Pulp Therapy for Primary and Immature Permanent Teeth

Latest Revision
2020

How to Cite: American Academy of Pediatric Dentistry. Pulp therapy for primary and immature permanent teeth. The Reference Manual of Pediatric Dentistry. Chicago, Ill.: American Academy of Pediatric Dentistry; 2022:415-23.

Abstract

This best practice supports clinicians in the diagnosis of pulp health or pathosis and provides evidence for various therapeutic interventions for pulp therapy in both primary and immature permanent teeth. The health status of pulp tissue determines which form of pulp therapy is indicated. Vital pulp therapies for primary teeth with normal pulp or reversible pulpitis include protective liner, indirect pulp treatment, direct pulp cap, and pulpotomy. Nonvital pulp treatment for primary teeth with irreversible pulpitis or necrotic pulp include pulpectomy and lesion stabilization/tissue repair. Vital pulp therapy for immature permanent teeth with a normal pulp or pulpitis include protective liners, apexogenesis, indirect pulp treatment, direct pulp cap, partial pulpotomy, and complete pulpotomy. Nonvital pulp treatment for permanent teeth includes conventional root canal treatment, apexification, and regenerative endodontics. Clinicians should familiarize themselves with these pulp therapies and consider the value of each tooth in question, restorability of the tooth, and potential alternative treatment.

This document was developed through a collaborative effort of the American Academy of Pediatric Dentistry Councils on Clinical Affairs and Scientific Affairs to offer updated information and guidance on pulp therapy for primary and immature permanent teeth.

KEYWORDS: DENTAL PULP, ROOT CANAL THERAPY, ROOT CANAL PREPARATION, PULP CAPPING, APEXIFICATION

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.[1] This document by the Council on Clinical Affairs is a revision of the previous version, last revised in 2014.[2] This revision included a new search of the PubMed®/MEDLINE database using the terms: pulpotomy, pulpectomy, pulpectomy primary teeth, indirect pulp treatment (**IPT**), 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, lesion sterilization tissue repair (**LSTR**), 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 goal of pulp therapy is to maintain the integrity and health of the teeth and their supporting tissues while maintaining 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.

The indications, objectives, and type of pulp therapy are based on the health status of the pulp tissue which is classified as: 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.[3] The clinical diagnosis derived from:[4-7]

1. a comprehensive medical history.
2. a review of past and present dental history and treatment, including current symptoms and chief complaint.

ABBREVIATIONS
AAE: American Association of Endodontists. **AAPD:** American Academy of Pediatric Dentistry. **DPC:** Direct pulp cap. **IPT:** Indirect pulp therapy. **ITR:** Interim therapeutic restoration. **LSTR:** Lesion sterilization/tissue repair. **MTA:** Mineral trioxide aggregate. **ZOE:** Zinc oxide eugenol.

3. a subjective evaluation of the area associated with the current symptoms/chief complaint by questioning the patient/parent on the location, intensity, duration, stimulus, relief, and spontaneity.
4. an objective extraoral examination as well as examination of the intraoral soft and hard tissues.
5. if obtainable, radiograph(s) to diagnose periapical or periradicular changes.
6. clinical tests such as palpation, percussion, and mobility; however, electric pulp and thermal tests are unreliable in immature permanent and primary teeth.

Teeth exhibiting provoked pain of short duration relieved with over-the-counter analgesics, by brushing, or upon the 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 therapy.[8-11]

Teeth exhibiting signs or symptoms such as a history of spontaneous unprovoked pain, 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 and are candidates for nonvital pulp treatment.[12] Regenerative endodontics may be considered for immature permanent teeth with apical periodontitis, a necrotic pulp, and immature apex.[13]

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.[4,12]

This document is intended to recommend the best 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 non-vital primary and immature permanent teeth. Pulp therapy requires periodic clinical and radiographic assessment of the treated tooth and the supporting structures.[14] Postoperative 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.[5] This can document the quality of the fill and 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.[15] 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. Immature permanent teeth treated with pulp therapy also should have close clinical and radiographic follow-up to confirm that pulp pathology is not developing.[16] Isolation is necessary to minimize bacterial contamination and to protect soft and hard tissues. Use of rubber dam isolation is considered a gold standard[17] for pulp treatment. When unable to use a rubber dam, other effective isolation may be considered.

When a pulp exposure occurs and pulp therapy is indicated, irrigants for pulp therapy should not come from dental unit water lines. The Centers for Disease Control and Prevention states "conventional dental units cannot reliably deliver sterile water even when equipped with independent water reservoirs containing sterile water because the water-bearing pathway cannot be reliably sterilized."[18] A single-use disposable syringe should be used to dispense irrigants for pulp therapy.

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 material placed on the dentin in proximity to the underlying 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 MTA, trisilicate cements, calcium hydroxide, or other biocompatible material is at the discretion of the clinician.[19,20]

- 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 postoperative sensitivity.[21,22]
- 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.[23] Adverse posttreatment clinical signs or symptoms such as sensitivity, pain, or swelling should not occur.

Indirect pulp treatment. IPT is a procedure performed in a tooth with a deep caries lesion approximating the pulp but without evidence of radicular pathology. "Indirect pulp

treatment is a procedure that leaves the deepest caries adjacent to the pulp undisturbed in an effort to avoid a pulp exposure. This caries-affected dentin is covered with a biocompatible material to produce a biological seal."[17] A radiopaque liner such as a dentin bonding agent,[24,25] resin modified glass ionomer,[4] calcium hydroxide,[25] or MTA (or any other biocompatible material)[26] is placed over the remaining carious dentin to stimulate healing and repair. The liner that is placed over the dentin (calcium hydroxide, glass ionomer, or bonding agents) does not affect the IPT success.[27] The tooth then is restored with a material that seals the tooth from microleakage.

Interim therapeutic restorations (**ITR**) with glass ionomer cements may be used for caries control in teeth with caries 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.[15,28] Current literature indicates there is no conclusive evidence that it is necessary to reenter the tooth to remove the residual caries.[29,30] 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.[29-34] Indirect pulp treatment has been shown to have a higher success rate than direct pulp cap (**DPC**) and pulpotomy in long term studies.[8,10,15,25,27,35-40] IPT also allows for a normal exfoliation time. Therefore, IPT can be chosen instead of DPC or pulpotomy when the pulp is normal or has a diagnosis of reversible pulpitis and there is no pulp exposure.

- Indications: IPT is indicated in a primary tooth with deep caries that exhibits no pulpitis or with reversible pulpitis when the deepest carious dentin is not removed to avoid a pulp exposure.[9,27] The pulp is judged by clinical and radiographic criteria to be vital and able to heal from the carious insult.[17,27]
- Objectives: The restorative material should seal completely the involved dentin from the oral environment. The tooth's vitality should be preserved. No posttreatment 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 exposure (one millimeter or less)[17] of the pulp is encountered during cavity preparation or following a traumatic injury, a biocompatible radiopaque base such as MTA[26,41-43] or calcium hydroxide[44] may be placed in contact with the exposed pulp tissue. The tooth is restored with a material that seals the tooth from microleakage.[8]

- Indications: This procedure is indicated in a primary tooth with a normal pulp following a small (one millimeter or less) pulp exposure of when conditions for a favorable response are optimal.[26,41-43]
- Objectives: The tooth's vitality should be maintained. No posttreatment 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 when caries removal results in a pulp exposure in a tooth with a normal pulp or reversible pulpitis or after a traumatic pulp exposure[12] and there is no radiographic sign of infection or pathologic resorption. The coronal pulp is amputated, pulpal hemorrhage is controlled, and the remaining vital radicular pulp tissue surface is treated with a long-term clinically-successful medicament. Only MTA and formocresol are recommended as the medicament of choice for teeth expected to be retained for 24 months or more.[17] Other materials or techniques such as ferric sulfate, lasers, sodium hypochlorite, and tricalcium silicate have conditional recommendations.[17] The AAPD's *Use of Vital Pulp Therapies in Primary Teeth with Deep Caries Lesions* recommended against the use of calcium hydroxide for pulpotomy.[17] After the coronal pulp chamber is filled with a suitable base, the tooth is restored with a restoration that seals the tooth from microleakage. 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.[45-47] However, for multisurface lesions, a stainless steel crown is the restoration of choice.[17]

- 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,[7] and when there are no radiographic signs of infection or pathologic resorption. When the coronal tissue is amputated, the remaining radicular tissue must be judged to be vital without suppuration, purulence, necrosis, or excessive hemorrhage that cannot be controlled by a cotton pellet after several minutes.[4]
- 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.[48-51] 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 inflamed or necrotic due to caries or trauma. The root canals are debrided and shaped with hand or rotary files[52] and then irrigated. A recent systematic review showed no difference in success when irrigating with chlorhexidine or one- to five-percent sodium hypochlorite or sterile water/saline.[53,54] Because it is a potent tissue irritant, sodium hypochlorite must not be extruded beyond the apex.[55] After the

canals are dried, a resorbable material such as non-reinforced zinc/oxide eugenol (**ZOE**),[56,57] iodoform-based paste[4], or a combination paste of iodoform and calcium hydroxide[58,59] is used to fill the canals. A recent systematic review reports that ZOE performed better long term than iodoform-based pastes.[53] The tooth then is restored with a restoration that seals the tooth from microleakage. Clinicians should evaluate non-vital pulp treatments for success and adverse events clinically and radiographically at least every 12 months.[53,54]

- 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 or pulp necrosis (e.g., suppuration, purulence) The roots should exhibit minimal or no resorption. When there is no root resorption present, pulpectomy is recommended over LSTR.[53,54]
- 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.[57-59] 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.

Lesion sterilization/tissue repair. LSTR is a procedure that usually has no instrumentation of the root canals but, instead, an antibiotic mixture is placed in the pulp chamber which is intended to disinfect the root canals.[53,54] After opening the pulp chamber of a necrotic tooth, the canal orifices are enlarged using a large round bur to create medication receptacles. The walls of the chamber are cleaned with phosphoric acid and then rinsed and dried.[60] A three antibiotic mixture of clindamycin, metronidazole, and ciprofloxacin is combined with a liquid vector of polyethylene glycol and macrogol to form a paste placed directly into the medication receptables and over the pulpal floor.[60] It then is covered with a glass-ionomer cement and restored with a stainless steel crown.[60] Previous studies have used minocycline in place of clindamycin[61], but there are concerns about staining when a tetracycline-like drug is used.[62] Although similar success rates have been reported whether minocycline or clindamycin is used[62], a more recent systematic review concluded statistically significant less success using a tetracycline mix versus a mix without tetracycline[53]. Therefore, the AAPD's *Use of Non-Vital Pulp Therapies in Primary Teeth* recommends antibiotic mixtures used in LSTR should not include tetracycline.[54]

- Indications: LSTR is indicated for 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 or pulp necrosis (e.g., suppuration, purulence). Root resorption and strategic tooth position in the arch should be considered prior to treatment. When a tooth is to be maintained for less than twelve months and exhibits root resorption, LSTR is preferred to pulpectomy.[53,54]
- Objectives: Following treatment, the radiographic infectious process should resolve as evidenced by bone deposition in the pretreatment radiolucent areas and pretreatment clinical signs and symptoms should resolve.

Immature permanent teeth

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

Protective liner. A protective liner is a thinly-applied material 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 MTA, trisilicate cements, calcium hydroxide, or other biocompatible material is at the discretion of the clinician.[19] The liner must be followed by a well-sealed restoration to minimize bacterial leakage from the restoration-dentin interface.[23]

- 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.[23] Adverse posttreatment 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. IPT 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.[12] In recent years, rather than completing 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.[63,64] The risk of this approach is either an unintentional pulp exposure or irreversible pulpitis.[64] When there is concern for pulp exposure, the step-wise excavation of deep caries may be considered.[16] This approach involves a two-step process. The first step is the removal of carious dentin along the dentin-enamel junction 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.[65-67] This interim restoration should be able to be maintained for up to 12 months.[16] The second step is the removal of the remaining caries and placement of a final restoration. Critical to both steps of excavation is the placement of a well-sealed restoration.[23] A recent meta-analysis has shown that long term success rates are equivalent for partial caries removal or stepwise caries removal with greater than 96 percent of teeth treated remaining vital after two years.[68]

- Indications: IPT is indicated in a permanent tooth with deep caries that exhibits no pulpitis or has been diagnosed as reversible pulpitis when the deepest carious dentin is not removed to avoid a pulp exposure. 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 posttreatment 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[44,69] or MTA[69] prior to placing a restoration that seals the tooth from microleakage.[23]

- 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.
- Objectives: The tooth's vitality should be maintained. No posttreatment 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. Pulp bleeding must be controlled by irrigation with a bacteriocidal agent such as sodium hypochlorite or chlorhexidine[51,70,71] before the site is covered with calcium hydroxide[12] or MTA.[72-74] While calcium hydroxide has been demonstrated to have long-term success, MTA results in more predictable dentin bridging and pulp health.[75] MTA (at least 1.5 millimeters thick) should cover the exposure and surrounding dentin followed by a layer of light-cured resin-modified glass ionomer.[69] 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 pulp bleeding is controlled within several minutes. The tooth must be vital, with a diagnosis of normal pulp or reversible pulpitis.
- 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 that is four millimeters or less in size[76] is removed to a depth of one to three millimeters or more to reach the deeper healthy tissue. While literature indicates that a Cvek pulpotomy may be completed up to nine days after an exposure, there is no evidence on tooth outcomes with longer periods of waiting time.[76] Pulp bleeding is controlled using irrigants such as sodium hypochlorite or chlorhexidine,[70,71] and the site then is covered with calcium hydroxide[77,78] or MTA[12,79]. MTA may cause tooth discoloration.[80,81] The two versions (light and gray) have been shown to have similar properties.[82,83] While calcium hydroxide has been demonstrated to have long-term success, MTA results in more predictable dentin bridging and pulp health.[75] MTA (at least 1.5 millimeters thick) should cover the exposure and surrounding dentin, followed by a layer of light-cured resin-modified glass ionomer.[79] A restoration that seals the tooth from microleakage is placed.

- Indications: This pulpotomy is indicated for a vital, traumatically-exposed, young permanent tooth, especially one with an incompletely formed apex
- 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 postoperatively. Teeth with immature roots should show continued normal root development and apexogenesis.

Complete pulpotomy. A complete or traditional pulpotomy involves complete surgical removal of the coronal vital pulp tissue followed by placement of a biologically acceptable material in the pulp chamber and restoration of the tooth.[6] Compared to the traditionally-used calcium hydroxide, MTA and tricalcium silicate exhibit superior long-term seal and reparative dentin formation leading to a higher success rate.[84-86]

- Indications: A full pulpotomy is indicated in immature permanent teeth with cariously exposed pulp as an interim procedure to allow continued root development (apexogenesis). It also may be performed as an emergency procedure for temporary relief of symptoms until a definitive root canal treatment can be accomplished.[6]
- Objectives: Full pulpotomy procedure in a vital permanent tooth aims to preserve the vitality of remaining radicular pulp.[3] The objective is to prevent adverse clinical signs and symptoms, obtain radiographic evidence of sufficient root development for endodontic treatment, prevent breakdown of periradicular tissues, and to prevent resorptive defects or accelerated canal calcification as determined by periodic radiographic evaluation.[6]

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 pulp 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 cleaning, disinfection, and shaping of the root canal system, obturation of the entire root canal is accomplished with a biologically-acceptable semi-solid or solid filling material.[6]

- Indications: Pulpectomy or conventional root canal treatment is indicated for a restorable permanent tooth with a closed apex that exhibits irreversible pulpitis or a necrotic pulp. 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 posttreatment 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 non-vital permanent tooth by removing the coronal and non-vital radicular tissue just short of the root end and placing a biocompatible agent such as calcium hydroxide in the canals for two weeks to one month to disinfect the canal space.[16] Root end closure is accomplished with an apical barrier such as MTA.[6] In instances when complete closure cannot be accomplished by MTA, an absorbable collagen wound dressing[87] 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.[6]

- Indications: This procedure is indicated for non-vital 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 posttreatment 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.

Regenerative endodontics. Regenerative endodontics is defined as biologically-based procedures designed to physiologically replace damaged tooth structure, including dentin and root structures, as well as the pulp-dentin complex.[88] The goals of the regenerative procedure are elimination of clinical symptoms/signs and resolution of apical periodontitis in teeth with a necrotic pulp and immature apex.[89] Thickening of the canal walls and/or continued root maturation is an additional goal.[89] The difference between regenerative endodontic therapy and nonsurgical conventional root canal therapy is that the disinfected root canal space in the former therapy is filled with the host's own vital tissue and the canal space in the latter therapy is filled with biocompatible foreign materials.

- Indications: This procedure is indicated for nonvital permanent teeth with incompletely formed roots.
- Objectives: This procedure should result in increased width of the root walls and may lead to increase in root length, both confirmed by radiographic evaluation. Adverse posttreatment 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. American Academy of Pediatric Dentistry. Pulp therapy for primary and young permanent teeth. In: American Academy of Pediatric Dentistry Reference Manual 1991-1992. Chicago, Ill.: American Academy of Pediatric Dentistry; 1991:53-7.
2. American Academy of Pediatric Dentistry. Pulp therapy for primary and immature permanent teeth. Pediatr Dent 2014;36(special issue):242-50.
3. American Association of Endodontists Special Committee to Revise the Glossary. Glossary of Endodontic Terms. 10th ed. Chicago, Ill.: American Association of Endodontists; 2020. Available at: "https://www.aae.org/specialty/clinical-resources/glossary-endodontic-terms/". Accessed August 3, 2020.

4. Fuks A, Kupietzky A, Guelmann M. Pulp therapy for the primary dentition. In: Nowak AJ, Christensen JR, Mabry TR, Townsend JA, Wells MH. eds. Pediatric Dentistry - Infancy through Adolescence. 6th ed. St. Louis, Mo., Elsevier-Saunders Co.; 2019:329-51.
5. Dean JA. Treatment of deep caries, vital pulp exposure, and pulpless teeth. In: Dean JA, ed. McDonald and Avery's Dentistry for the Child and Adolescent. 10th ed. St. Louis, Mo.: Elsevier; 2016:222.
6. American Association of Endodontists. Guide to Clinical Endodontics. 6th ed. Chicago, Ill.: American Association of Endodontists; 2013. Available at: "https://www.aae.org/specialty/clinical-resources/guide-clinical-endodontics/". Accessed August 3, 2020.
7. Camp JH. Diagnosis dilemmas in vital pulp therapy: Treatment for the toothache is changing, especially in young, immature teeth. Pediatr Dent 2008;30(3):197-205.
8. 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.
9. Fuks AB. Current concepts in vital pulp therapy. Eur J Pediatr Dent 2002;3(3):115-20.
10. 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.
11. Murray PE, About I, Franquin JC, Remusat M, Smith AJ. Restorative pulpal and repair responses. J Am Dent Assoc 2001;132(4):482-91.
12. 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.
13. American Association of Endodontists. AAE clinical considerations for a regenerative procedure. Revised 4/1/2018. Available at: "https://www.aae.org/specialty/wp-content/uploads/sites/2/2018/06/ConsiderationsForRegEndo_AsOfApril2018.pdf". Accessed June 21, 2020.
14. American Academy of Pediatric Dentistry. Prescribing dental radiographs for infants, children, adolescents, and individuals with special health care needs. The Reference Manual of Pediatric Dentistry. Chicago, Ill.: American Academy of Pediatric Dentistry; 2020:248-51.
15. Coll JA. Indirect pulp capping and primary teeth: Is the primary tooth pulpotomy out of date? Pediatr Dent 2008;30(3):230-6.
16. Fuks A, Nuni E. Pulp therapy for the young permanent dentition. In: Nowak AJ, Christensen JR, Mabry TR, Townsend JA, Wells MH. eds. Pediatric Dentistry - Infancy through Adolescence. 6th ed. St. Louis, Mo., Elsevier-Saunders Co.; 2019:482-96.
17. 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.
18. Centers for Disease Control and Prevention. Summary of Infection Prevention Practices in Dental Settings: Basic Expectations for Safe Care. Atlanta, Ga.: Centers for Disease Control and Prevention, U.S. Department of Health and Human Services; October 2016. Available at: "https://www.cdc.gov/hai/settings/outpatient/outpatient-care-guidelines.html". Accessed November 5, 2020.
19. 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.
20. Kuhn E, Chibinski ACR, Reis A, Wambier DS. The role of glass ionomer cement on the remineralization of infected dentin: An in vivo study. Pediatr Dent 2014;36 (4):E118-E124.
21. 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.
22. 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.
23. 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.
24. 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.
25. 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.
26. 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.
27. Coll JA, Seale NS, Vargas K, Marghalani AA, Shamali S, Graham L. Primary tooth vital pulp therapy. Systematic review and meta-analysis. Pediatr Dent 2017;39(1):16-27. E15-E110.
28. 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.
29. Schwendicke F, Dorfer C, Paris S. Incomplete caries removal: A systemic review and meta-analysis. J Dent Res 2013;92(4):306-14.
30. 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.

References continued on the next page.

31. 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.
32. Loyola-Rodriguez JP, García-Godoy F, Linquist R. Growth inhibition of glass ionomer cements on mutans streptococci. Pediatr Dent 1994;16(5):346-9.
33. 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.
34. Oliveira EF, Carminatti G, Fontanella V, Maltz M. The monitoring of deep caries lesions after incomplete dentine caries removal: Results after 14-18 months. Clin Oral Investig 2006;10(2):134-9.
35. 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.
36. 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.
37. 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.
38. 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.
39. 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.
40. 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.
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. 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.
45. Guelmann M, Fair J, Bimstein E. Permanent versus temporary restorations after emergency pulpotomies in primary molars. Pediatr Dent 2005;27(6):478-81.
46. 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.
47. Guelmann M, McIlwain MF, Primosch RE. Radiographic assessment of primary molar pulpotomies restored with resin-based materials. Pediatr Dent 2005;27(1):24-7.
48. 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.
49. Thompson KS, Seale NS, Nunn ME, Huff G. Alternative method of hemorrhage control in full strength formocresol pulpotomy. Pediatr Dent 2001;23(3):217-22.
50. 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.
51. Siqueira JF Jr, Rôças IN, Paiva SS, Guimarães-Pinto T, Magalhaes KM, Lima KC. Bacteriologic investigation of the effectiveness 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.
52. 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.
53. Coll JA, Vargas K, Marghalani AA, et al. A systematic review and meta-analysis of nonvital pulp therapy for primary teeth. Pediatr Dent 2020;42(4):256-72.E11-E199.
54. Coll JA, Dhar V, Vargas K, et al. Use of non-vital pulp therapies in primary teeth. Pediatr Dent 2020;42(5): 337-49.
55. Mehdipour O, Kleier DJ, Averbach RE. Anatomy of sodium hypochlorite accidents. Compend Contin Educ Dent 2007;28(10):548-50.
56. Coll JA, Sadrian R. Predicting pulpectomy success and its relationship to exfoliation and succedaneous dentition. Pediatr Dent 1996;18(1):57-63.
57. 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.
58. 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.
59. 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.
60. Burrus D, Barbeau L, Hodgson B. Treatment of abscessed primary molars utilizing lesion sterilization and tissue repair: Literature review and report of three cases. Pediatr Dent 2014;36(3):240-4.
61. Takushige T, Cruz EV, Asgor Moral A, Hoshino E. Endodontic treatment of primary teeth using a combination of antibacterial drugs. Int Endod J 2004;37(2):132-8.

62. Raslan N, Mansour O, Assfoura L. Evaluation of antibiotic mix in non-instrumentation endodontic treatment of necrotic primary molars. Eur J Paediatr Dent 2017;18 (4):285-290.
63. 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.
64. 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.
65. 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.
66. 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.
67. 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.
68. Hoefler V, Nagaoka H, Miller CS. Long-term survival and vitality outcomes of permanent teeth following deep caries treatment with step-wise and partial-caries-removal: A systematic review. J Dent 2016;54:25-32.
69. 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.
70. 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.
71. Zehnder M. Root canal irrigants. J Endod 2006;32(5): 389-98.
72. 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.
73. 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.
74. Witherspoon DE, Small JC, Harris GZ. Mineral trioxide aggregate pulpotomies: A series outcomes assessment. J Am Dent Assoc 2006;137(9):610-8.
75. Chacko V, Kurikose S. Human pulpal response to mineral trioxide aggregate (MTA): A histological study. J Clin Pediatr Dent 2006;30(3):203-10.
76. Bimstein E, Rotstein I. Cvek pulpotomy – revisited. Dental Traumatol 2016;32(6):438-42.
77. Blanco L, Cohen S. Treatment of crown fractures with exposed pulps. J Calif Dent Assoc 2002;30(6):419-25.
78. 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.
79. 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.
80. Belobrov I, Parashos P. Treatment of tooth discoloration after the use of white mineral trioxide aggregate. J Endod 2011;37(7):1017-20.
81. Subay RK, Ilhan B, Ulukapi H. Mineral trioxide aggregate as a pulpotomy agent in immature teeth: Long term case report. Eur J Dent 2013;7(1):133-8.
82. Ferris DM, Baumgartner JC. Perforation repair comparing two types of mineral trioxide aggregate. J Endod 2004; 30(6):422-4.
83. 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.
84. Witherspoon DE. Vital pulp therapy with new materials: New directions and treatment perspectives–Permanent teeth. Pediatr Dent 2008;30(3):220-4.
85. Aguilar PA, Linsuwanont P. Vital pulp therapy in vital permanent teeth with cariously exposed pulp: A systematic review. J Endod 2011;37(5):581-7.
86. Taha NA, Abdulkhader SZ. Full pulpotomy with Biodentine in symptomatic young permanent teeth with carious exposure. J Endod 2018;44(6):932-7. Epub 2018 Apr 19.
87. 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.
88. American Association of Endodontists Special Committee on the Scope of Endodontics. AAE Position Statement: Scope of Endodontics: Regenerative Endodontics. 2013. Available at: "https://www.aae.org/specialty/wp-content/uploads/sites/2/2017/06/scopeofendo_regendo.pdf". Accessed August 3, 2020.
89. American Association of Endodontists. Regenerative Endodontics. Endodontics Colleagues for Excellence, Spring 2013. Available at: "https://f3f142zs0k2w1kg84k-5p9i1o-wpengine.netdna-ssl.com/specialty/wp-content/uploads/sites/2/2017/06/ecfespring2013.pdf". Accessed August 3, 2020.