Pulp Therapy for Primary and Immature Permanent Teeth: Indications and Objectives

Latest Revision
2026

Abbreviations
AAPD: American Academy of Pediatric Dentistry.
IPT: Indirect pulp therapy.
LSTR: Lesion sterilization/tissue repair.
MeSH: Medical subject heading.
MTA: Mineral trioxide aggregate.
Tiab: Title and abstract.

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 includes pulpectomy and lesion stabilization/tissue repair. Vital pulp therapy for immature permanent teeth with a normal pulp or reversible pulpitis includes protective liners, 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. A complete pulpotomy may be considered in select primary and permanent teeth exhibiting signs of irreversible pulpitis in absence of clinical and radiographic signs of infection. 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 revision by the Council on Clinical Affairs follows a partial revision limited to the second on primary tooth pulp therapy in 2025.[2.] A search of the PubMed/MEDLINE database was performed using the terms: *evidence based dentistry* [**MeSH**] OR *pulpotomy* [**Tiab**] OR *pulpectomy* [Tiab] OR *tooth, deciduous* [MeSH] OR *indirect pulp treatment* [Tiab] OR *stepwise* [Tiab] OR *pulp therapy* [Tiab] OR *pulp capping* [Tiab] OR *vital pulp therapy* [Tiab] OR *pulp exposure* [Tiab] OR *calcium hydroxide* [Tiab] OR *formocresol* [Tiab] OR *ferric*

sulfate [Tiab] OR *glass ionomer* [Tiab] OR *mineral trioxide aggregate* [Tiab] OR *lesion sterilization tissue repair* [Tiab] OR *dentin bonding agents* [Tiab] OR *resin modified glass ionomer* [Tiab] OR *endodontic irrigants* [Tiab]; filters applied: randomized controlled trial, systematic review, in the last 5 years, humans, English. One thousand fifty-three articles met these criteria. Papers for review were chosen from this list and from references within the selected articles. Additionally, the International Association of Pediatric Dentistry's *Consensus-Based Recommendations on Pulp Therapies in Primary and Permanent Teeth: IAPD Porto Forum*[3], the AAPD's *Guideline for Use of Vital Pulp Therapy in Permanent Teeth*[4], and related publications[5,6] were reviewed. When data did not appear sufficient or were inconclusive, recommendations were based upon expert opinion or consensus by experienced researchers and clinicians.

Background

The primary goal of pulp therapy is to preserve 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 vital 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.

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.[7p39-40] The clinical diagnosis is derived from[8p4,9p266-268,10p331-332]

- a comprehensive medical history;
- a review of past and present dental history and treatment, including current symptoms and chief complaint;
- 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 of pain;
- an objective extraoral examination as well as examination of the intraoral soft and hard tissues;
- if obtainable, radiograph(s) to assess depth of caries and to diagnose periapical or periradicular changes; and
- clinical tests such as palpation, percussion, and mobility.

For the purposes of this document, deep caries refers to decay that extends two-thirds to three-quarters of the entire dentin thickness but still retains a definitive barrier of dentin between the caries and the pulp. Extremely deep caries penetrates the entire thickness of dentin and exhibits no discernable radiographic barrier.[3,4,11] In slowly progressing deep caries lesions, low-grade inflammation from bacterial invasion stimulates odontoblasts to produce reactionary dentin, helping protect the pulp.[12] In extremely deep caries, however, bacterial invasion leads to severe inflammation and odontoblastic cell death.[13] With timely intervention, a supportive environment can be created in which signaling molecules from the inflammatory process promote the differentiation of resident stem cells into odontoblast-like cells that form reparative dentin to limit pulp damage.[3]

Thermal and electric pulp tests have limited reliability in primary and immature permanent teeth. More importantly, pulp sensibility tests cannot definitively assess the degree of inflammation or the pulp's healing potential.[6] 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. Teeth diagnosed with a normal pulp requiring pulp therapy or with reversible pulpitis should be treated with vital pulp therapy.[14-17] Historically, 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 had a clinical diagnosis of irreversible pulpitis or necrosis and were candidates for nonvital pulp treatment.[10p335] However,

recent clinical studies have demonstrated the potential of vital pulp therapy (eg, calcium silicate pulpotomy) in teeth with carious pulp exposure, even with a mature root apex or in the presence of irreversible pulpitis.[5] Regenerative endodontics may be considered for immature permanent teeth with apical periodontitis, a necrotic pulp, and immature apex.[18]

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

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

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.[10p336]

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 nonvital primary and immature permanent teeth. Pulp therapy requires periodic clinical and radiographic assessment of the treated tooth and the supporting structures.[19] Postoperative clinical assessment generally should be performed every 6 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.[10p346] 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 images,[10p346] the type and frequency of which are at the clinician's discretion.[20] Radiographic evaluation of primary tooth pulpotomies should occur at least annually as the success rate of pulpotomies diminishes over time.[21] 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.[22p488-489] Isolation is necessary to minimize bacterial contamination and to protect soft and hard tissues. Use of rubber dam isolation is considered a gold standard[23] for pulp treatment. When unable to use a rubber dam, other effective isolation should be considered.

The goal of caries excavation is to reduce the number of bacteria and microorganisms near the pulp. Failure of such removal leaves the pulp tissue at risk of irreversible inflammation if microorganisms can enter the tissue. Caries removal may be selective, stepwise, or nonselective (complete). Nonselective caries removal results in increased frequency of pulp exposures, but the method of removal has not been found to significantly affect the success of vital pulp therapy.[23] The choice for caries removal may be influenced by multiple factors including the patient's medical history and ability to cooperate for treatment, ability to achieve profound local anesthesia, and parental preferences.[23] Prior treatment of the tooth with a caries-arresting medicament (ie, silver diammine fluoride) may alleviate the need for additional caries excavation and/or vital pulp therapies.[24]

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 low-microbial or sterile water because the water-bearing pathway cannot be reliably sterilized."[25p15] A single-use disposable syringe should be used to dispense irrigants for pulp therapy,

including sterile water, sterile saline, or sodium hypochlorite[23,26,27] but avoiding the use of tap or dental unit water.[28]

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, resin-modified glass ionomer, bioceramics, trisilicate cements, calcium hydroxide, or other biocompatible material is at the discretion of the clinician.[29,30]

- 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 promote pulp tissue healing and minimize postoperative sensitivity.[31,32] The placement of a liner may be able to further reduce bacterial load and its acidic byproducts.[33]
- 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.[16] Adverse posttreatment clinical signs or symptoms such as sensitivity, pain, or swelling should not occur.

Indirect pulp treatment. Indirect pulp treatment (**IPT**) is a procedure performed in a tooth with a deep caries lesion approximating the pulp, diagnosed with a normal pulp or reversible pulpitis, without evidence of radicular pathology. Indirect pulp treatment utilizes selective caries removal to avoid a pulp exposure. This caries-affected dentin is covered with a biocompatible material to produce a biological seal A radiopaque liner such as a dentin bonding agent,[34,35] resin modified glass ionomer,[10p337] calcium hydroxide,[35] or MTA (or any other biocompatible material)[36] is placed over the remaining carious dentin to stimulate healing and repair. The liner that is placed over the dentin does not affect the IPT success.[37] 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.[38,39] The interim therapeutic restoration can be removed once the pulp's vitality is determined and, if the pulp is vital, an indirect pulp cap can be performed.[21] Current literature provides no conclusive evidence that it is necessary to reenter the tooth to remove the residual caries.[40,41] 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.[40-42] IPT has been shown to have a higher success rate than direct pulp cap (DPC) and pulpotomy in long term studies.[14,17,21,35,43-49]

- 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.[15,44] The pulp is judged by clinical and radiographic criteria to be vital and able to heal from the carious insult.[44]• Objectives: A restoration to minimize bacterial leakage from the restoration-dentin interface 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 progressive internal root resorption or furcation/apical radiolucency. There should be no harm to the succedaneous tooth.

Direct pulp cap. When a noncarious, small mechanical, or traumatic exposure) of the pulp is encountered, a biocompatible radiopaque base such as MTA[35,50-52] or calcium hydroxide[53] may be placed in contact with the exposed pulp tissue. The tooth is restored with a material that seals the tooth from microleakage.[14]

- Indications: This procedure is indicated in a primary tooth with a normal pulp following a small (<1 mm) pulp exposure when conditions for a favorable response are optimal.[35,50-52]
- 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[9p272] or after a traumatic pulp exposure and no radiographic sign of infection or pathologic resorption is evident. The coronal pulp is amputated, pulpal hemorrhage is controlled using a damp cotton pellet, and the remaining vital radicular pulp tissue surface is treated with a long-term clinically successful medicament. Calcium silicate cements, such as MTA and biodentine, have shown increased success rates in pulpotomies compared to other materials.[23] A calcium silicate pulpotomy may also be recommended in primary teeth exhibiting signs of irreversible pulpitis such as spontaneous pain with no clinical or radiographic signs of infection.[54] After the coronal pulp chamber is filled with a suitable base, the tooth is restored with a restoration that seals the tooth from microleakage. While contemporary systematic reviews have indicated that, after 1 year, multiple types of final restorations shared similar success following MTA pulpotomies and that multisurface caries versus occlusal caries did not have a significant effect on pulpotomy success, more longer-term studies are needed.[23]

- Indications: The pulpotomy procedure primarily is indicated when caries removal results in pulp exposure in a primary tooth with a normal pulp or reversible pulpitis[9p272] or after a traumatic pulp exposure[8p8] and no radiographic signs of infection or pathologic resorption are evident. 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.[10p340]
- Objectives: The tooth's vitality should be maintained, and the radicular pulp should remain asymptomatic with no posttreatment adverse clinical signs or symptoms such as sensitivity, pain, or swelling. There should be no postoperative radiographic signs of pathologic external root resorption, including furcation or periapical radiolucencies, at follow-up visits. Internal root resorption may be self-limiting and stable. The clinician should monitor internal resorption, removing the affected tooth if perforation causes loss of supportive bone and/or clinical signs of infection and inflammation.[55-58] 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[59] and then irrigated. A recent systematic review showed no difference in success when irrigating with chlorhexidine or 1% to 5% sodium hypochlorite or sterile water/saline.[60,61] Because it is a potent tissue irritant, sodium hypochlorite must not be extruded beyond the apex.[62] After the canals are dried, a resorbable material such as nonreinforced zinc/oxide eugenol (ZOE),[63,64] iodoform-based paste,[7p29,8p11,10p344] or a combination paste of iodoform and calcium hydroxide[65,66] is used to fill the canals. A recent systematic review reports that zinc/oxide eugenol performed better long term than iodoform-based pastes.[61] The tooth then is restored with a restoration that seals the tooth from microleakage. Clinicians should evaluate nonvital pulp treatments for success and adverse events clinically and radiographically at least every 12 months.[60,61]

- 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 (eg, suppuration, purulence) The roots should exhibit minimal or no resorption.[60,61]
- Objectives: Following treatment, the radiographic infectious process should resolve in 6 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.[63,65,66] 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. 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.[60,61] After opening the pulp chamber of a necrotic tooth, the canal orifices are enlarged using a round bur to create medication receptacles. The walls of the chamber are cleaned with 37% phosphoric acid and then rinsed and dried.[67] A cotton pellet soaked in 10% sodium hypochlorite can be used to control hemorrhage if it is present.[68] A triple 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.[67] The mixture can be made on site[69] or dispensed from a compounding pharmacy. The mixture, which will not set, is covered with glass-ionomer cement which is light-cured to form a seal over the mixture. The tooth then is restored, preferably with a stainless steel crown to ensure the best seal.[67,70] Previous studies have used minocycline in place of clindamycin,[68] but staining may be a concern when a tetracycline-like drug is used.[71] Although similar success has been reported whether minocycline or clindamycin is used,[71] a more recent systematic review concluded statistically significant less success using a tetracycline mix versus a mix without tetracycline.[61] Doxycycline has greater clinical and radiographic success than minocycline.[72] The AAPD's *Use of Non-Vital Pulp Therapies in Primary Teeth* provides conditional recommendation based on very low-quality evidence to use antibiotic mixtures without tetracycline in LSTR.[60] Data surrounding LSTR has been inconsistent. One meta-analysis compared LSTR to pulpectomy procedures and did not find a significant difference at 18-months follow-up; however, multiple LSTR antibiotic regimens were utilized with different vehicles.[73]

- 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 (eg, 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 12 months and exhibits root resorption, LSTR is preferred to pulpectomy.[60,61]
- Contraindications: LSTR is contraindicated in patients with allergy to the agents used, with radiographic evidence of excessive internal or external resorption, for a primary tooth nearing exfoliation, in cases with perforated pulpal floor, or for patients at risk for infective endocarditis.[69,74]
- Objectives: Following LSTR, pretreatment clinical signs and symptoms should resolve. Periodic radiographic monitoring should indicate resolution of the infectious process by bone deposition in the pretreatment radiolucent areas.

Immature permanent teeth

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 (ie, indirect pulp treatment, direct pulp capping, partial pulpotomy for carious exposures and traumatic exposures).[75] Additionally, revascularization may be considered for nonvital immature permanent teeth as a means of promoting further root development.

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

Factors affecting vital pulp therapy success include preoperative diagnosis, root apex development, pain severity, ability to achieve hemostasis, choice of wound lavage solution, capping agent/liner, and time elapsed before final restoration.[76]

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.[77] Calcium silicate cements have demonstrated superior success when used as a liner: 96% success vs 90% for glass ionomer vs 87%

calcium hydroxide at 24 months postoperative.[78,79] The liner must be followed by a well-sealed restoration to minimize bacterial leakage from the restoration-dentin interface.[16]

- 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.[16] Adverse posttreatment signs or symptoms such as sensitivity, pain, or swelling should not occur.

Indirect pulp treatment. IPT is a procedure that utilizes selective caries removal in a tooth with a diagnosis of reversible pulpitis and deep caries that might otherwise need endodontic therapy if the decay was completely removed.[4,80p907] IPT with selective caries removal is a procedure in which the provider excavates caries as close as possible to the pulp, places a biocompatible protective liner, and restores the tooth without a subsequent reentry to remove any remaining affected dentin.[81-84] The step-wise caries removal approach involves a 2-step process and may be considered for caries lesions approaching three-quarters of the radiographic dentin thickness.[6] The first step is the selective 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 objectives are to change the cariogenic environment by decreasing the number of bacteria and closing the remaining caries from the biofilm of the oral cavity, and to slow or arrest the caries development by placing a temporary restoration.[85-87] The second step is the nonselective removal of all remaining caries to firm dentin and placement of a final restoration. Critical to both steps of excavation is the placement of a well-sealed restoration.[16] Selective and stepwise caries removal have shown similar vital pulp therapy success.[83,88-90] However, the advantages of selective caries removal are it results in fewer pulp exposures and is completed in 1 visit.[4]) Selective caries removal in permanent teeth is more cost effective compared to stepwise caries removal in protecting the pulp from exposure and avoiding the need for root canal treatment.[91]

- 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 biocompatible material such as calcium hydroxide[33,53] or MTA[33] prior to placing a restoration that seals the tooth from microleakage.[16] Direct pulp capping in teeth with carious exposed pulps has a high success rate, with better outcomes at 36 months when calcium silicate cements are used compared to calcium hydroxide.[4]COLL guideline 2025

- 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 in extremely deep caries lesions (no radiographic barrier between caries and pulp) is a procedure in which the inflamed pulp tissue beneath an exposure is removed to a depth of 1-3 mm or deeper to eliminate infected tissue and to visually assess the pulp's vitality and ability to achieve hemostasis.[4] Pulp bleeding must be controlled—using irrigation and a cotton pellet moistened with an agent such as sodium hypochlorite[4])—before the site is covered with calcium hydroxide[80p910] or MTA.[92-94] While calcium hydroxide has been demonstrated to have long-term success (85% success), calcium silicate cements result in more predictable dentin bridging and pulp health with success rates approaching 93%.[95] Calcium silicate cements (at least 1.5 mm thick) should cover the exposure and surrounding dentin followed by a layer of light-cured resin-modified glass ionomer.[33] A restoration that seals the tooth from microleakage is placed.

- Indications: 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 is a procedure in which the inflamed pulp tissue beneath a traumatic exposure that is 4 mm or less[96] is removed to a depth of 1-3 mms or more to reach the deeper healthy tissue.[97] Partial pulpotomy has a higher success rate than complete pulpotomy and direct pulp capping (89% and 43% respectively)[4,98] for teeth with traumatic exposures, and, therefore, is the treatment of choice for complicated coronal fractures.[99.100] While literature indicates that a Cvek pulpotomy may be completed up to 9 days after an exposure, there is no evidence on tooth outcomes with longer periods of waiting time.[96] Pulp bleeding is controlled using irrigants such as sodium hypochlorite[4] The site then can be covered with calcium hydroxide[101,102p653-654] or silicate cement.[4,102p653-654] While calcium hydroxide has been demonstrated to have long-term success, calcium silicate cement results in more predictable dentin bridging and pulp health.[95] The calcium silicate cement 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] Light and gray versions of MTA have similar properties[104,105] and may cause tooth discoloration.[106,107] If esthetics are a concern, nonstaining calcium silicates (without bismuth) should be considered.[3,4] 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.[8p8] Pulpotomies demonstrate greater success in permanent teeth with normal pulp or reversible pulpitis than teeth with symptoms of irreversible pulpitis eg, spontaneous or lingering pain).[4]) In young permanent teeth with symptomatic irreversible pulpitis, the chance of success was higher when pulpal hemostasis was achieved in 6 minutes or less.[4,108] 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.[75,109-112]

- Indications: A complete pulpotomy is indicated in immature permanent teeth with cariously-exposed pulp to allow continued root development (apexogenesis). Such teeth should be monitored for need

for further endodontic treatment. It also may be performed as an emergency procedure for temporary relief of symptoms until a definitive root canal treatment can be accomplished.[8p8] Pulpotomy can be a viable option for immature teeth with irreversible pulpitis,[113,114] with success rates of 91% at 24 months[4,115].

- Objectives: Complete pulpotomy procedure in a vital permanent tooth aims to preserve the vitality of remaining radicular pulp.[7p40] 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.[8p8]

Nonvital pulp treatment

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 traditionally had been accomplished by placing a biocompatible agent such as calcium hydroxide in the canals for 2 weeks to 1 month to disinfect the canal space.[22p489] Root end closure accomplished with an apical barrier or plug such as MTA or other calcium silicate cement has demonstrated success rates greater than 94%.[8p14,116] In instances when complete closure cannot be accomplished by MTA, an absorbable collagen wound dressing[117] 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.[118]

- 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 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 endodontic treatment. Regenerative endodontic treatment (RET), also known by the following terms: regeneration, pulp revascularization, and revitalization[119], is defined as biologically-based procedures designed to physiologically repair and regenerate damaged tooth structure, including dentin and root structures, as well as the pulp-dentin complex.[120] This is accomplished by utilizing stem cells or bioactive molecules (ie, growth factors) and may require tissue engineering via bioactive scaffolds.[119,121] 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.[120] Thickening of the canal walls and continued root maturation with apical closure are favorable outcomes with the aim of regaining pulp vitality.[119,120] For these aforementioned reasons, regenerative endodontic treatment may be preferred over traditional apexification methods.[122] The difference between regenerative endodontic treatment and nonsurgical root canal treatment 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. A recent study suggested cases with initial inflammatory root resorption had a poorer prognosis, indicating the periodontal ligament plays a role in case success.[123] A 2021 systematic and meta-analysis described the moderate quality evidence that regenerative techniques did not show difference in relative risk of success or failure in comparison to traditional root canal therapy but did suggest many of the studies were in subjects diagnosed with trauma or dens invaginatus.[119,124]

- 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.

Pulpectomy (conventional root canal treatment). Pulpectomy in apexified permanent teeth is conventional nonsurgical 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.[8p12]

- Indications: Pulpectomy or nonsurgical 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.

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