as calcium hydroxide[88-92] or MTA[92] prior to placing a restoration that seals the tooth from microleakage.[17,18]

- Indications: Direct pulp capping is indicated for a permanent tooth that has a small carious or mechanical exposure in a tooth with a normal pulp.[7]
- Objectives: The tooth's vitality should be maintained. No post-treatment clinical signs or symptoms of sensitivity, pain, or swelling should be evident. Pulp healing and reparative dentin formation should occur. There should be no radiographic evidence of internal or external root resorption, periapical radiolucency, abnormal calcification, or other pathologic changes. Teeth with immature roots should show continued root development and apexogenesis.

Partial pulpotomy for carious exposures. The partial pulpotomy for carious exposures is a procedure in which the inflamed pulp tissue beneath an exposure is removed to a depth of one to three millimeters or deeper to reach healthy pulp tissue. Pulpal bleeding must be controlled by irrigation with a bacteriocidal agent such as sodium hypochlorite or chlorhexidine[70-72] before the site is covered with calcium hydroxide[6,93,94] or MTA.[95-97] While calcium hydroxide has been demonstrated to have long-term success, MTA results in more predictable dentin bridging and pulp health.[98] MTA (at least 1.5 mm thick) should cover the exposure and surrounding

dentin followed by a layer of light cured resin-modified glass ionomer.[92] A restoration that seals the tooth from microleakage is placed.

- Indications: A partial pulpotomy is indicated in a young permanent tooth for a carious pulp exposure in which the pulpal bleeding is controlled within several minutes. The tooth must be vital, with a diagnosis of normal pulp or reversible pulpitis.[6]
- Objectives: The remaining pulp should continue to be vital after partial pulpotomy. There should be no adverse clinical signs or symptoms such as sensitivity, pain, or swelling. There should be no radiographic sign of internal or external resorption, abnormal canal calcification, or periapical radiolucency postoperatively. Teeth having immature roots should continue normal root development and apexogenesis.

Partial pulpotomy for traumatic exposures (Cvek pulpotomy). The partial pulpotomy for traumatic exposures is a procedure in which the inflamed pulp tissue beneath an exposure is removed to a depth of one to three millimeters or more to reach the deeper healthy tissue. Pulpal bleeding is controlled using bacteriocidal irrigants such as sodium hypochlorite or chlorhexidine,[71,72] and the site then is covered with calcium hydroxide[99-102] or MTA.[6,103] White, rather than gray, MTA is recommended in anterior teeth to decrease the chance of discoloration. The two versions have been shown to have similar properties.[104,105] While calcium hydroxide has been demonstrated to have long-term success, MTA results in more predictable dentin bridging and pulp health.[98] MTA (at least 1.5 mm thick) should cover the exposure and surrounding dentin, followed by a layer of light-cured resin-modified glass ionomer.[103] A restoration that seals the tooth from micro-leakage is placed.

- Indications: This pulpotomy is indicated for a vital, traumatically-exposed, young permanent tooth, especially one with an incompletely formed apex. Pulpal bleeding after removal of inflamed pulpal tissue must be controlled. Neither time between the accident and treatment nor size of exposure is critical if the inflamed superficial pulp tissue is amputated to healthy pulp.[106]
- Objectives: The remaining pulp should continue to be vital after partial pulpotomy. There should be no adverse clinical signs or symptoms of sensitivity, pain, or swelling. There should be no radiographic signs of internal or external resorption, abnormal canal calcification, or periapical radiolucency post-operatively. Teeth with immature roots should show continued normal root development and apexogenesis.

Nonvital pulp treatment

Pulpectomy (conventional root canal treatment). Pulpectomy in apexified permanent teeth is conventional root canal (endodontic) treatment for exposed, infected, and/or necrotic teeth to eliminate pulpal and periradicular infection. In all cases, the entire roof of the pulp chamber is removed to gain access to the canals and eliminate all coronal pulp tissue. Following debridement, disinfection, and shaping of the root canal system, obturation of the entire root canal is accomplished with a biologically-acceptable, nonresorbable filling material. Obturation as close as possible to the cementodentinal junction should be accomplished with gutta percha or other filling material acceptable as described in the AAE's *Guide to Clinical Endodontics*.[14]

- Indications: Pulpectomy or conventional root canal treatment is indicated for a restorable permanent tooth with irreversible pulpitis or a necrotic pulp in which the root is apexified. For root canal-treated teeth with unresolved periradicular lesions, root canals that are not accessible from the conventional coronal approach, or calcification of the root canal space, endodontic treatment of a more specialized nature may be indicated.
- Objectives: There should be evidence of a successful filling without gross overextension or underfilling in the presence of a patent canal. There should be no adverse post-treatment signs or symptoms such as prolonged sensitivity, pain, or swelling, and there should be evidence of resolution of pretreatment pathology with no further breakdown of periradicular supporting tissues clinically or radiographically.

Apexification (root end closure). Apexification is a method of inducing root end closure of an incompletely formed nonvital permanent tooth by removing the coronal and nonvital radicular tissue just short of the root end and placing a biocompatible agent such as calcium hydroxide in the canals for two to four weeks to disinfect the canal space. Root end closure is accomplished with an apical barrier such as MTA.[107] In instances when complete closure cannot be accomplished by MTA, an absorbable collagen wound dressing (e.g., Colla-Cote®)[108] can be placed at the root end to allow MTA to be packed within the confines of the canal space. Gutta percha is used to fill the remaining canal space. If the canal walls are thin, the canal space can be filled with MTA or composite resin instead of gutta percha to strengthen the tooth against fracture.[109]

- Indications: This procedure is indicated for nonvital permanent teeth with incompletely formed roots.
- Objectives: This procedure should induce root end closure (apexification) at the apices of immature roots or result in an apical barrier as confirmed by clinical and radiographic evaluation. Adverse post-treatment clinical signs or symptoms of sensitivity, pain, or swelling should not be evident. There should be no radiographic evidence of external root resorption, lateral root pathosis, root fracture, or breakdown of periradicular supporting tissues during or following therapy. The tooth should continue to erupt, and the alveolus should continue to grow in conjunction with the adjacent teeth.

References

1. Fuks AB. Pulp therapy for the primary dentition. In: Pinkham JR, Casamassimo PS, Fields HW Jr., McTigue DJ, Nowak A, eds. Pediatric Dentistry: Infancy Through Adolescence. 5th ed. St. Louis, Mo.: Elsevier Saunders Co.; 2013:331-51.

2. American Association of Endodontists. Glossary of Endodontic Terms. 7th ed. Chicago, Ill.: American Association of Endodontists; 2003.
3. American Association of Endodontists. Systematic endodontic diagnosis. Insert to the Fall/Winter edition of Endodontics. Chicago, Ill.: Colleagues for Excellence; 1996.
4. McDonald RE, Avery DR, Dean JA, Jones JE. Management of trauma to the teeth and supporting tissues. In: Dean JA, Avery DR, McDonald RE, eds. McDonald and Avery's Dentistry for the Child and Adolescent. 9th ed. St Louis, Mo.: Mosby Elsevier Inc.; 2011:403-42.
5. Coll JA, Sadrian R. Predicting pulpectomy success and its relationship to exfoliation and succedaneous dentition. Pediatr Dent 1996;18(1):57-63.
6. Camp JH, Fuks AB. Pediatric endodontics: Endodontic treatment for the primary and young permanent dentition. In: Cohen S, Hargreaves KM, eds. Pathways of the Pulp. 10th ed. St. Louis, Mo.: Mosby Elsevier; 2011:808-57.
7. Farooq NS, Coll JA, Kuwabara A, Shelton P. Success rates of formocresol pulpotomy and indirect pulp therapy in the treatment of deep dentinal caries in primary teeth. Pediatr Dent 2000;22(4):278-86.
8. Fuks AB. Current concepts in vital pulp therapy. Eur J Pediatr Dent 2002;3(3):115-20.
9. Vij R, Coll JA, Shelton P, Farooq NS. Caries control and other variables associated with success of primary molar vital pulp therapy. Pediatr Dent 2004;26(3):214-20.
10. Murray PE, About I, Franquin JC, Remusat M, Smith AJ. Restorative pulpal and repair responses. J Am Dent Assoc 2001;132(4):482-91.
11. Holan G, Eidelman E, Fuks AB. Long-term evaluation of pulpotomy in primary molars using mineral trioxide aggregate or formocresol. Pediatr Dent 2005;27(2):129-36.
12. American Association of Endodontists. Guide to Clinical Endodontics. 5th ed. Chicago, Ill.: American Association of Endodontists; 2013.
13. Itota T, Nakabo S, Torii Y, Narukami T, Doi J, Yoshiyama M. Effect of fluoride-releasing liner on demineralized dentin. Quintessence Int 2006;37(4):297-303.
14. Weiner RS, Weiner LK, Kugel G. Teaching the use of bases and liners: A survey of North American dental schools. J Am Dent Assoc 1996;127(11):1640-5.
15. Wisithphrom K, Murray PE, About I, Windsor LJ. Interactions between cavity preparation and restoration events and their effects on pulp vitality. Int J Periodontics Restorative Dent 2006;26(6):596-605.
16. de Souza Costa CA, Teixeira HM, Lopes do Nascimento AB, Hebling J. Biocompatibility of resin-based dental materials applied as liners in deep cavities prepared in human teeth. J Biomed Mater Res B Appl Biomater 2007;81(1):175-84.
17. Murray PE, Hafez AA, Smith AJ, Cox CF. Bacterial microleakage and pulp inflammation associated with various restorative materials. Dent Mater 2002;18(6):470-8.
18. Rabchinsky J, Donly KJ. A comparison of glass-ionomer cement and calcium hydroxide liners in amalgam restorations. Int J Periodontics Restorative Dent 1993;13(4):378-83.
19. Büyükgüral B, Cehreli ZC. Effect of different adhesive protocols vs calcium hydroxide on primary tooth pulp with different remaining dentin thicknesses: 24 month results. Clin Oral Investig 2008;12(1):91-6.
20. Falster CA, Araújo FB, Straffon LH, Nör JE. Indirect pulp treatment: in vivo outcomes of an adhesive resin system vs calcium hydroxide for protection of the dentin-pulp complex. Pediatr Dent 2002;24(3):241-8.
21. Lo EC, Holmgren CJ, Hu D, Van Palenstein Helderman W. Six-year follow up of atraumatic restorative treatment restorations placed in Chinese school children. Community Dent Oral Epidemiol 2007;35(5):387-92.
22. de Souza EM, Cefaly DF, Terada RS, Rodrigues CC, de Lima Navarro MF. Clinical evaluation of the ART technique using high density and resin-modified glass ionomer cements. Oral Health Prev Dent 2003;1(3):201-7.
23. Pinto AS, de Araújo FB, Franzon R, et al. Clinical and microbiological effect of calcium hydroxide protection in indirect pulp capping in primary teeth. Am J Dent 2006;19(6):382-6.
24. Al-Zayer MA, Straffon LH, Feigal RJ, Welch KB. Indirect pulp treatment of primary posterior teeth: A retrospective study. Pediatr Dent 2003;25(1):29-36.
25. Davidovich E, Weiss E, Fuks AB, Beyth N. Surface antibacterial properties of glass ionomer cements used in a traumatic restorative treatment. J Am Dent Assoc 2007;138(10):1347-52.
26. Marchi JJ, de Araújo FB, Froner AM, Straffon LH, Nör JE. Indirect pulp capping in the primary dentition: A 4 year follow-up study. J Clin Pediatr Dent 2006;31(2):68-71.
27. Menezes JP, Rosenblatt A, Medeiros E. Clinical evaluation of atraumatic restorations in primary molars: A comparison between 2 glass ionomer cements. J Dent Child 2006;73(2):91-7.
28. Brännström M. Communication between the oral cavity and the dental pulp associated with restorative treatment. Oper Dent 1984;9(2):57-68.
29. Pereira JC, Manfio AP, Franco EB, Lopes ES. Clinical evaluation of Dycal under amalgam restorations. Am J Dent 1990;3:67-70.
30. Tam LE, Pulver E, McComb D, Smith DC. Physical properties of calcium hydroxide and glass-ionomer base and lining materials. Dent Mater 1989;5:145-9.
31. Lewis BA, Burgess JO, Gray SE. Mechanical properties of dental base materials. Am J Dent 1992;5:69-72.
32. Duque C, Negrini Tde C, Hebling J, Spolidorio DM. Inhibitory activity of glass-ionomer cements on cariogenic bacteria. Oper Dent 2005;30(5):636-40.

33. Loyola-Rodriguez JP, García-Godoy F, Linquist R. Growth inhibition of glass ionomer cements on mutans streptococci. Pediatr Dent 1994;16(5):346-9.
34. Wambier DS, dos Santos FA, Guedes-Pinto AC, Jaeger RG, Simionato MR. Ultrastructural and microbiological analysis of the dentin layers affected by carious lesions in primary molars treated by minimal intervention. Pediatr Dent 2007;29(3):228-35.
35. Coll JA. Indirect pulp capping and primary teeth: Is the primary tooth pulpotomy out of date? Pediatr Dent 2008;30(3):230-6.
36. Schwendicke F, Dorfer C, Paris S. Incomplete caries removal: A systemic review and meta-analysis. J Dent Res 2013;92(4):306-14.
37. Thompson V, Craig RG, Curro FA, Green WS, Ship JA. Treatment of deep carious lesions by complete excavation or partial removal: A critical review. J Am Dent Assoc 2008;139(6):705-12.
38. Ribeiro CC, Baratieri LN, Perdigao J, Baratieri NM, Ritter AV. A clinical, radiographic, and scanning electron microscopic evaluation of adhesive restorations on carious dentin in primary teeth. Quintessence Int 1999;30(9):591-9.
39. Foley J, Evans D, Blackwell A. Partial caries removal and cariostatic materials in carious primary molar teeth: A randomized controlled clinical trial. Br Dent J 2004; 197(11):697-701.
40. Oliveira EF, Carminatti G, Fontanella V, Maltz M. The monitoring of deep caries lesions after incomplete dentin caries removal: Results after 14-18 months. Clin Oral Investig 2006;10(2):134-9.
41. Agamy HA, Bakry NS, Mounir MM, Avery DR. Comparison of mineral trioxide aggregate and formocresol as pulp-capping agents in pulpotomized primary teeth. Pediatr Dent 2004;26(4):302-9.
42. Maroto M, Barbería E, Planells P, García-Godoy F. Dentin bridge formation after mineral trioxide aggregate (MTA) pulpotomies in primary teeth. Am J Dent 2005;18(3): 151-4.
43. Caicedo R, Abbott PV, Alongi DJ, Alarcon MY. Clinical, radiographic and histological analysis of the effects of mineral trioxide aggregate used in direct pulp capping and pulpotomies of primary teeth. Aust Dent J 2006;51 (4):297-305.
44. Tuna D, Olmez A. Clinical long-term evaluation of MTA as a direct pulp capping material in primary teeth. Int Endod J 2008;41(4):273-8.
45. Kopel HM. The pulp capping procedure in primary teeth "revisited". ASDC J Dent Child 1997;64(5):327-33.
46. Smith NL, Seale NS, Nunn ME. Ferric sulfate pulpotomy in primary molars: A retrospective study. Pediatr Dent 2000;22(3):192-9.
47. Burnett S, Walker J. Comparison of ferric sulfate, formocresol, and a combination of ferric sulfate/formocresol in primary tooth vital pulpotomies: A retrospective radiographic survey. ASDC J Dent Child 2002;69(1):44-8.
48. Ibricevic H, Al-Jame Q. Ferric sulphate and formocresol in pulpotomy of primary molars: Long term follow-up study. Eur J Paediatr Dent 2003;4(1):28-32.
49. Loh A, O'Hoy P, Tran X, et al. Evidence-based assessment: Evaluation of the formocresol versus ferric sulfate primary molar pulpotomy. Pediatr Dent 2004;26(5):401-9.
50. Markovic D, Zivojinovic V, Vucetic M. Evaluation of three pulpotomy medicaments in primary teeth. Eur J Paediatr Dent 2005;6(3):133-8.
51. Vargas KG, Packham B. Radiographic success of ferric sulfate and formocresol pulpotomies in relation to early exfoliation. Pediatr Dent 2005;27(3):233-7.
52. Huth KC, Paschos E, Hajek-Al-Khatar N, et al. Effectiveness of 4 pulpotomy techniques – Randomized controlled trial. J Dent Res 2005;84(12):1144-8.
53. Vostatek S, Kanellis M, Weber-Gasparoni K, Gregorsok RL. Sodium hypochlorite pulpotomies in primary teeth: A retrospective assessment. Pediatr Dent 2011;33(4): 327-32.
54. Shabbzendedar M, Mazhari F, Alami M, Talebi M. Sodium hypochlorite vs formocresol as pulpotomy in primary molars 1 year follow up. Pediatr Dent 2013;35(4): 329-32.
55. Ruby D, Cox C, Mitchell SC, Makhija S, Chompu-Inwai P, Jackson J. A randomized study of sodium hypochlorite versus formocresol pulpotomy in primary molars. Int J Pediatr Dent 2012;23(2):145-52.
56. Zurn D, Seale NS. Light-cured calcium hydroxide vs formocresol in human primary molar pulpotomies: A randomized controlled trial. Pediatr Dent 2008;30(1): 34-41.
57. Farsi N, Alamoudi N, Balto K, Al Mushayt A. Success of mineral trioxide aggregate in pulpotomized primary molars. J Clin Pediatr Dent 2005;29(4):307-11.
58. Maroto M, Barbería E, Vera V, García-Godoy F. Mineral trioxide aggregate as pulp dressing agent in pulptomy treatment of primary molars: 42-month clinical study. Am J Dent 2007;20(5):283-6.
59. Peng L, Ye L, Tan H, Zhou X. Better outcomes in pulpotomies on primary molars with MTA. Evid Based Dent 2007;8:11-12.
60. Sushynski J, Zealand C, Botero TM, et al. Comparison of gray mineral trioxide aggregate and diluted formocresol in pulpotomized primary molars: A 6 to 24 month observation. Pediatr Dent 2012;34(5):120-8.
61. Fuks AB, Papagiannoulis L. Pulpotomy in primary teeth: Review of the literature according to standardized criteria. Eur Arch Paediatr Dent 2006;7(2):64-71.
62. Ng FK, Messer LB. Mineral trioxide aggregate as a pulpotomy medicament: A narrative review. Eur Arch Paediatr Dent 2008;9(1):4-11.
63. Seale NS, Glickman GN. Contemporary perspectives on vital pulp therapy: Views from the endodontists and pediatric dentists. Pediatr Dent 2008;30(3):261-7.

References continued on the next page.

64. Dean JA, Mack RB, Fulkerson BT, Sanders BJ. Comparison of electrical and formocresol pulpotomy procedures in children. Int J Pediatr Dent 2002;12(3):177-82.
65. Guelmann M, Fair J, Bimstein E. Permanent versus temporary restorations after emergency pulpotomies in primary molars. Pediatr Dent 2005;27(6):478-81.
66. Holan G, Fuks AB, Keltz N. Success rate of formocresol pulpotomy in primary molars restored with stainless steel crown vs amalgam. Pediatr Dent 2002;24(3):212-6.
67. Guelmann M, McIlwain MF, Primosch RE. Radiographic assessment of primary molar pulpotomies restored with resin-based materials. Pediatr Dent 2005;27(1):24-7.
68. Thompson KS, Seale NS, Nunn ME, Huff G. Alternative method of hemorrhage control in full strength formocresol pulpotomy. Pediatr Dent 2001;23(3):217-222.
69. Strange DM, Seale NS, Nunn ME, Strange M. Outcome of formocresol/ZOE sub-base pulpotomies utilizing alternative radiographic success criteria. Pediatr Dent 2001;23(3):331-6.
70. Siqueira JF Jr, Rôças IN, Paiva SS, Guimarães-Pinto T, Magalhaes KM, Lima KC. Bacteriologic investigation of the effects of sodium hypochlorite and chlorhexidine during the endodontic treatment of teeth with apical periodontitis. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2007;104(1):122-30.
71. Ercan E, Ozekinci T, Atakul F, Gül K. Antibacterial activity of 2% chlorhexidine gluconate and 5.25% sodium hypochlorite in infected root canal: In vivo study. J Endod 2004;30(2):84-7.
72. Zehnder M. Root canal irrigants. J Endod 2006;32(5):389-98.
73. Mehdipour O, Kleier DJ, Averbach RE. Anatomy of sodium hypochlorite accidents. Compend Contin Educ Dent 2007;28(10):548-50.
74. Casas MJ, Kenny DJ, Johnston DH, Judd PL. Long-term outcomes of primary molar ferric sulfate pulpotomy and root canal therapy. Pediatr Dent 2004;26(1):44-8.
75. Holan G, Fuks AB. A comparison of pulpectomies using ZOE and KRI paste in primary molars: A retrospective study. Pediatr Dent 1993;15(6):403-7.
76. Ozalp N, Saroğlu I, Sönmez H. Evaluation of various root canal filling materials in primary molar pulpectomies: An in vivo study. Am J Dent 2005;18(6):347-50.
77. Kubota K, Golden BE, Penugonda B. Root canal filling materials for primary teeth: A review of the literature. ASDC J Dent Child 1992;59(3):225-7.
78. Primosch RE, Ahmadi A, Setzer B, Guelmann M. A retrospective assessment of zinc oxide-eugenol pulpectomies in vital maxillary primary incisors successfully restored with composite resin crowns. Pediatr Dent 2005;27(6):470-7.
79. Oen KT, Thompson VP, Vena D, et al. Attitudes and expectations of treating deep caries: A PEARL Network survey. Gen Dent 2007;55(3):197-203.
80. Maltz M, de Oliveira EF, Fontanella V, Bianchi R. A clinical, microbiologic, and radiographic study of deep caries lesions after incomplete caries removal. Quintessence Int 2002;33(2):151-9.
81. Fairbourn DR, Charbeneau GT, Loesche WJ. Effect of improved Dycal and IRM on bacteria in deep carious lesions. J Am Dent Assoc 1980;100(4):547-52.
82. Leksell E, Ridell K, Cvek M, Mejàre I. Pulp exposure after stepwise versus direct complete excavation of deep carious lesions in young posterior permanent teeth. Endod Dent Traumatol 1996;12(4):192-6.
83. Massler M. Treatment of profound caries to prevent pulpal damage. J Pedod 1978;2(2):99-105.
84. Bjørndal L, Thylstrup A. A practice-based study on stepwise excavation of deep carious lesions in permanent teeth: A 1-year follow-up study. Community Dent Oral Epidemiol 1998;26(2):122-8.
85. Bjørndal L, Larsen T, Thylstrup A. A clinical and microbiological study of deep carious lesions during stepwise excavation using long treatment intervals. Caries Res 1997;31(6):411-7.
86. Bjørndal L, Larsen T. Changes in the cultivable flora in deep carious lesions following a stepwise excavation procedure. Caries Res 2000;34(6):502-8.
87. Bjørndal L, Mjör IA. Pulp-dentin biology in restorative dentistry. Part 4: Dental caries-characteristics of lesions and pulpal reactions. Quintessence Int 2001;32(9):717-36.
88. Horsted P, Sondergaard B, Thylstrup A, El Attar K, Fejerskov O. A retrospective study of direct pulp capping with calcium hydroxide compounds. Endod Dent Traumatol 1985;1(1):29-34.
89. Baume LJ, Holz J. Long term clinical assessment of direct pulp capping. Int Dent J 1981;31(4):251-60.
90. Barthel CR, Rosenkranz B, Leuenberg A, Roulet JF. Pulp capping of carious exposures: Treatment outcome after 5 and 10 years–A retrospective study. J Endod 2000;26(9):525-8.
91. Matsuo T, Nakanishi T, Shimizu H, Ebisu S. A clinical study of direct pulp capping applied to carious-exposed pulps. J Endod 1996;22(10):551-6.
92. Bogen G, Kim JS, Bakland LK. Direct pulp capping with mineral trioxide aggregate: An observational study. J Am Dent Assoc 2008;139(3):305-15.
93. Mejàre I, Cvek M. Partial pulpotomy in young permanent teeth with deep carious lesions. Endod Dent Traumatol 1993;9(6):238-42.
94. 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(3):221-6.
95. El-Meligy OAS, Avery DR. Comparison of mineral trioxide aggregate and calcium hydroxide as pulpotomy agents in young permanent teeth (apexogenesis). Pediatr Dent 2006;28(5):399-404.

96. 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(2):99-104.
97. Witherspoon DE, Small JC, Harris GZ. Mineral trioxide aggregate pulpotomies: A series outcomes assessment. J Am Dent Assoc 2006;137(9):610-8.
98. Chacko V, Kurikose S. Human pulpal response to mineral trioxide aggregate (MTA): A histological study. J Clin Pediatr Dent 2006;30(3):203-10.
99. Fuks AB, Gavra S, Chosack A. Long-term follow-up of traumatized incisors treated by partial pulpotomy. Pediatr Dent 1993;15(5):334-6.
100. de Blanco LP. Treatment of crown fractures with pulp exposure. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1996;82(5):564-8.
101. Blanco L, Cohen S. Treatment of crown fractures with exposed pulps. J Calif Dent Assoc 2002;30(6):419-25.
102. Cvek M. Endodontic management and the use of calcium hydroxide in traumatized permanent teeth. In: Andreasen JO, Andreasen FM, Andersson L, eds. Textbook and Color Atlas of Traumatic Injuries to the Teeth. 4th ed. Ames, Iowa: Blackwell Munksgaard; 2007:598-657.
103. Bakland LK. New endodontic procedures using mineral trioxide aggregate (MTA) for teeth with traumatic injuries. In: Andreasen JO, Andreasen FM, Andersson L, eds. Textbook and Color Atlas of Traumatic Injuries to the Teeth. 4th ed. Ames, Iowa: Blackwell Munksgaard; 2007:658-68.
104. Ferris DM, Baumgartner JC. Perforation repair comparing two types of mineral trioxide aggregate. J Endod 2004; 30(6):422-4.
105. Menezes R, Bramante CM, Letra A, Carvalho VG, Garcia RB. Histologic evaluation of pulpotomies in dog using two types of mineral trioxide aggregate and regular and white Portland cements as wound dressings. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2004;98(3): 376-9.
106. Pereira JC, Stanley HR. Pulp capping: Influence of the exposure site on pulp healing: Histologic and radiographic study in dog's pulp. J Endod 1981;7(5):213-23.
107. Torabinejad M, Chivian N. Clinical applications of mineral trioxide aggregate. J Endod 1999;25(3):197-205.
108. Patino MG, Neiders ME, Andreana S, Noble B, Cohen RE. Collagen as an implantable material in medicine and dentistry. J Oral Implantol 2002;28(5):220-5.
109. Katebzadeh N, Dalton BC, Trope M. Strengthening immature teeth during and after apexification. J Endod 1998;24(4):256-9.