

# Pulp Therapy for Primary and Immature Permanent Teeth

Latest Revision

2025\*

## Abbreviations

AAPD: American Academy of Pediatric Dentistry.

IPT: Indirect pulp therapy.

LSTR: Lesion sterilization/tissue repair.

MTA: Mineral trioxide aggregate.

MeSH: Medical subject heading.

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 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. 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.*

*\* This revision is limited to the section on pulp therapy for primary teeth. The section on pulp therapy for immature permanent teeth will be revised in 2026.*

**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.<sup>1</sup> This document by the Council on Clinical Affairs is a partial revision of the previous version, last revised in 2020.<sup>2</sup> This revision included a new search of the PubMed®/MEDLINE database using the terms: *evidence based dentistry* [MeSH] OR *pulpotomy* [Tiab] OR *pulpectomy* [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. 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 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.<sup>3</sup> The clinical diagnosis is derived from<sup>4(pp266-268)-6(pp331,332)</sup>.

- 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;
- an objective extraoral examination as well as examination of the intraoral soft and hard tissues;
- if obtainable, radiograph(s) to diagnose periapical or periradicular changes; and
- clinical tests such as palpation, percussion, and mobility.

Thermal and electric pulp tests are unreliable in primary and immature permanent 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.<sup>7-10</sup>

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.<sup>6(pp335)</sup> Regenerative endodontics may be considered for immature permanent teeth with apical periodontitis, a necrotic pulp, and immature apex.<sup>11</sup>

## **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.<sup>6(pp336)</sup>

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 pulp therapy for primary and immature permanent teeth. Pulp therapy requires periodic clinical and radiographic assessment of the treated tooth

and the supporting structures.<sup>12</sup> 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.<sup>6(pg346)</sup> 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<sup>6(pg346)</sup> (the type and frequency of which are at the clinician's discretion).<sup>13</sup> Radiographic evaluation of primary tooth pulpotomies should occur at least annually as the success rate of pulpotomies diminishes over time.<sup>14</sup> Bitewing radiographs obtained as part of the patient's periodic comprehensive examinations may suffice. If a bitewing radiograph does not display the interradiacicular 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.<sup>15(pp488,489)</sup> Isolation is necessary to minimize bacterial contamination and to protect soft and hard tissues. Use of rubber dam isolation is considered gold standard<sup>16</sup> for pulp treatment. When unable to use a rubber dam, other effective isolation may 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 complete. Complete 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.<sup>17</sup> 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.<sup>17</sup>

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."<sup>18</sup> A single-use disposable syringe should be used to dispense irrigants for pulp therapy, including sterile water or sodium hypochlorite<sup>17,19</sup> but avoiding the use of tap or dental unit water.

## 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.<sup>20,21</sup>

- **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.<sup>22,23</sup> The placement of a liner may be able to further reduce bacterial load and its acidic byproducts.<sup>24</sup>
- **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.<sup>9</sup> Adverse posttreatment clinical signs or symptoms such as sensitivity, pain, or swelling should not occur.

**Indirect pulp treatment (IPT).** 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."<sup>16</sup> A radiopaque liner such as a dentin-bonding agent,<sup>25,26</sup> resin modified glass ionomer,<sup>6(pg337)</sup> calcium hydroxide,<sup>26</sup> or MTA (or any other biocompatible material)<sup>27</sup> 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.<sup>28</sup> 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.<sup>29,30</sup> The interim therapeutic restoration can be removed once the pulp's vitality is determined and, if the pulp is vital, indirect pulp therapy can be performed.<sup>14</sup> Current literature provides no conclusive evidence that it is necessary to reenter the tooth to remove the residual caries.<sup>31,32</sup> 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.<sup>31-36</sup> Indirect pulp therapy has been shown to have a higher success rate than direct pulp cap (DPC) and pulpotomy in long term studies.<sup>7,10,14,26,28,37-42</sup>

- 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.<sup>8,28</sup> The pulp is judged by clinical and radiographic criteria to be vital and able to heal from the carious insult.<sup>16,28</sup>
- 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 pinpoint exposure ( $\leq 1$  mm)<sup>16</sup> of the pulp is encountered during cavity preparation or following a traumatic injury, a biocompatible radiopaque base such as MTA<sup>27,43-45</sup> or calcium hydroxide<sup>46</sup> may be placed in contact with the exposed pulp tissue. The tooth is restored with a material that seals the tooth from microleakage.<sup>7</sup>

- Indications: This procedure is indicated in a primary tooth with a normal pulp following a small ( $\leq 1$  mm) pulp exposure of when conditions for a favorable response are optimal.<sup>27,43-45</sup>
- 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<sup>4(pg272)</sup> or after a traumatic pulp exposure<sup>47</sup> and no radiographic sign of infection or pathologic resorption is evident. 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. Previously, only MTA and formocresol were recommended as the medicament of choice for teeth expected to be retained for 24 months or more,<sup>16</sup> and other materials or techniques such as ferric sulfate, lasers, sodium hypochlorite, and tricalcium silicate had conditional recommendations.<sup>16</sup> The AAPD's *Use of Vital Pulp Therapies in Primary Teeth with Deep Caries Lesions* recommended against the use of calcium hydroxide for pulpotomy.<sup>16</sup> Recently, calcium silicate cements, such as MTA and biodentine, have shown increased success rates in pulpotomies compared to other materials.<sup>17</sup> 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 multi-surface caries versus occlusal caries did not have a significant effect on pulpotomy success, more longer-term studies are needed.<sup>17</sup> If sufficient supporting enamel remains, amalgam or composite resin can provide a functional alternative to a full-coverage crown when the primary tooth has a life span of 2 years or less.<sup>48-50</sup> However, for multisurface lesions, a stainless steel crown is the restoration of choice.<sup>16</sup>

- Indications: The pulpotomy procedure is indicated when caries removal results in pulp exposure in a primary tooth with a normal pulp or reversible pulpitis<sup>4(pg272)</sup> or after a traumatic pulp exposure,<sup>5(pg8),47</sup> 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.<sup>6(pg340)</sup>
- 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.<sup>51-54</sup> 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<sup>55</sup> 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.<sup>56,57</sup> Because it is a potent tissue irritant, sodium hypochlorite must not be extruded beyond the apex.<sup>58</sup> After the canals are dried, a resorbable material such as nonreinforced zinc/oxide eugenol (ZOE),<sup>59,60</sup> iodoform-based paste,<sup>3,5(pg11),6(pg344)</sup> or a combination paste of iodoform and calcium hydroxide<sup>61,62</sup> is used to fill the canals. A recent systematic review reports that zinc/oxide eugenol performed better long term than iodoform-based pastes.<sup>57</sup> 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.<sup>56,57</sup>

- 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.<sup>56,57</sup>
- Objectives: Following treatment, the radiographic infectious process should resolve in 6 months as evidenced by bone deposition in the pretreatment radiolucent areas, and pre-treatment clinical signs and symptoms should resolve within a few weeks. There should be radiographic evidence of successful filling without gross overextension or underfilling.<sup>60-62</sup> 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.<sup>56,57</sup> 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.<sup>63</sup> A cotton pellet soaked in 10% sodium hypochlorite can be used to control hemorrhage if it is present.<sup>64</sup> 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 receptacles and over the pulpal floor.<sup>63</sup> The mixture can be made on site<sup>65</sup> 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.<sup>63,66</sup> Previous studies have used minocycline in place of clindamycin,<sup>64</sup> but staining may be a concern when a tetracycline-like drug is used.<sup>67</sup> Although similar success has been reported whether minocycline or clindamycin is used,<sup>67</sup> a more recent systematic review concluded statistically significant less success using a tetracycline mix versus a mix without tetracycline.<sup>57</sup> Doxycycline has greater clinical and radiographic success than minocycline.<sup>68</sup> 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.<sup>56</sup> 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.<sup>69</sup> 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 twelve months and exhibits root resorption, LSTR is preferred to pulpectomy.<sup>56,57</sup>

- 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.<sup>65,70</sup>
- 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**

*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.<sup>71</sup> The liner must be followed by a well-sealed restoration to minimize bacterial leakage from the restoration-dentin interface.<sup>9</sup>

- 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.<sup>9</sup> 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 (ie, 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.<sup>72</sup> In recent years, rather than completing the caries removal in 2 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.<sup>73,74</sup> The risk of this approach is either an unintentional pulp exposure or irreversible pulpitis.<sup>74</sup> When there is concern for pulp exposure, the step-wise excavation of deep caries may be considered.<sup>15</sup> This approach involves a 2-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.<sup>75-77</sup> This interim restoration should be able to be maintained for up to 12 months.<sup>15</sup> 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.<sup>9</sup> 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% of teeth treated remaining vital after 2 years.<sup>78</sup>

- 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 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<sup>24,46</sup> or MTA<sup>24</sup> prior to placing a restoration that seals the tooth from microleakage.<sup>9</sup>

- 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 1 to 3 mm or deeper to reach healthy pulp tissue. Pulp bleeding must be controlled by irrigation with a bacteriocidal agent such as sodium hypochlorite or chlorhexidine<sup>52,79,80</sup> before the site is covered with calcium hydroxide<sup>72</sup> or MTA.<sup>81-83</sup> While calcium hydroxide has been demonstrated to have long-term success, MTA results in more predictable dentin bridging and pulp health.<sup>84</sup> 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.<sup>24</sup> 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 for traumatic exposures is a procedure in which the inflamed pulp tissue beneath an exposure that is  $\leq 4$  mm<sup>85</sup> is removed to a depth of 1 to 3 mm or more to reach the deeper healthy tissue. 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.<sup>85</sup> Pulp bleeding is controlled using irrigants such as sodium hypochlorite or chlorhexidine,<sup>79,80</sup> and the site then is covered with calcium hydroxide<sup>86,87</sup> or MTA.<sup>72,88</sup> MTA may cause tooth discoloration.<sup>89,90</sup> The 2 versions (light and gray) have been shown to have similar properties.<sup>91,92</sup> While calcium hydroxide has been demonstrated to have long-term success, MTA results in more predictable dentin bridging and pulp health.<sup>84</sup> 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.<sup>88</sup> 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.

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- 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.<sup>5</sup> 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.<sup>93-95</sup>

- 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.<sup>5</sup>
- Objectives: Full pulpotomy procedure in a vital permanent tooth aims to preserve the vitality of remaining radicular pulp.<sup>3</sup> 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.<sup>5</sup>

### *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.<sup>5</sup>

- 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 peri-radicular 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 peri-radicular 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 2 weeks to 1 month to disinfect the canal space.<sup>15</sup> Root end closure is accomplished with an apical barrier such as MTA.<sup>5</sup> In instances when complete closure cannot be accomplished by MTA, an absorbable collagen wound dressing<sup>96</sup> 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.<sup>5</sup>

- 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 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.<sup>97</sup> 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.<sup>98</sup> Thickening of the canal walls and/or continued root maturation is an additional goal.<sup>98</sup> 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 an 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.

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