

Endodontic treatment in primary teeth

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Abstract

Endodontic treatment in primary teeth, commonly referred to as pulpectomy, is an essential clinical procedure aimed at preserving primary teeth affected by pulp or periradicular infections until their physiological exfoliation. Maintaining primary teeth is crucial for proper mastication, speech development, arch integrity, and guidance of permanent tooth eruption. This comprehensive review summarizes current concepts, materials, and techniques used in the root canal treatment of primary teeth, with a focus on improving clinical outcomes. The complex and dynamic root canal anatomy of primary teeth, particularly the presence of physiological root resorption, presents unique challenges for endodontic procedures. Successful treatment depends on accurate diagnosis, careful case selection, effective chemomechanical preparation, optimal irrigation, and the use of appropriate root canal filling materials. Irrigation plays a critical role in eliminating microorganisms that cannot be removed by mechanical instrumentation alone. Commonly used irrigants include sodium hypochlorite, chlorhexidine, ethylenediaminetetraacetic acid, citric acid, and newer combination solutions, each with specific advantages and limitations regarding antimicrobial activity, tissue dissolution, and biocompatibility. Advances in instrumentation, particularly the use of nickel-titanium rotary systems specifically designed for pediatric patients, have improved cleaning efficiency, reduced treatment time, and enhanced patient cooperation. Determination of working length using electronic apex locators in combination with radiography has further increased procedural accuracy while minimizing radiation exposure. Root canal filling materials for primary teeth must meet specific criteria, including biocompatibility, adequate antimicrobial properties, resorption compatible with physiological root resorption, and safety for the underlying permanent tooth germ. Zinc oxide eugenol, calcium hydroxide-based pastes, iodoform-containing materials, and newer bioceramic-based pastes are commonly used, although no material fully satisfies all ideal requirements. In conclusion, endodontic treatment in primary teeth is a reliable and effective approach when performed with proper technique and material selection. Continuous updates in materials and technologies, along with adherence to evidence-based protocols, are essential for enhancing treatment success and supporting the overall oral health and development of pediatric patients.

Keywords: Primary tooth root canal treatment, root canal filling materials, irrigation solutions, chemomechanical preparation

1. Introduction

Primary teeth, which are the first teeth to erupt in an individual's mouth, play many important roles during the early years of life, such as enhancing chewing and feeding efficiency to support growth and development, stimulating the growth of the jawbone, and maintaining arch length and width to preserve space for the succeeding permanent teeth. They also contribute to proper phonation in children. Early loss of primary teeth due to trauma, caries, or ectopic eruption can lead to undesirable movements of both primary and permanent teeth, resulting in arch length discrepancies. These discrepancies can cause significant orthodontic problems. Furthermore, infected primary teeth that are left untreated can often affect the underlying permanent tooth germ, leading to local enamel hypoplasia, Turner's tooth, or other anomalies. Therefore, various treatments are performed to maintain primary teeth in the oral cavity in a healthy condition until their natural exfoliation time (1, 2).

One of these treatment options is root canal treatment for primary teeth, also known as a pulpectomy, which has many advantages over extraction and aims to keep primary teeth, whose pulp has been infected for various reasons, healthy in the oral cavity until their physiological exfoliation time (3).

The complex root canal system of primary teeth is one of the critical factors that influence the outcome and effectiveness of root canal treatment. Other factors affecting the outcome of root canal treatment in primary teeth include root canal instrumentation performed to eliminate canal infections, enhancing the effectiveness of mechanical instrumentation by irrigating the root canals with appropriate irrigating solutions, ensuring canal disinfection, achieving a hermetic seal of the root canals with filling materials, and restoring the damaged coronal structures with ideal restorative materials (3, 4).

Before deciding on endodontic treatment for primary teeth, careful planning should be made, taking into consideration the short- and long-term prognosis. Factors related to the patient, such as systemic condition, age, cooperation, oral hygiene, and restorability of the tooth, should be considered before starting treatment. Thus, a proper medical and dental history, as well as radiographic and clinical evaluations, are crucial. Meeting all these conditions can be particularly challenging in young children. Therefore, it is essential to discuss alternative treatment options in advance in case of pulp exposure during deep caries removal (4).

Clinical tests used to diagnose root canal infections in children can be traumatic, and these tests are often not reliable parameters for accurate diagnosis in primary teeth and immature young permanent teeth. For these reasons, a large part of the research on pulp diagnosis in children is based on experimental treatment outcomes and case reports. When diagnosing the current status of the pulp, the characteristics of the existing pain should be combined with additional information obtained from

clinical and radiographic examinations. Signs such as tooth discoloration, large carious lesions, redness and swelling of the vestibule, or the presence of a draining sinus tract, the color and amount of pulp bleeding, and uncontrolled hemorrhage strongly indicate pulp pathologies. Extensive cracks, damaged restorations, and recurrent caries may increase the risk of infection reaching the pulp through permeable dentin at the cavity floor. Although pre-treatment pulp status in studies is often based on retrospective data, the definitive detection of pulp inflammation is only possible through histological examination (5).

The American Academy of Pediatric Dentistry (AAPD) and various studies state that teeth with spontaneous or unprovoked pain, soft tissue inflammation not associated with gingivitis or periodontitis, mobility other than due to trauma or physiological exfoliation, sinus tract, interradicular or apical radiolucency, or radiographic findings of internal and external resorption should be treated with root canal therapy (5-7).

Indications for root canal treatment in primary teeth (3, 8):

- Spontaneous pain or night pain,
- Sensitivity to vertical percussion,
- Presence of abscess or fistula,
- Pulpal bleeding lasting longer than 5 minutes and cannot be controlled,
- Teeth diagnosed with pulp necrosis or irreversible pulpitis showing furcation and/or periapical radiolucency on radiographs.

Contraindications for root canal treatment in primary teeth (9):

- Non-restorable tooth structure,
- Internal resorption visible on radiographs,
- Teeth with mechanical or carious perforations at the base of the pulp chamber,
- Pathological root resorption affecting more than one-third of the root length,
- Pathological bone support loss with concomitant loss of normal periodontal attachment,
- Presence of dentigerous or follicular cyst,
- Periapical or interradicular lesions affect the development of permanent tooth germs.

The quality of root canal fillings (underfilling, optimal filling, or overfilling) has been assessed based on both clear clinical criteria (absence of pain, absence of abnormal mobility, absence of tenderness or percussion sensitivity, absence of swelling, resolution of pre-treatment inflammation and fistulas, etc.) and radiographic criteria (resolution of preoperative

pathological interradicular and/or periapical radiolucencies, absence of new postoperative pathological radiolucencies, absence of pathological internal or external root resorption, maintenance of normal lamina dura appearance for at least six months and up to twenty-four months, etc.) (6, 10, 11).

Insufficient chemomechanical preparation and inadequate root canal filling are the most common causes of endodontic treatment failure, usually due to the incomplete removal of intra- and extraradicular microorganisms. These issues can arise from inadequate canal preparation, root canal fillings that do not provide sufficient apical sealing, leakage during clinical crown restoration, insufficiently cleaned canals, apical transportation, inadequate access cavities, perforations, and instrument fractures, which are considered iatrogenic factors (10).

2. Microorganisms involved in root canal infections

The success of root canal treatments is closely related to a thorough understanding of the pathogenic factors that cause infections in the root canal system. These infections are caused by complex bacterial communities dominated predominantly by anaerobic gram-positive bacteria. It has been reported that the root canal microbiota obtained from asymptomatic teeth differs from that isolated from symptomatic teeth (12-14).

The number of microorganisms per canal varies between 10^2 and 10^8 , and studies on the microbiota of primary tooth root canals are limited. Both aerobic and anaerobic microorganisms are found in the infected root canals of primary teeth. The most common bacterial species identified in infected root canals of primary teeth include *Enterococcus faecalis*, *Porphyromonas gingivalis*, and *Treponema denticola*. Actinobacteria and Verrucomicrobia species are frequently encountered in permanent teeth. Despite these differences, it has been reported that the overall canal microbiota is similar in infected primary and permanent teeth (13-18).

3. Determination of working length in primary teeth

It is particularly challenging to predict the root canal anatomy of primary teeth, especially primary molars, as root resorption causes the shape, size, and position of the root apex to change constantly. This condition makes it difficult to accurately identify the exact location of the true apex. To minimize periapical injuries and potential complications, root canal length should be carefully determined, and the working length should not exceed the physiological apex (19).

Finger sensitivity and conventional radiography are commonly used techniques to determine the working

length, but both have certain disadvantages. The finger sensitivity technique requires experience on the part of the clinician. In radiographic techniques, anatomical variations and projection errors make accurate detection challenging, and this technique carries a radiation risk for both the patient and dental personnel. Additionally, obtaining diagnostic radiographs in children can be difficult due to a lack of cooperation and limited oral access (19-21).

In 1962, Sunada introduced electronic apex locators for measuring root canal length. The most significant advantage of these devices is their ability to measure root canal length up to the apical foramen accurately. Apex locators are easy and quick to use, capable of recognizing artificial perforations, and reduce radiation exposure for both patient and clinician. Today, the use of apex locators in combination with radiography is frequently preferred for determining working length in the root canal treatment of primary teeth (19, 21, 22).

4. Nickel-titanium rotary files used in primary tooth root canal treatment

The success of root canal treatment largely depends on the biomechanical preparation of the root canal systems. The chemical and mechanical preparation of the root canal includes both mechanical instrumentation and canal irrigation, with the main goal being the effective elimination of microorganisms from the root canal system. While manual instrumentation was once commonly used for the preparation of primary teeth root canals, the use of nickel-titanium (NiTi) rotary instruments has become widespread due to the disadvantages of manual instrumentation, such as prolonged preparation time and the risk of aspiration in patients (23-24).

Barr et al., the first to use NiTi rotary files in primary teeth, reported that using rotary files in these teeth is more effective and faster for canal preparation and that the preparation with these instruments provides more uniform root canal fillings (23).

However, the complexity of the root canal morphology of primary teeth and the thinner root dentin structure compared to permanent teeth limit the use of rotary instruments for preparation in these teeth. To overcome these anatomical challenges of primary teeth, the design of rotary files has been modified over the years, and new file systems have been developed to work in harmony with the root canal morphology (23, 24).

The flexibility and design of these developed files enable them to follow the root canal path more closely to their original shape. The irregular root canal anatomy and curved canal walls of primary molars can be effectively cleaned by these developed rotary files, which, through their clockwise motion, help remove infected tissues from the canal (25).

The following special pediatric rotary files are suitable for use in primary teeth (24, 26):

- **Pro-AF Baby Gold:** These instruments, manufactured using NiTi CM-Wire technology, have fixed taper rates of 4% and 6% and are 17 mm in length, consisting of five instruments in total, with only two instruments generally required for preparation.
- **Prime Pado:** These heat-treated instruments have a shape memory and a triangular cross-section, providing improved cleaning efficiency and better filling quality.
- **DXL-Pro-TM:** These files, with a non-cutting blunt tip and a convex triangular cross-section, feature a controlled memory property. They offer better cleaning efficiency and filling quality compared to Prime Pado files.
- **Kedo-S:** The Kedo-S rotary system consists of instruments specifically developed for children and is presented in four generations:
 - First Generation Kedo-S: Includes D1, E1, and U1 instruments, designed with a variable taper ratio (4%-8%) and a total length of 16 mm, with a working length of 12 mm. These files offer the advantage of preserving the original anatomy in curved roots.
 - Second Generation Kedo-SG: These heat-treated NiTi instruments utilize M-Wire technology, offering better-filling quality.
 - Third Generation Kedo-SG Blue: Coated with titanium oxide, these files show 75% greater resistance to cyclic fatigue.
 - Fourth Generation Kedo-S Square: Consists of P1 and A1 instruments, designed with a triangular cross-section in the apical 5 mm and a drop-shaped cross-section in the coronal 7 mm. With its enhanced cross-section, this system provides less dentin preparation and a less aggressive preparation in the apical region.

5. Irrigation in root canal treatment

Successful root canal treatment is achieved through ideal preparation, irrigation, and filling of the root canal. The anatomical complexities of primary teeth roots, such as accessory canals, root apex bifurcation, and dentinal tubules, make it impossible to eliminate microorganisms solely through mechanical instrumentation (14, 27).

Therefore, irrigation solutions are used during root canal treatment to achieve an antimicrobial effect. The primary goal is to clean the root canal system by removing hard and soft tissues that harbor microorganisms. Irrigation performed after biomechanical preparation of the root canal is critical to

completely eliminate necrotic tissue and microorganisms from the root canal (28).

Due to the possibility of open apices resulting from physiological resorption in primary teeth, the irrigation solutions used should be limited to the canal lumen only. Special care must be taken to avoid extruding solutions beyond the apex, as excessive pressure during irrigation can pose a danger to surrounding tissues (5).

The characteristics of an ideal root canal irrigation solution are as follows (28, 29):

- It should have a broad antimicrobial spectrum.
- It should exhibit high efficacy against anaerobic and aerobic microorganisms organized in biofilms.
- It should have the ability to dissolve residues of necrotic pulp tissue.
- It should be capable of inactivating endotoxins.
- It should prevent the formation of a smear layer during instrumentation or have the ability to dissolve it after formation.
- It should not be systemically toxic when in contact with tissues, should not harm periodontal tissues, and should have a low potential for causing anaphylactic reactions.
- Since no single irrigation solution possesses all these optimal properties, it is recommended to use two or more solutions in a specific sequence or combination to achieve better results.

5.1 Saline Solution

Normal saline is isotonic compared to body fluids and is considered one of the most commonly used irrigation solutions in all endodontic and surgical procedures, along with sodium hypochlorite. Additionally, it is known to cause no adverse effects even if extruded into periapical tissues. However, saline should not be used as a standalone irrigation agent; it is preferably used in combination with other solutions, such as sodium hypochlorite, or between other irrigants (14).

According to the research by Byström and Sundqvist, when comparing the pre- and post-procedural microbial status of the root canal using only saline solution, it was found that a reduction of bacteria by approximately 100 to 1,000 times could be achieved. In 1999, Siqueira et al. reported that using only saline solution and various root canal instruments during canal shaping resulted in the removal of 90% of the bacteria (30).

5.2 Sodium Hypochlorite (NaOCl)

NaOCl is the most commonly used root canal irrigation solution in endodontics. When combined with water, NaOCl forms sodium and hypochlorite ions, which establish equilibrium with hypochlorous acid. This equilibrium is responsible for NaOCl's antibacterial activity. The solution is a weak base that denatures

albumin (pulp tissue remnants, food debris, and microorganisms) by making it soluble in water. It also disrupts the vital functions of microorganisms, leading to cell death. However, NaOCl cannot remove the smear layer formed during instrumentation. Lowering the concentration of the solution reduces its toxicity, but it also diminishes its antibacterial effect and tissue dissolution ability. The most effective irrigation regimen has been reported as the use of 5.25% NaOCl for 40 minutes. The American Association of Endodontists (AAE) recommends a concentration of 1.5% NaOCl for regenerative endodontic treatments. The effectiveness of NaOCl can be enhanced by adjusting pH, temperature, and ultrasonic activation (14, 31).

Siqueira et al. suggested that 4% NaOCl shows significant efficacy in disinfecting root canals contaminated with *Enterococcus faecalis* compared to saline solution. Additionally, 5.25% NaOCl has been found to be more effective against *E. faecalis* than lower concentrations. Ercan et al. also reported that the use of 5.25% NaOCl significantly reduced microorganisms (27).

Recent laboratory experiments using three Gram-negative anaerobic bacteria (*Porphyromonas gingivalis*, *P. endodontalis*, and *Prevotella intermedia*) isolated from root canals of primary teeth with apical periodontitis demonstrated that these microorganisms exhibited high sensitivity to NaOCl, and were killed within 15 seconds at all tested concentrations (0.5%-5%) (32).

The combination of 2.5% NaOCl with 0.2% chlorhexidine (CHX) has shown greater antimicrobial efficacy than when each agent was used individually. However, a carcinogenic by-product called par-chloroaniline (PCA) is formed as a result of the reaction between NaOCl and CHX, raising concerns about the potential leakage of this product into surrounding tissues. Therefore, the routine use of this combination is not recommended. The disadvantages of NaOCl include its unpleasant taste and odor, partial removal of the smear layer, inconsistent root canal disinfection, toxicity to periradicular tissues, and its potential to harm the permanent tooth follicle, surrounding tissues, and oral mucosa (14, 28).

5.3 Chlorhexidine Gluconate (CHX)

A 2% CHX solution is widely used as a root canal irrigant; however, CHX lacks the ability to dissolve tissues and disrupt biofilms. The antimicrobial efficacy of CHX is pH-dependent, with an optimal range of 5.5-7. The 2% CHX solution is significantly effective against root canal pathogens such as *Actinomyces israelii* and *Enterococcus faecalis*. At low concentrations, CHX exhibits a bacteriostatic effect, while at high concentrations, it is bactericidal (14).

In an in vitro study by Basson and Tait, 2% CHX solution was reported to be the only irrigant capable of completely disinfecting canals contaminated with *Actinomyces israelii* even after two months. In another in vitro study, Oncag et al. found that 2% CHX was more

effective against *Enterococcus faecalis* than 5.25% NaOCl after both 5 minutes and 48 hours. Adverse effects of CHX, such as tooth discoloration, gingival inflammation, photosensitivity, and rarely, anaphylactic reactions, have been reported in various studies (27).

Although CHX has not been shown to cause long-term damage to host tissues when used as a root canal irrigant, it has been reported to induce inflammatory responses in host tissues when extruded beyond the apex (13).

5.4 Ethylenediaminetetraacetic Acid (EDTA) and Citric Acid (CA)

In endodontic procedures, a neutralized 17% EDTA solution is commonly used. Calt and Serper demonstrated that irrigation with 10 ml of 17% EDTA solution for 1 minute effectively removes the smear layer from the canal walls. They observed that dentin demineralization increases with the duration of contact, EDTA concentration (from 10% to 17%), and pH (from 7.5 to 9). Ultrasonic application of 17% EDTA is particularly effective in removing the smear layer from the apical third of the root canal, and continuous use of liquid EDTA during root canal treatment is recommended (33).

Although CA can be used at concentrations ranging from 1% to 50%, the 10% solution is the most commonly used because it is effective in removing the smear layer. Both EDTA and CA are available in gel and liquid forms, and both effectively dissolve inorganic components and the smear layer (31).

However, neither EDTA nor CA exhibits antibacterial activity. Although it has been found that EDTA is more effective in removing the smear layer when used in combination with NaOCl, the use of EDTA has been associated with damage to dentinal tubules, erosion of peritubular dentin, and deterioration of intertubular dentin in primary teeth. Studies have shown that irrigation with 6% CA for 15 or 30 seconds is highly effective in removing all components of the smear layer in primary teeth, but the use of CA as an irrigation solution at higher concentrations can lead to the destruction of peritubular dentin (13, 28).

CA is better tolerated by stem cells in the apical papilla, meaning it is less toxic than EDTA for the apical papilla in immature permanent teeth with pulp necrosis and in primary teeth (34).

5.5 MTAD

This solution was first introduced by Torabinejad. MTAD consists of 3% doxycycline, 4.25% citric acid, and a detergent (0.5% Polysorbate, known as Tween 80). It is used as an alternative to EDTA to effectively remove the smear layer and disinfect the primary teeth' root canals. The solution also has bacteriostatic activity. It is only effective as an intra-canal irrigation solution when used at the full dose of 5 ml per root canal. Although some studies have shown that MTAD is effective against *E.*

faecalis and is a better alternative for intra-canal disinfection compared to 5.25% NaOCl, further clinical studies are needed to obtain more conclusive results (27).

Various studies have demonstrated that MTAD is effective in removing the smear layer when used as a final rinse following NaOCl irrigation and does not cause any significant changes to the structure of dentinal tubules. Moreover, compared to 2.5% NaOCl, 17% EDTA, and 2% CHX, MTAD has shown superior antimicrobial efficacy against *E. faecalis*, *P. intermedia*, and *T. forsythensis*, and has been reported to eliminate all bacteria in human root canals infected with saliva. Studies have also shown that MTAD is less cytotoxic compared to other endodontic agents (e.g., eugenol, 3% hydrogen peroxide, EDTA). However, the use of MTAD in the root canal treatment of primary teeth is limited due to the potential risk of discoloration in the underlying permanent tooth germ (13).

In another study, the best results were obtained using XP-Endo Finisher protocols containing EDTA and citric acid, as well as with Gentlefile containing citric acid (34).

5.6 Tetraclean

Tetraclean is a solution composed of doxycycline, citric acid, and polypropylene glycol. The concentration of citric acid and the type of detergent used in Tetraclean differ from those in MTAD. Tetraclean's properties are enhanced by its low surface tension, which allows better adaptation of the solution to dentinal walls. Tetraclean removes the smear layer and is effective against obligate and facultative anaerobic bacteria, such as *E. faecalis* (13).

Tetraclean is recommended as a final rinse after root canal preparation. It has been reported to be capable of eliminating all bacteria and the smear layer in the root canal system when used as a final irrigation solution (32).

Due to the complex anatomy of the root canal system, several areas, such as isthmuses, lateral canals, apical ramifications, and the most apical part of the canal remain untouched during instrumentation and traditional needle irrigation. However, in cases of root canal treatment failure, microorganisms are often found in these areas. Additionally, the disinfection of the root canal system is challenging with conventional syringe and needle irrigation, particularly due to the multi-species structure of biofilms. Conventional needle irrigation is often inadequate for delivering the irrigating solution to hard-to-reach areas due to its low flow rate and limited effect beyond the needle tip (35).

Currently, passive ultrasonic irrigation (PUI) is one of the most widely used methods for activating endodontic irrigation solutions. The effectiveness of ultrasonic activation is due to its ability to optimize the disinfection process by increasing wall shear stress through acoustic streaming effects and disrupting the intraradicular structure of the biofilm. However, PUI has

some disadvantages. Specifically, the oscillating instruments have limited contact time with the root canal walls; it is less likely for these instruments to move freely in curved root canals, and even in straight canals, adequate wall contact is achieved only 20% of the total working time. Additionally, although ultrasonic instruments are non-cutting, they are made of metal alloys that are harder than root dentin, posing a risk of altering root canal morphology. To avoid these adverse effects, it is recommended that irrigation solutions be activated using non-cutting plastic tips that operate sonically. In this context, the EndoActivator system is one of the most well-documented methods. This device, which operates with polyamide tips, activates the irrigation solution effectively without damaging the root canal walls or widening the apical constriction. Low-frequency passive sonic activation is more advantageous than PUI in terms of reducing the risk of irrigant extrusion to the apex in curved root canals. Furthermore, studies using simulated lateral canal models have shown no significant difference in cleaning efficacy between PUI and low-frequency passive sonic activation (12).

Laser-activated irrigation (LAI) performed using erbium lasers (Er:YAG: 2980 nm, Er,Cr:YSGG: 2780 nm) has been proposed as an alternative method to enhance the penetration of irrigation solutions deeper into the root canal system and increase the cleaning capacity. LAI occurs through the formation, expansion, and collapse of vapor bubbles induced by the laser, resulting in acoustic transmission. This process creates an effect similar to laser cutting forces due to the pressure and shock waves generated by the laser. Studies have shown that LAI provides a strong bactericidal effect by effectively eliminating the smear layer even in the apical third of the root canal. However, the main disadvantage of laser irrigation is the risk of damaging the periodontal ligament due to thermal effects that may occur during application (36-38).

6. Root canal filling materials used in primary tooth treatment

Achieving successful hermetic sealing in primary tooth root canal treatment depends on various factors, such as good biomechanical preparation, the type of filling material used, and minimizing voids within the canal. An ideal root canal filling should create a seal along the entire root, from the coronal opening to the apical end, thereby eliminating all entry points between the periodontium and the root canal system (39).

Additionally, the ideal filling material for endodontic treatment in primary teeth should not cause damage to periapical tissues or the permanent tooth germ, should resorb in harmony with physiological root resorption, be easy to apply in root canals, adhere well to canal walls, be easily resorbable when extruded beyond the apex, possess sufficient radiopacity, and not cause discoloration of the tooth. Root canal filling

materials used in primary teeth include zinc oxide eugenol-based pastes, calcium hydroxide-based pastes, iodoform-based pastes, calcium hydroxide-iodoform combinations, and zinc oxide eugenol-calcium hydroxide-iodoform-based pastes (8).

Rabinowitch defined the properties of an ideal filling material as follows (39):

- It should not irritate periapical tissues or coagulate organic remnants within the canal.
- It should have a stable disinfectant property.
- It should be easily resorbable when excess material is extruded beyond the apex.
- It should be easy to place in the root canal and removable when necessary.
- It should adhere to canal walls and not shrink.
- It should not dissolve in body fluids.
- It should not cause tooth discoloration.
- It should be radiopaque.
- It should stimulate vital periapical tissue to close the canal with calcified or connective tissue.
- It should not harm adjacent tooth germs.
- It should not harden to a degree that would prevent the eruption of permanent teeth.

Rifkin also proposed criteria for an ideal root canal filling material in pulpectomy (1):

- Resorbability
- Antiseptic properties
- Non-inflammatory and non-irritating to the underlying permanent tooth germ
- Good radiopacity for visibility in radiographs
- Easy placement and removal
- No tooth discoloration
- However, none of the existing filling materials currently meet all these criteria.

6.1 Zinc Oxide Eugenol (ZOE)-Based Pastes

Eugenol was the first volatile oil proven to have significant antimicrobial activity and was first used in dentistry by Chisholm in 1876. One of the most frequently used root canal filling materials in primary teeth is zinc oxide eugenol (ZOE)-based pastes (40).

The success rates of ZOE range from 65% to 100%, with an average of 83%. While some studies have found no significant difference in treatment success when ZOE is compared with calcium hydroxide or iodoform pastes, other studies comparing ZOE with KRI paste and Vitapex have shown that KRI paste may have higher success rates in certain cases (39, 40).

Most studies indicate that ZOE is more effective against gram-negative bacteria than gram-positive bacteria. Navit et al. observed that eugenol-based root canal filling materials exhibited the highest antimicrobial activity against *E. faecalis* within a 24-hour period (40, 41).

Canals filled with ZOE that extend beyond the apex can irritate periapical tissues and cause bone and cementum necrosis. Extruded ZOE resorbs very slowly and often remains in the root tip area even after the primary tooth exfoliates, potentially altering the eruption path of permanent teeth. Additionally, some enamel defects have been observed in permanent teeth underlying primary teeth treated with ZOE, although this has not been shown to significantly affect the overall success or failure of root canal treatment procedures. However, ZOE remains a commonly used root canal filling material in primary teeth due to its anti-inflammatory and analgesic properties, broad bacterial inhibition spectrum, easy availability, radiopacity, insolubility in tissue fluids, ease of mixing, and long working time (39, 40).

6.2 Calcium Hydroxide (CH)-Based Pastes

Although CH-based pastes exhibit excellent biological properties, they do not possess sufficient physical properties for standalone clinical use. These pastes are permeable to tissue fluids and easily dissolve within the root canal. Additionally, they have poor flow, viscosity, and adhesion properties and are radiolucent (40). Therefore, CH-based pastes are often combined with other filling materials, such as iodoform or ZOE. When combined with iodoform, CH provides a high pH (>10) environment that enhances its bacteriostatic effect (40).

Vitapex™ (Neo Dental International Inc., Burnaby, British Columbia) and Metapex™ (Meta Biomed LTD, South Korea) are pre-mixed, syringe-form pastes that contain iodoform and CH and are radiopaque. Both pastes are resorbable, making them preferable for use in primary teeth. These pastes are rapidly resorbed and eliminated either through diffusion or by macrophages when they extrude into furcal or apical regions without causing foreign body reactions. CH-based pastes used in primary teeth (Calcicur™, Voco America Inc., USA; Apexit Plus™, Ivoclar Vivadent AG, Schaan, Liechtenstein; and Sealapex™, Kerr Corp., USA) can be used as pre-mixed syringes or by mixing powder and water (42).

CH-based pastes are also beneficial in cases of periapical lesions as they accelerate periapical healing (39).

6.3 Iodoform-Based Pastes

Iodoform is an iodine preparation obtained by heating the alcoholic solution of potassium iodide with chlorinated lime at 1040 °F. It is a bactericidal and radiopaque material known for its high clinical success rates after pulpotomy and primary tooth root canal treatments. Iodoform has no irritating effect, helps

alleviate pain, and is a potent disinfectant. Compared to ZOE, iodoform pastes have better resorption, biocompatibility, and disinfectant properties. However, they can cause yellowish-brown discoloration of the tooth (41).

6.3.1 Maisto Paste

Maisto paste, developed by Maisto and used clinically for years, is an iodoform-based paste. It contains zinc oxide, iodoform, thymol, chlorophenol camphor, and lanolin. These ingredients reduce the resorption rate of the paste in the root canals of endodontically treated primary teeth. Recent study evaluated the antimicrobial efficacy of zinc oxide eugenol, iodoform paste, KRI paste, Maisto paste, and Vitapex against aerobic and anaerobic bacteria obtained from infected necrotic primary anterior teeth. According to the study, the antimicrobial activity ranking was reported as Maisto paste > Iodoform paste > Zinc Oxide Eugenol > Vitapex (39).

6.3.2 Vitapex

The combination of calcium hydroxide and iodoform pastes has shown good clinical results in the endodontic treatment of primary teeth. Some studies have found that Vitapex is more effective than ZOE and does not cause extruded material in periapical tissues. In terms of antimicrobial activity, Vitapex has been found to be statistically significantly superior compared to the root canal filling materials containing only calcium hydroxide (41).

6.3.3 KRI Paste

KRI paste was introduced by Volkoff as a resorbable iodoform paste suitable for root canal filling. This paste comprises 80.5% iodoform, 4.84% camphor, 2.023% para-chlorophenol, and 1.213% menthol. KRI is a radiopaque endodontic root canal filling material. Camphor and menthol are mixed with para-chlorophenol, an antimicrobial agent, to minimize coagulation with surrounding tissues. According to Rifkin, this paste meets all the criteria expected of an ideal root canal filling material for primary teeth. KRI also has a long-lasting bactericidal potential; its success rate in primary tooth root canal treatment is 84% (39).

6.3.4 Endoflas

Endoflas is a resorbable paste produced in South America and is available in powder-liquid form. It comprises 56.5% ZOE, 40.6% iodoform, 1.07% calcium hydroxide, 1.63% barium sulfate, and pentachlorophenol. This paste provides good sealing of the root canals. Its broad-spectrum antibacterial activity, assistance in disinfecting hard-to-reach dentinal tubules and accessory canals, and resorption rate similar to physiological root resorption are among its clinical characteristics. Compared to zinc oxide eugenol, Endoflas has a high success rate. Its clinically proven success rate ranges from 93.3% to

95.1%. Despite its various advantages, it has not gained widespread use among clinicians (39).

6.3.5 Metapex

In 2009, the AAPD guidelines suggested iodoform-based pastes as suitable alternatives to zinc oxide eugenol. Metapex is a combination of 30.3% calcium hydroxide,

7. Bioceramic-based pastes

The increasing popularity of bioceramics is based on their superior physicochemical and biological properties, such as resistance to alkaline pH, lack of shrinkage, chemical stability in biological environments, biocompatibility, and bioactivity. Most bioceramics consist of calcium silicate materials developed as alternatives to traditional calcium hydroxide. These bioactive materials are used for various purposes in permanent teeth, such as pulpotomy, pulp capping, resorption-perforation repair, and root canal filling. Recently, these materials have also started to be used in primary teeth. For primary teeth, Bio-C Pulpecto (Bio-CP) (Angelus, Londrina, Paraná, Brazil) was developed as the first resorbable bioceramic filling material. This material is composed of calcium silicate, toluene sulfonamide, calcium tungstate, sulfuric acid, ester glycol, and titanium oxide (43).

8. Conclusion

Primary tooth root canal treatment is a reliable method applied to maintain primary teeth with pulp or periradicular tissue infections in the oral cavity in a healthy condition until their physiological exfoliation time. To achieve successful root canal treatment, optimal intra-canal disinfection should be ensured with adequate biomechanical preparation and irrigation, followed by hermetically filling the root canals with a suitable filling material. When proper case selection is made, and techniques are meticulously followed, primary tooth root canal treatment significantly contributes to the child's overall health.

New materials and techniques for root canal treatment are being developed continuously and introduced into clinical practice. Dentists should stay up to date with recent developments and integrate newly developed agents into their clinical applications to enhance treatment success.

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