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Outcome of Vital Pulp Therapy on Immature Permanent Teeth with Calcium Silicate-Based Materials: Retrospective Cohort Study

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Outcome of Vital Pulp Therapy on Immature Permanent Teeth Using Calcium Silicate-Based Materials: Retrospective Cohort Study

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Dentistry at Virginia Commonwealth University.

By

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Abstract

Outcome of Vital Pulp Therapy on Immature Permanent Teeth Using Calcium Silicate-Based Materials: Retrospective Cohort Study

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Introduction: The purpose of vital pulp therapy is to maintain pulp viability by eliminating bacteria from the dentin-pulp complex and to establish an environment in which apexogenesis can occur. The aim of this retrospective cohort study was to evaluate the clinical and radiographic outcomes of vital pulp therapy on immature permanent teeth using different calcium silicate-based materials. **Methods**: This study was carried out in the Virginia Commonwealth University Graduate Endodontics department in Richmond, Virginia. Vital pulp therapy cases performed by graduate endodontic residents were retrospectively searched and charts were reviewed to determine inclusion into this study. All cases selected for this study were vital pulp therapy treatments performed on immature permanent teeth using a calcium silicate-based material. The treatment outcomes were assessed clinically and radiographically at a minimum of 6 months post-treatment. Six examiners (3 endodontists and 3 endodontic residents) were selected to assess the pre- and post-treatment radiographs. The examiners were calibrated and used 3 different radiographic assessment categories (Orstavik's PAI, a root development category, and a final assessment category) to assess periapical healing and treatment outcome. **Results**: A total of 823 vital pulp therapy treatment notes were identified, 209 charts were reviewed as potential candidates for the study, and 51 met the inclusion criteria and were included in this study. The study showed an overall success rate of 89%. The failures noted were subsequently treated with either conventional root canal therapy or regenerative endodontic procedures. Dental sensitivity to cold reported by patients reduced over time, radiographic outcomes showed an increase in apical dentin deposition, and all immature teeth showed continued root formation. **Conclusions**: Vital pulp therapy on immature permanent teeth using calcium silicate-based materials is a viable treatment option for treating teeth affected by traumatic or carious exposures of a vital pulp. **Funding Source**: Foundation for Endodontics.

Introduction

Dental caries is one of the most prevalent diseases across the globe. The World Health Organization has stated that dental caries is the most common noncommunicable disease worldwide (1). If not treated in time, dental caries affects not only the mastication function but also the speech, smile, and psychosocial environment and the quality of life of the individual and the family (2). The treatment of dental diseases is expensive in all countries and prevention is very simple and effective. Even with the advances in caries prevention, hundreds of millions of people are negatively affected by dental caries every year. When dental caries extends beyond the first protective layer of the tooth, the enamel, the likelihood of the disease effecting the dental pulp greatly increases. The dental pulp is found in the inner core of the tooth and is the lifeblood of our teeth. The preservation of the pulp is vital, especially in immature permanent teeth.

Dental pulp is a type of connective tissue found within the hard tissue (dentin and enamel) of the teeth (3). Embryologically, histologically, and functionally, the dentin and the pulp are the same and are considered together, which is why they are also referred to as the pulp-dentin complex (4). The main functions of the pulp include (1) formation of dentin and (2) nutrition to the dentin, which is avascular, protective, and reparative (4). The structure of the dental pulp is similar to the other connective tissues in the body. The mature pulp demonstrates 4 morphologic zones, including the odontoblastic layer, the cell poor zone, the cell-rich zone, and the pulp proper. These 4 zones are fundamental to the protection, nutrition, and immune response to the tooth itself. When exposed to damage such as caries or tooth fracture, dental pulp is at risk of infection, which can lead to pain, necrosis, and infection of the jawbone and surrounding tissue (5). Traumatic or carious exposures of a vital pulp in an immature permanent tooth can present a significant clinical and biological challenge to maintain proper vitality. If the pulp is damaged beyond repair in an immature permanent tooth, the development and growth of the tooth can be severely affected, leading to early breakdown and eventual loss of the tooth.

As stated earlier, the pulp is encased within the dentin. This places the pulp in a low-compliance environment and the pulp receives its blood supply from the blood vessels that traverse through the apical foramen. Some studies have reported that the pulp has some physiologic feedback mechanisms to counteract inflammation and increased tissue pressure, which in turn explains why inflammation of the pulp could be long standing and could heal if appropriate measures are taken in a timely manner (6). Thus, protection of the pulp by applying capping agents directly or indirectly on pulp tissue is called vital pulp therapies (VPTs) (5).

Vital pulp therapies have become an important topic in clinical dentistry in recent years. A basic tenet for clinical dentistry is that treatment is recommended and performed after the formulation of a sound diagnosis. This has been considered of particular relevance when vital pulp therapy was to be considered (7). The current American Association of Endodontists (AAE) diagnostic terminology assigns a vital pulp to one of three categories: “normal”, “reversible pulpitis” or “irreversible pulpitis” (which could be symptomatic or asymptomatic) (8). Traditionally the designation of a pulpal diagnosis is based upon the clinician’s consideration of a patient’s pain history, dental history, and appropriate clinical testing to assess the status of the pulp including the application of a cold stimulus and electric pulp testing. These tests would be best termed pulp sensibility tests, as definitive tests of pulp vitality, such as measures of pulp oxygen tension, are not currently available for clinical use (9).

Historically, there has been a widespread belief that, even in aggregate, clinical test results are not well correlated with histologic descriptions of the pulpal status (10). The viewpoint that VPT is an option only for cases where testing results were consistent with “reversible pulpitis” has recently been challenged (11). Based on clinical, biological and theoretical considerations, the irreversibility of the pulpal disease has come into question. Histologic evidence of the progression of pulpitis suggests that there is no discrete boundary that would render a pulp beyond repair (6). Rather, pulpitis may be interpreted as a temporally and spatially graded disease, with some suggesting the following terms for gradation: “initial”, “mild”, “moderate” and “severe pulpitis” (12).

Currently in permanent teeth, root canal therapy is the most common treatment for the infected pulp (3). Vital pulp therapy is a potential alternative to root canal treatment. Vital pulp therapy is a restorative dental procedure that aims to treat teeth with a compromised dental pulp without the full removal or excavation of all healthy pulp tissue. Vital pulp therapy is performed to preserve the health status of the tooth and its ultimate position in the arch for the expected life of the tooth (4). Vital pulp therapy techniques are means of preserving the vitality and function of the dental pulp after injury resulting from trauma, caries, or restorative procedures (7). Vital pulp therapy procedures have traditionally included indirect or direct pulp capping, and partial or complete pulpotomies.

Indirect pulp capping, direct pulp capping, and partial or complete pulpotomies are all procedures with the sole purpose of maintaining the integrity of the dental pulp (13). The indirect pulp capping procedure is generally used in deep cavity preparations, with or without carious dentin remaining which is in close proximity to the pulp but showing no visible pulp exposure. This treatment method is intended to protect primary odontoblasts (dentin-producing cells) and promote reactionary dentin formation at the pulp-dentin junction. Direct pulp capping treatment is used when the vital asymptomatic pulp is visibly exposed due to caries or trauma, or due to a misadventure during tooth preparation or caries removal. The pulpal wound is essentially sealed with a biomaterial placed directly on exposed pulp to facilitate formation of reparative dentin and maintenance of the vital pulp (14). In contrast to pulp capping procedures, which does not involve any pulp tissue removal, partial pulpotomy removes 2-3 mm of the pulp tissue at the site of exposure. In practice this technique is used for removing the superficial layer of infected tissue in case of asymptomatic carious pulp exposure or when the pulp has been exposed to the oral environment. A full pulpotomy is defined as “the surgical removal of the entire coronal portion of the vital pulp to preserve the vitality of the remaining radicular portion” (7). This treatment approach is indicated when it is predicted that the inflammation of the pulp tissue has extended to deep levels of the coronal pulp. After the removal of the coronal pulp, hemostasis must be achieved, and a biomaterial is placed over the remaining pulp tissue.

As stated earlier, vital pulp therapy is defined as a treatment which aims to preserve and maintain pulp tissue that has been compromised but not destroyed by caries, trauma, or restorative procedures to a health state (14). The longevity of the teeth in the mouth depends on a proper crown/root ratio and sufficient thickness of the dentin walls (15). For this reason, protecting the dental pulp is the first aim for the young permanent dentition. For years, the focus of VPT was on the preservation of the radicular pulp in immature adult teeth, so as to assure completion of root formation (apexogenesis) (16). Today, the focus of VPT is broader; practitioners may have treatment options to consider other than pulpectomy or root canal therapy (RCT) in mature teeth, including teeth previously thought to have irreversibly inflamed pulps (7). Vital pulp therapy has a high success rate if the following conditions are met: (1) the remaining pulp is not inflamed, (2) hemorrhage is properly controlled, (3) a nontoxic capping material is applied, and (4) the capping material and restoration seal out bacteria (4).

In recent years, with the progress of regenerative and molecular approaches, it is known that the efficacy of direct and indirect pulp capping might be affected by the biomaterials used and their biological properties. Some studies have suggested that the effect of using calcium hydroxide or glass-ionomer cement on dentine caries is not superior to the use of an inert material such as wax (5). Many materials have been used and tested in vital pulp therapy treatments for immature permanent teeth. Calcium hydroxide ($Ca(OH)_2$) is the most popular material that has been tested in indirect pulp capping (IPC) treatments (13).

Many studies have looked at the different materials used in vital pulp therapy procedures. Historically, a number of materials have been advocated to induce normal root development in immature permanent teeth. In the past, the material of choice has been calcium hydroxide ($Ca(OH)_2$). However, it still has several drawbacks: insufficient adherence to dentinal walls, multiple tunnel defects in the induced dentin bridges, poor sealing ability, dissolution over time and lack of antibacterial properties. Long-term clinical studies showed success rates with calcium hydroxide pulp capping on carious exposures to be highly variable, generally unpredictable, and often unsuccessful. Indeed, calcium hydroxide no longer seems to be the best possible material of choice. Due to its high basicity, calcium hydroxide in direct contact with the pulp locally destroys a layer of pulp tissue, and thus creates an uncontrolled necrotic zone. This necrotic layer induces an inflammatory reaction which persists in time or leads to formation of intra-pulpal calcifications. However, it is the high solubility of calcium hydroxide that is the major disadvantage of its use as a pulp capping and pulpotomy agent. The dissolution of the material within two years after application and the formation of defects in reparative dentin underneath the capping material are responsible for failing to provide a permanent seal against bacterial infection.

Most recently, an alternative material, mineral trioxide aggregate (MTA), has become available for use in pulpal procedures (10). MTA is a bioactive cement pioneered by Torabinejad et al in the early 1990s as an endodontic repair and root-end filling material with favorable physical properties. MTA has proven to induce mineralization beneath exposed pulp and have the potential of maintaining pulp vitality. Hence, the indications for the use of MTA have expanded considerably from its original use, and it has recently became a superior substitute for calcium hydroxide in many other clinical applications, including direct and indirect pulp capping, perforation repairs in roots or in furcations and in apexification procedures. The powder of MTA is a mixture of a purified Portland cement and bismuth oxide to provide radiopacity. The main constituent phases of cement are tricalcium and dicalcium silicate and tricalcium aluminate.

Several properties are necessary when choosing a material to be used in vital pulp treatment. These include the ability of the material to kill bacteria, induce mineralization, and establish a tight bacterial seal (17). The ideal material for vital pulp treatment should be able to resist long-term bacterial leakage and stimulate the remaining pulp tissue to return to a healthy state, promoting the formation of dentin. The early data for MTA suggest that it is the optimum material for fulfilling these goals when vital pulp therapy is the treatment of choice. Even with all its clinical benefits, MTA has its drawbacks. Discoloration of the marginal gingiva and the crown has been reported with MTA use (18). Materials based on calcium silicate with alternative radiopacifiers are also available clinically.

Biodentine is one of the alternative calcium silicate-based materials that has also been used clinically in vital pulp therapy treatment. Biodentine is resin-free and mainly composed of pure tricalcium silicate, which is able to set in wet conditions (19). Biodentine has been shown to induce odontoblastic differentiation of dental pulp stem cells, and produce more uniform and thicker dentin bridge formations, with less inflammatory response and less necrosis of pulp tissue than calcium hydroxide (19). Biodentine is commonly used today and has proven to be very effective in VPT treatments.

Another material that is becoming more and more popular in VPT treatments is bioceramic (BC) putty. Most recently developed materials used in vital pulp therapy treatments are based on tricalcium silicate (TCS). One particularity of TCS-based materials is their potential to express bioactivity, which is considered as a surrogate for bone-bonding ability (20). BC putty is a TCS-based material that is commercialized as a root repair material that can be used for perforation repair, resorption repair, root-end closure procedures, pulp capping, and as a retrograde filling material during surgical procedures (20). MTA, Biodentine, and BC putty have all shown to be effective in the formation of a dentin bridge in vital pulp therapies (21). These bioceramic materials are also becoming more and more popular because of their excellent biocompatibility, their sealing ability, and being associated with desirable clinical outcomes when used for repair of perforations, vital pulp therapies, root-end fillings and root fillings, and when used as an apical plug (22).

The definition of regenerative endodontic procedures such as ‘biologically based procedures designed to replace damaged structures’ does not distinguish if the procedures involve regeneration or repair. Regeneration is the formation of a physiological-like dentine tissue, while repair is the formation of a new tissue resembling the native pulp-dentine complex at the histologic level with the expected physiological functions ((23). Although the ultimate goal of vital pulp therapy is the complete regeneration of tissues lost to caries or traumatic injuries, it is unlikely that the current therapies are capable of stimulating the formation of native dentine (24). Removal of superficially inflamed tissue in the partial pulpotomy technique provides more space for the dressing material that comes in contact with the pulp. A partial pulpotomy also preserves the cell-rich coronal pulp tissue, which possesses better healing potential and can continue the physiologic dentine deposition at the cervical area of the affected tooth. The clinical success rates of partial pulpotomies have been shown to be approximately 94%. Partial pulpotomies performed with calcium silicate-based materials have been shown to provide favorable outcomes in immature permanent teeth.

Endodontic treatment of an open and divergent root apex is difficult. Moreover, the root canal treatment leads to dentin deposition arrest along the canal walls and eventually makes the tooth more prone to fracture. An infected pulp shows degenerative changes which usually progress in a coronal to apical direction. Healthy pulp tissue may be found in the deeper portion of the root canal system when pulpal inflammation is localized adjacent to the carious lesion. The primary aim when treating an immature permanent tooth with deep dentin caries should be to potentiate the regenerative capacity of the affected pulp. Affected pulp tissue generally refers to a reversible pulpitis where the inflammation is mild and the tooth pulp remains healthy enough to save (25).

Many studies have compared and contrasted the older materials vs the newer materials used in vital pulp therapy procedures. However, there is a gap in the existing knowledge concerning the comparisons and efficacy of MTA vs Biodentine vs BC putty. This research project will review the outcomes of indirect and direct pulp capping procedures, partial pulpotomies, and complete pulpotomies in immature permanent teeth treated with these three calcium silicate-based materials in the VCU Graduate Endodontic clinic in Richmond, Virginia.

Each case included in this study was performed by a graduate endodontic resident under the direction of an endodontic faculty member at VCU. These outcomes will be assessed by reviewing patient charts who have undergone one of these vital pulp therapy treatment modalities and by reviewing both clinical and radiographic follow-up exams. Six examiners (3 endodontists and 3 endodontic residents) were chosen to review both pre-operative radiographs and at least a 6 month or longer post-operative radiograph.

Methods & Materials

All patient records for this study were pooled from resident cases completed at Virginia Commonwealth University in the Graduate Endodontic department after approval from the Institutional Review Board at the university (HM20021629). Cases were selected from January of 2010 through December of 2020. In order to identify cases, a search of the VCU School of Dentistry's patient charting software, axiUm CE (LEADTOOLS Technologies, ©2017), was performed using the codes established by the American Dental Association (ADA) and the American Association of Endodontists (AAE) in 2022 for vital pulp therapy procedures – D3220 (therapeutic pulpotomy), and D3110 (direct pulp cap); a more extensive review of all D3220 codes was performed to assess whether the pulpotomy was a complete coronal pulpotomy or a partial pulpotomy, as there is no ADA or AAE code for partial pulpotomy. Additionally, a key word search was performed for the following terms within chart notes from the prescribed time period: indirect pulp cap, direct pulp cap, pulp cap, partial pulpotomy, full pulpotomy, therapeutic pulpotomy, Cvek pulpotomy, partial pulpectomy, and vital pulp therapy. This search yielded a total of 534 vital pulp therapy cases. A search was also performed that reviewed all patient treatment logs of VCU endodontic residents from 2010-2020. The treatment logs were reviewed for any vital pulp therapy procedures performed in the VCU Graduate Endodontic clinic. This search yielded 289 vital pulp therapy cases. Between the two search techniques, 823 notes were identified. Once redundant patient charts and those identified as cases pertaining to restorative, periodontal, or other dental procedures were eliminated, 209 cases were identified and reviewed as potential candidates for this study. Of the 209 cases identified as potential candidates, 53 of them met clinical selection criteria and had a radiographic follow-up of at least 6 months or longer (see Appendix A).

Cases that filled the following criteria were included for analysis:

1. Population: permanent teeth with immature root formation treated with vital pulp therapy with a calcium silicate-based material in the VCU Graduate Endodontic clinic.

2. Interventions: vital pulp therapy including indirect or direct pulp capping, Cvek/partial pulpotomy, and full pulpotomy treated with a calcium silicate-based material with the appropriate protocols from start to finish.

3. Outcomes: the success criteria should include clinical success (elimination of clinical symptoms including pain, percussion, and palpation) and radiographic success (absence of periapical radiolucency). The 6 selected evaluators (3 endodontists and 3 endodontic residents) evaluated radiographic outcomes based on 3 categories: 1 - periapical index (PAI) score based on a 1-5 scale described by Orstavik (26), 2 - root status/development, and 3 - a final assessment (complete healing, incomplete healing, or treatment failure).

4. Study Design: a retrospective cohort study in the VCU Graduate Endodontic clinic.

Selected cases that had at least one follow-up appointment with documentation of a clinical exam and at least a 6 month or longer radiographic analysis. Cases were excluded if there was a change of treatment protocols from vital pulp therapy to another treatment type, either revascularization/regeneration, apexification, or non-surgical root canal therapy during the initial treatment phase. Two hundred nine teeth were treated following vital pulp therapy endodontic procedure protocols, however, almost three-fourths of these were lost to follow up. The final number of cases included within the parameters of this study was 51 (2 cases were deemed ineligible due to insufficient radiographs). The eligible patient charts needed to include a preoperative diagnosis; the etiology of disease; details of the procedures and the types of materials used; a clear definition for the success of treatment-clinical criteria (the absence of pain, percussion, or palpation), radiographic criteria (the absence of a periapical radiolucency), or any additional criteria; and a minimum follow-up period of 6 months or longer.

Additional information regarding the patient and case was recorded: gender, age, tooth type, arch, pre-operative pulpal status, pre-operative periapical status, tooth number, provider, type of vital pulp therapy procedure performed, material used, clinical symptoms, radiographic analysis, etiology precipitating treatment, and method of tooth closure. Once the collected information was gathered, the data was deidentified by removing identifying information and the case was then assigned a case number in a consecutive sequence.

Outcomes were assessed according to the following 3 categories and based on radiographic and clinical data from the follow-up visits. Each case was assigned to one of the following subgroups within each of the 3 assessment categories:

1. Orstavik's periapical index (PAI) (26): 1 – normal (no periapical bone loss evident), 2 – small bony changes evident, 3 – bony changes with mineral loss (characteristic of apical periodontitis), 4 – apical periodontitis with well-defined radiolucent area, and 5 – severe apical periodontitis with radiating expansion of bony changes. After all examiners were calibrated, only 1, 3, and 5 were used for calibration purposes.
2. Root status/development: 1 – no continued root development, 2 – continued root development, and 3 – complete root development with closure of the apical foramen.
3. Final assessment: 1 – complete healing, 2 – incomplete healing, and 3 – treatment failure.

A total of 6 examiners (3 endodontists and 3 endodontic residents) were calibrated to understand radiographic outcome determinants and asked to place each case into one of the subcategories under each of the 3 assessment categories using a PowerPoint (Microsoft © 2022) presentation. An example of the evaluator calibration can be seen in below (see Appendix B) that included both a Word (Microsoft © 2022) document and a PowerPoint (Microsoft © 2022). Specialist evaluators graded radiographic healing only, without knowledge of patient symptoms or knowledge of subsequent diagnostic testing. Once all data and survey responses were collected, they were provided to a statistician for analysis.

Statistical Methods

All data was gathered via chart review from the axiUm CE (LEADTOOLS Technologies, ©2017) program, with all data placed into an Excel (Microsoft © 2022) spreadsheet. The data were described using counts and percentages. Interrater reliability was assessed with Cohen's Kappa statistic for pairs of raters for each index (PAI, Root Development, and Final Assessment). Average Kappa Statistics were calculated based on the combinations of raters (i.e., two faculty members (FF), two residents (RR), or a faculty-resident pairing (FR)). Significance level was set at 0.05. SAS EG v.8.2 (SAS Institute, Cary, NC) was used for all analyses.

Results

The results of this study begin with a description of the teeth that were included for evaluation. Characteristics of the patients, the etiology of disease, pulpal and periapical status, and follow-up length are outlined under this section. The next section highlights the association between clinical parameters and indices by rater. Finally, a description is made of the evaluators who determined radiographic healing status for the teeth treated with vital pulp therapy and differences in the responses by the evaluators is shown.

Description of the Teeth

A total of 53 cases were reviewed by the raters but 51 cases were included after excluding 2 with insufficient radiographs. The sample included more females than males (63% vs 37%), etiology was predominantly due to caries (78%). The majority of the cases were for molars (n=38, 76%), but also included 9 anterior teeth (18%) and 4 premolars (8%). More mandibular teeth were included than maxillary (61% vs 39%). The majority were treated with MTA (n=36, 71%). Only 4 cases were treated with BC (8%), and the remaining 11% were treated with other materials including SDF (n=1), Biodentine (n=1), Dycal (n=1), or Theracal (n=1). The procedures performed on the 51 cases included pulpotomy (n=29, 57%), direct pulp cap (n=10, 20%), indirect pulp cap (n=6, 12%), and Cvek Pulp (n=6, 12%). Pulpal status included symptomatic irreversible pulpitis (SIP) (65%) and asymptomatic irreversible pulpitis (AIP) (33%). Periapical status was predominantly normal (61%) or SAP (37%). The average follow-up time was 25.5 months and ranged from 6 to 109 months. Descriptive of the cases are included in Table 1.

Table 1: Clinical Characteristics of Cases Included (n=51)

	n	%
Gender		
Female	32	63%
Male	19	37%
Etiology		
Caries	40	78%
Dens Evaginatus	3	6%
Trauma/Fracture	8	16%
Arch		
Mandible	31	61%
Maxilla	20	39%
Tooth Type		
Anterior	9	18%
Molar	38	75%
Premolar	4	8%
Procedure		
Pulpotomy	29	57%
Direct Pulp Cap	10	20%
Indirect Pulp Cap	6	12%
Cvek Pulp	6	12%
Material		
Mineral Trioxide Aggregate (MTA)	36	71%
Bioceramic (BC)	4	8%
Other	11	22%
Pulpal Status		
AIP	17	33%
SIP	33	65%
Necrotic	1	2%
Periapical Status		
CAA	1	2%
Normal	31	61%
SAP	19	37%

The average agreement across all pairings was highest for final assessment and considered to be “moderate” at k=0.73. The agreement between the two endodontic faculty members was k=0.89, 0.69 for faculty-resident pairs and 0.67 for pairs of residents. For the PAI, the average agreement was k=0.67, and also considered "moderate." Among resident pairs, the agreement was highest at k=0.77, followed by faculty pairs at 0.67, and faculty-resident pairs at 0.63. The root development ratings demonstrated the lowest average agreement at k=0.61 but is still considered to be in the "moderate" range. Faculty pairs had the highest agreement k=0.75 followed by faculty-resident pairs at 0.59, and resident pairs were lowest with 0.55. Complete agreement statistics are provided in Table 2. Perhaps this agreement data gives validity to the outcomes of the cases treated in this project as evaluated by the 6 evaluators.

Table 2: Interrater Reliability for Paired Raters

	Kappa		
	Average	Min	Max
Final Assessment	**0.73**	**0.56**	**0.96**
FF	0.89	0.84	0.96
FR	0.69	0.58	0.83
RR	0.67	0.56	0.81
PAI	**0.67**	**0.53**	**1.00**
FF	0.67	0.53	0.88
FR	0.63	0.55	0.74
RR	0.77	0.65	1.00
Root Development	**0.61**	**0.48**	**0.96**
FF	0.75	0.63	0.96
FR	0.59	0.48	0.72
RR	0.55	0.48	0.60

Based on the Final Assessment ratings, a score of 1 or 2 in this category was considered a success since these were considered "complete healing" and "incomplete healing," respectively and a score of 3 was "treatment failure." The status designations were created using the system illustrated by Bukhari and are described in the methods with each healing type illustrated in figures 1-3 (27).

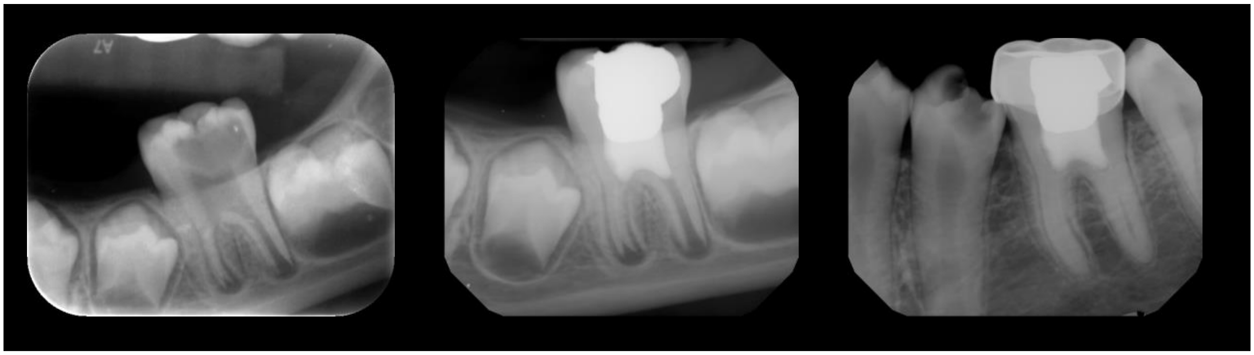


Figure 1: Example of Complete Healing (Pulpotomy, Tooth #19)

The overall success rate, averaged across all raters, was 89% of the 51 cases included. The success rate ranged from n=45 to n=46 or 88%-90% for all raters. A complete summary is provided in Table 3.

Table 3: Success Rate as Defined by Final Assessment Rating by Rater

Rater	n	%
Faculty 1	45	88%
Faculty 2	45	88%
Faculty 3	45	88%
Resident 1	46	90%
Resident 2	46	90%
Resident 3	46	90%
Average	**45.5**	**89%**

Associations between Clinical Parameters and Indices by Rater

None of the clinical parameters demonstrated associations with the PAI. Based on several raters, there was evidence of an association between the root development score and the tooth type, and the procedure performed. Final assessment scores from all raters were significantly associated with the material used. The procedure performed also demonstrated the potential of an association with final assessment (p-values are provided in Table 4).

Table 4: P-values for Association between Clinical Parameters and Indices by Rater

	F1	F2	F3	R1	R2	R3
PAI						
Tooth Type	1.000	1.000	1.000		1.000	
Procedure	0.454	0.695	0.454		0.682	
Material	1.000	1.000	1.000		0.506	
Gender	0.134	1.000	1.000		0.134	
Etiology	1.000	1.000	1.000		1.000	
Arch	1.000	0.514	0.702		0.514	
Pulpal Status	1.000	1.000	1.000		1.000	
Periapical Status	0.173	1.000	0.501		1.000	
Root Development						
Tooth Type	0.298	0.519	0.430	0.785	0.555	0.582
Procedure	0.657	0.135	0.110	0.517	**0.048**	1.000
Material	0.503	**0.038**	**0.028**	0.636	**0.008**	0.726
Gender	0.544	**0.067**	**0.047**	0.699	**0.050**	0.725
Etiology	0.328	0.324	0.288	0.574	0.652	1.000
Arch	0.186	0.466	0.245	1.000	0.749	0.486
Pulpal Status	1.000	0.815	0.894	1.000	0.828	1.000
Periapical Status	0.553	0.482	0.391	1.000	0.564	0.577
Final Assessment						
Tooth Type	**0.092**	**0.100**	**0.090**	**0.029**	**0.040**	**0.035**
Procedure	0.130	**0.095**	**0.089**	**0.031**	0.133	0.229
Material	0.837	0.660	0.574	0.638	0.426	0.352
Gender	**0.052**	**0.042**	**0.063**	**0.002**	**0.013**	**0.005**
Etiology	0.745	0.490	0.439	0.543	0.513	0.347
Arch	0.805	0.735	0.590	0.622	0.543	0.640
Pulpal Status	0.915	0.925	0.923	0.794	0.755	0.922
Periapical Status	0.463	0.434	0.362	**0.096**	0.302	0.317

Figure 2: Example of Incomplete Healing (Direct Pulp Cap, Tooth #18)

Description of Respondents and Respondent Selections

As specified in the Methods section, pre-treatment and follow-up radiographs were included in a PowerPoint (Microsoft © 2022) presentation. Respondents to the survey were asked for their assessment of healing for each of the 51 cases. There were 3 endodontists and 3 endodontic resident respondents. After categorizing the final assessment scores into two categories: (1) complete healing or incomplete healing and (2) treatment failure, there was perfect agreement among the faculty members and among the residents, but the two groups disagreed on one case. Using these scores, there was a significant association between success and the material (p-values=0.0325 for faculty evaluators and 0.0132 for residents). None of the four cases treated with BC putty were considered failures by any of the six evaluators. Based on evaluations from faculty raters, 6% (n=2) of the 36 cases treated with MTA were considered failures and 3% (n=1) according to the resident evaluators. The 11 cases treated with other materials were considered failures by all the raters at a rate of 36%. The four cases considered failures were treated with Dycal (n=2 of 6 cases) and Biodentine (n=2 of 3 cases). Final assessment ratings by faculty members were also significantly associated with the procedure (p-value=0.0290). None of the 6 cases treated with Cvek pulpotomy were considered failures. For the 29 cases treated with pulpotomy, 3% (n=1) were considered treatment failure. Approximately a third of the cases treated with indirect (n=1, 33%) and direct (n=3, 30%) pulp capping procedures were considered failures. Patient gender was also significantly associated with final assessment for both faculty and residents (p-value=0.0050 for faculty and 0.0222 for residents). For final ratings assessed by faculty members, all cases were considered complete healing or incomplete healing for females but only 74% of cases involving male patients (p-value=0.0050). Based on resident ratings, 96% of females were considered complete healing or incomplete healing and 74% of male patients (p-value=0.0222). A summary of the associations between final assessment and these clinical parameters are provided in Table 5.

Table 5: Associations between Materials and Procedure with Failure Rates

	Failure Rate	
	Faculty	**Residents**
Material (P-value)	**0.0325**	**0.0132**
MTA	6%	3%
BC	0%	0%
Other	36%	36%
Procedure	**0.0290**	**0.0662**
Pulpotomy	3%	3%
DPC	30%	30%
IPC	33%	17%
Cvek Pulp	0%	0%
Gender	**0.0050**	**0.0222**
Male (n=19)	26%	26%
Female (n=32)	0%	3%

Figure 3: Example of Treatment Failure (Direct Pulp Cap, Tooth #31, NSRCT Performed)

Discussion

This retrospective cohort study showed an 89% success rate of vital pulp therapy (including indirect pulp cap, direct pulp cap, Cvek pulpotomy, and pulpotomy) in treating teeth with both asymptomatic and symptomatic irreversible pulpitis. The different etiologies of the pulpal disease did not appear to affect the outcome of vital pulp therapy. Symptomatic irreversible pulpitis was the most common pulpal diagnosis, and the most common periapical status was normal apical tissues of the teeth treated. The most predominant etiology of teeth needing treatment was caries with trauma being the second most common etiology. Most of the teeth treated by one of the vital pulp therapy procedures were mandibular molars. Overall, more mandibular teeth were treated than maxillary teeth. MTA was the material most often selected in treatment and complete pulpotomy was the most common vital pulp therapy treatment modality selected. The average follow-up time was 25.5 months and ranged from 6 to 109 months. One of the most recent systematic reviews published by Cushley et al (28) reported the success rate of vital pulp therapy on caries-exposed pulps was approximately 86% at the 1-year follow-up when using MTA or Biodentine. The results of this study seem to follow the success rates of other studies done prior to this one.

Another interesting note was that the average agreement across all pairings was highest for the final assessment category. The agreement between the endodontic faculty members was the highest in this category and the agreement between the pairs of residents was the lowest. For the periapical index category, the agreement between resident pairs was higher than for the faculty pairs. Of all the assessment categories, the root development ratings demonstrated the lowest average but was still in the “moderate” statistical range. Faculty pairs had the highest agreement in the root development category and the resident pairs showed the lowest average agreement in this category. Overall, the faculty pairs exhibited the highest average agreement. This could possibly be due to the experience of radiographic analysis of the faculty members with the residents having much less experience in reviewing radiographs.

It is also interesting to note that none of the clinical parameters demonstrated associations with the periapical index category. Based on several raters, there was evidence of an association between the root development score and the tooth type, and the procedure performed. Final assessment scores from all raters were significantly associated with the material used. The procedure performed also demonstrated the potential of an association with the final assessment. As stated in the results section, after categorizing the final assessment scores into two categories: (1) complete healing or incomplete healing and (2) treatment failure, there was perfect agreement among the group of faculty members and among the group of residents, but the two groups disagreed on one case. Using these scores, there was a significant association between success and the material. None of the four cases treated with BC putty were considered failures by any of the six evaluators. Based on evaluations from faculty raters, 6% (n=2) of the 36 cases treated with MTA were considered failures and 3% (n=1) according to the resident evaluators. The 11 cases treated with other materials were considered failures by all the raters at a rate of 36%. The four cases considered failures were treated with Dycal (n=2 of 6 cases) and Biodentine (n=2 of 3 cases). Final assessment ratings by faculty members were also significantly associated with the procedure (p-value=0.0290). None of the 6 cases treated with Cvek Pulp were considered failures. For the 29 cases treated with pulpotomy, 3% (n=1) were considered failure. Approximately a third of cases treated with indirect (n=1, 33%) and direct (n=3, 30%) pulp capping were considered failures. Patient gender was also significantly associated with final assessment for both faculty and residents (p-value=0.0050 for faculty and 0.0222 for residents).

For final ratings assessed by faculty members, all cases were considered complete healing or incomplete healing for females but only 74% of cases involving male patients (p-value=0.0050). Based on resident ratings, 96% of females were considered healed or healing and 74% of male patients (p-value=0.0222).

With appropriate materials and techniques, vital pulp therapy can be effective in preventing the progression of pulpal disease (29). In a series of studies by Asgary et al (30), teeth with irreversible pulpitis were treated with pulpotomy using MTA or calcium-enriched mixture as a capping material; 98% of the cases achieved clinical success at the 5-year recall. Because clinical signs and symptoms do not always accurately reflect the actual pulp condition (31), vital pulp therapy can be justified as an alternative treatment to NSRCT with prudent examinations and treatment planning.

The amount of pulpal tissue that was removed in each of these cases (no pulp tissue was removed in the indirect or direct pulp capping cases) and the selection of capping materials varied from one to another, which would ultimately influence the treatment outcomes and vitality of the radicular pulpal tissue (see figure 4). For direct pulp capping or indirect pulp capping, several studies have included sensibility as criterion for treatment success. On the contrary, in most pulpotomy studies, success is often only defined as the elimination of clinical symptoms

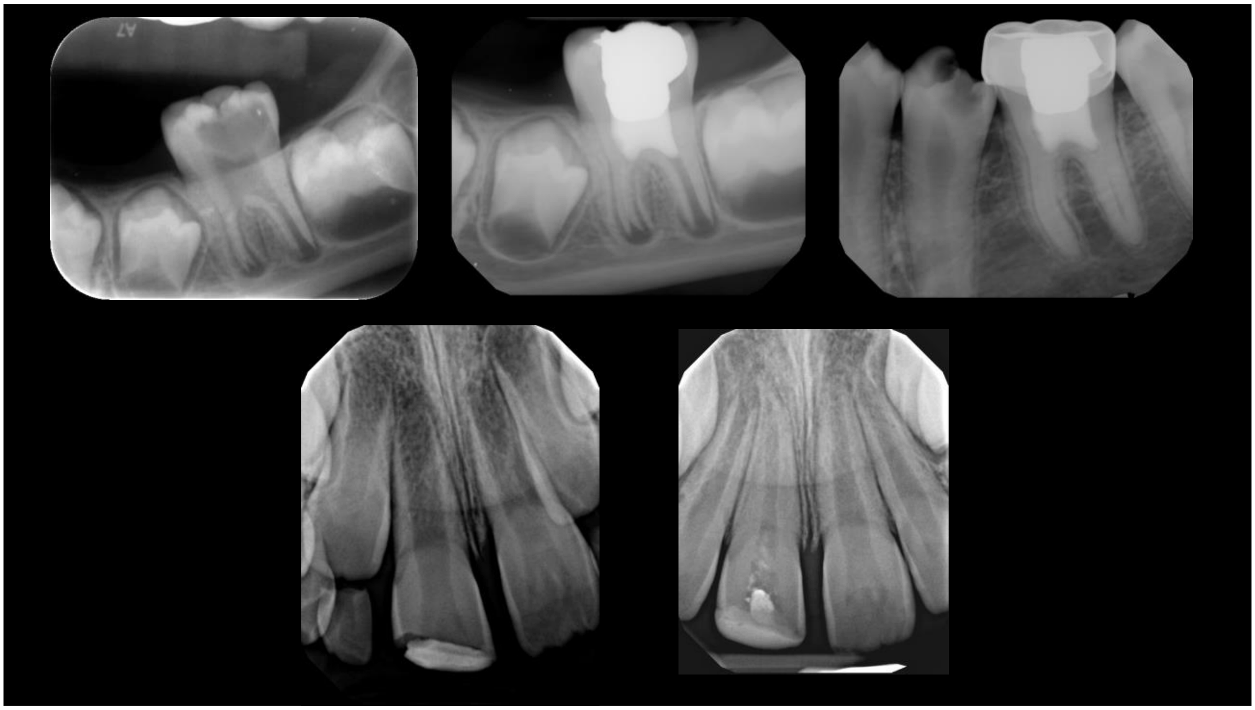


Figure 4: Shows the difference in the amount of pulpal tissue removed

and the absence of radiographic lesions, leaving the status of the radicular pulpal tissue largely unclear from these studies. Because it is very challenging to assess radicular vitality by clinical radiographic examinations after a pulpotomy, the technical difficulty can limit our understanding on the physiological changes of the radicular pulpal tissue (29). However, some indirect evidence such as root development can shed light on the health status of the radicular pulp. Based on the limited number of studies that have studied root development or apical closure after vital pulp therapy, the continuation of root development may be seen in 70-80% of immature teeth after pulpotomy (32). Ricucci et al (33) examined the extracted VPT-treated teeth histologically in a case series study; the pulpal tissue in 5 of 17 teeth had developed irreversible inflammation after vital pulp therapy. Caries-free teeth were treated with experimental pulpotomy, and 5 of 19 teeth also developed irreversible inflammation after the procedure.

Therefore, further histologic or long-term follow-up pulpotomy studies will be available to unravel the underlying effect of VPT on radicular pulp tissue (29).

Generally, medicaments and obturation materials used in NSRCT are confined in the canals without much interaction with the extraradicular tissue. In contrast, in vital pulp therapy, capping materials are directly in contact with the highly vascularized pulpal tissue. The therapeutic capability, biocompatibility, and sealing quality of these materials play a critical role in the success of vital pulp therapy (34). Calcium hydroxide has been used traditionally in vital pulp therapy. In regenerative endodontic therapy, calcium hydroxide was shown to be conducive for the survival and proliferation of apical papilla stem cells (35). On the other hand, the quality of reparative tissue induced by calcium hydroxide could be compromised by adjacent liquefaction necrosis and mild inflammatory cell infiltration that it has caused (36). Mente et al (37) reported an 80% success rate of direct pulp capping with MTA compared with a 59% success rate with calcium hydroxide in their retrospective study.

Calcium silicate-based materials have demonstrated a substantially superior quality of the hard tissue bridge formed in both animal models and human teeth (see figure 5). A dentinal or cementum-like bridge induced by these materials serves as a barrier between the vital pulp tissue and the capping material, which is essential to preserve the vitality and microenvironment of the pulp (29). Based on previous studies on apexification, an average of 6 months (range 5-20 months) is often needed for calcium hydroxide to induce a calcified barrier, whereas calcium silicate-based materials require less time for the bridge formation with minimal inflammatory cell inclusions (38) (see figure 5).

Figure 5: Note the hard tissue bridge formed under the MTA on tooth #20

Perhaps this study suggests some implications for future research. How are preoperative endodontic diagnoses related to the treatment outcomes of vital pulp therapy? What are some pathophysiological responses of the remaining pulpal tissue to materials used in vital pulp therapy? Vitality testing with long-term follow-up as well as histologic studies may lead to better understanding of these questions. This study also provides implications for clinical practice. This retrospective study is relevant to gauging the effectiveness of vital pulp therapy as an alternative treatment for pulp disease. Compared with conventional NSRCT, vital pulp therapy is less technique sensitive and preserves the vitality of the remaining pulpal tissue. For this reason, vital pulp therapy is the preferred treatment modality for immature permanent teeth because vitality of the radicular pulpal tissue is indispensable for the continuation of root development and formation of the natural apical foramen (29). The outcomes of vital pulp therapy in this retrospective study provide clinicians with critical information for decision making.

Conclusion

With a low certainty of evidence, this study concluded that vital pulp therapy using calcium silicate-based materials is an effective treatment modality to treat immature permanent teeth with an 89% success rate. The etiology of the pulpal diseases, the selection of materials (limited to calcium silicate-based material), and the preoperative diagnosis had no significant correlation with treatment prognosis. No major adverse effects of vital pulp therapy were reported, except for tooth discoloration associated with MTA. Development of minimally invasive biologically based therapies aimed at preservation of the pulp vitality remains the key theme within contemporary clinical endodontics. The findings in this study confirm that both MTA, and other calcium silicate-based materials, are reliable materials in the matter of inducing dentin bridge formation while keeping a vital pulp in the different treatment modalities of vital pulp therapy.

Data collected from this chart review spanned a time frame of 10 years, yielding 209 cases of vital pulp therapy (51 of which had at least a 6-month radiographic follow-up). Fifty-one treatments seem to be an adequate starting point to establish guidelines for treatment within the VCU School of Dentistry. First, the number of cases could have been higher, had several patients not been lost after treatment planning. Additionally, 156 patients did not return for any clinical or radiographic follow-up.

Establishing a recall timeframe early and committing residents, patients, and where applicable, patient guardians to this series of recalls, will be essential to better understand outcomes of vital pulp therapy. Patients should not only be informed of the risks and benefits of vital pulp therapy but should also understand that they are committed to return. A potential solution would be to establish early recall periods within relatively short periods of time, similar to those seen after a traumatic injury. A comparable schedule of 1 month, 3 month, and 6 month early recalls, followed by a 12 month and then a yearly recall for at least 1 subsequent year would be more than adequate to establish whether patient symptoms have resolved and whether radiographic healing has occurred. By creating the necessity for early recalls, more patients and their guardians will be invested in seeing how well the vital pulp therapy works and will know that their provider is committed to seeing the best possible outcome for them.

The results of this retrospective chart review suggest that vital pulp therapy procedures are a successful treatment option when faced with a permanent tooth with immature root development and a vital pulp. Perhaps a correlation exists between the type of material used and the vital pulp therapy treatment modality used on immature permanent teeth. Changes could be made to improve recording clinical information when performing vital pulp therapy procedures. Additionally, practitioners and patients need to be committed to the process of vital pulp therapy, including follow-up visits. While protocol in establishing follow-up time frames should be improved, with high percentages of success, vital pulp therapy endodontic procedures continue to be a treatment option for the immature permanent tooth with a vital pulp.

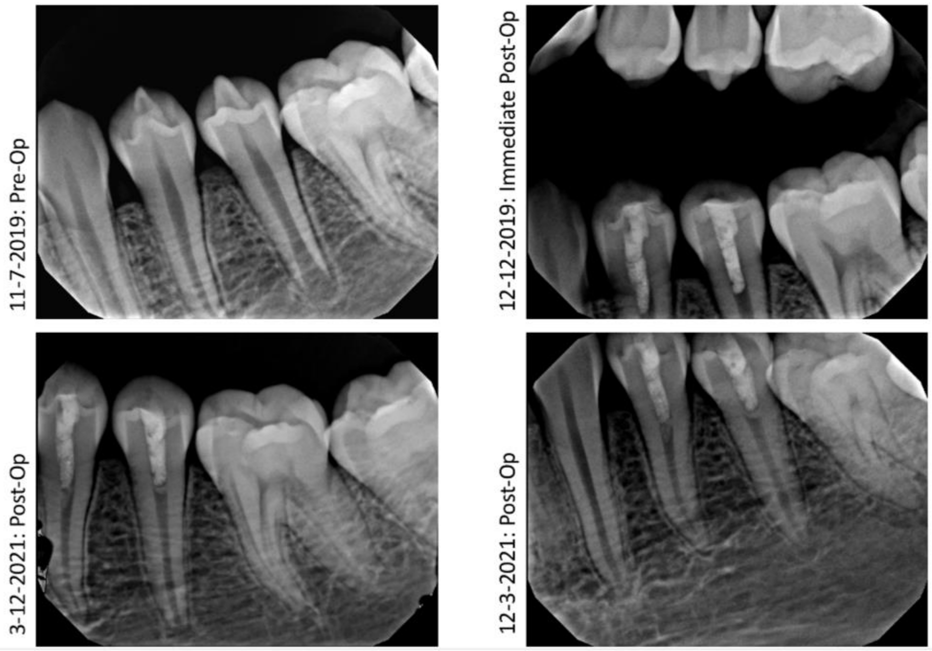
Appendix A: Cases used in this study

Vital Pulp Therapy Case Portfolio

Case #:	Patient ID	Gender	Age	Etiology	Tooth Type	Arch	Pulpal Status	Periapical Status	Tooth #	Procedure	Material	Date of Procedure	Date of Follow-Up	Follow-Up Length
1	VPT007	F	9	Caries	Molar	Mand	SIP	Normal	19	IPC	Biodentine	2.7.2017	9.14.2021	55 Months
2	VPT008	F	11	Dens Evag	Premolar	Mand	SIP	Normal	20	Pulpotomy	NeoMTA	12.12.2019	12.3.2021	24 Months
3	VPT009	F	11	Dens Evag	Premolar	Mand	SIP	Normal	21	Pulpotomy	NeoMTA	12.12.2019	12.3.2021	24 Months
4	VPT010	F	11	Dens Evag	Premolar	Mand	SIP	Normal	28	Pulpotomy	NeoMTA	12.12.2019	12.3.2021	24 Months
5	VPT017	F	14	Caries	Molar	Max	SIP	Normal	15	Pulpotomy	MTA	2.2.2021	10.19.2021	8 Months
6	VPT027	F	14	Caries	Molar	Mand	SIP	Normal	18	DPC	MTA	1.16.2019	2.7.2020	12 Months
7	VPT041	F	12	Caries	Molar	Mand	SIP	SAP	19	DPC	GMTA	3.27.2019	10.20.2020	19 Months
8	VPT044	M	16	Caries	Molar	Mand	SIP	Normal	19	IPC	NeoMTA	1.10.2020	2.8.2021	13 Months
9	VPT066	M	7	Trauma/Fracture	Anterior	Max	SIP	SAP	9	DPC	Biodentine	8.15.2019	3.24.2020	7 Months
10	VPT083	F	13	Caries	Molar	Max	SIP	Normal	2	Pulpotomy	BC Putty	5.24.2018	9.29.2021	40 Months
11	VPT117	F	10	Caries	Molar	Max	AIP	Normal	3	IPC	SDF	2.2.2018	2.2.2019	12 Months
12	VPT118	F	11	Caries	Molar	Mand	AIP	Normal	30	IPC	MTA	7.31.2019	8.23.2021	25 Months
13	VPT120	M	9	Caries	Molar	Mand	SIP	SAP	19	Pulpotomy	MTA	8.12.2015	11.11.2021	75 Months
14	VPT121	M	13	Caries	Molar	Mand	SIP	SAP	31	Cvek Pulp	MTA	11.1.2017	5.9.2018	6 Months
15	VPT123	M	8	Caries	Molar	Mand	SIP	SAP	19	Pulpotomy	GMTA	5.21.2018	6.19.2019	13 Months
16	VPT127	F	9	Caries	Molar	Mand	AIP	Normal	30	Cvek Pulp	Dycal	6.3.2019	6.15.2020	12 Months
17	VPT128	M	13	Caries	Molar	Max	SIP	SAP	14	IPC	Dycal	8.21.2017	8.30.2018	12 Months
18	VPT134	F	7	Trauma/Fracture	Anterior	Max	SIP	SAP	8	Cvek Pulp	BC RRM	6.29.2018	5.9.2019	11 Months
19	VPT137	M	12	Caries	Molar	Mand	AIP	Normal	31	DPC	Biodentine	5.1.2017	5.31.2017	Failure
20	VPT144	M	20	Trauma/Fracture	Anterior	Max	SIP	SAP	9	Pulpotomy	BC Putty	9.25.2017	9.7.2018	12 Months
21	VPT146	M	11	Caries	Molar	Mand	SIP	Normal	19	IPC	Dycal	12.8.2017	6.15.2018	6 Months
22	VPT148	M	14	Caries	Anterior	Max	AIP	Normal	6	DPC	MTA	12.16.2015	2.8.2018	26 Months
23	VPT153	F	13	Caries	Molar	Mand	AIP	Normal	18	DPC	Dycal	2.6.2017	3.26.2019	25 Months
24	VPT154	F	13	Caries	Molar	Mand	AIP	Normal	19	DPC	Dycal	2.6.2017	3.26.2019	25 Months
25	VPT155	F	13	Caries	Molar	Mand	AIP	Normal	31	Pulpotomy	MTA	2.23.2017	2.4.2019	24 Months
26	VPT158	F	9	Caries	Molar	Mand	AIP	Normal	19	Cvek Pulp	BC RRM	8.3.2016	11.8.2017	15 Months
27	VPT164	M	11	Caries	Molar	Mand	AIP	Normal	19	Pulpotomy	GMTA	8.29.2014	2.10.2015	6 Months
28	VPT170	M	9	Caries	Molar	Mand	SIP	SAP	19	Pulpotomy	GMTA	6.24.2015	10.10.2016	16 Months
29	VPT171	M	8	Trauma/Fracture	Anterior	Max	SIP	SAP	8	DPC	Dycal	12.15.2015	1.6.2017	13 Months
30	VPT174	M	7	Trauma/Fracture	Anterior	Max	Necrotic	CAA	8	Cvek Pulp	MTA	10.20.2014	4.15.2016	18 Months
31	VPT175	F	18	Caries	Molar	Mand	AIP	Normal	18	DPC	Theracal	4.22.2016	1.27.2017	9 Months
32	VPT178	F	16	Caries	Molar	Mand	SIP	Normal	18	Pulpotomy	WMTA	10.27.2015	5.22.2019	43 Months
33	VPT179	F	11	Caries	Premolar	Mand	SIP	Normal	20	Pulpotomy	MTA	2.20.2013	10.6.2015	32 Months
34	VPT181	F	15	Caries	Molar	Max	SIP	SAP	2	Pulpotomy	MTA	12.13.2013	10.3.2017	46 Months
35	VPT182	F	15	Caries	Molar	Max	SIP	SAP	15	Pulpotomy	MTA	1.6.2014	10.3.2017	45 Months
36	VPT183	M	18	Caries	Molar	Mand	AIP	Normal	31	Cvek Pulp	MTA	8.29.2011	1.4.2013	17 Months
37	VPT184	M	12	Caries	Molar	Max	SIP	Normal	14	DPC	GMTA	10.30.2012	4.23.2013	6 Months
38	VPT187	F	8	Caries	Molar	Mand	SIP	SAP	30	Pulpotomy	GMTA	9.10.2013	3.19.2014	6 Months
39	VPT188	F	9	Caries	Molar	Mand	SIP	SAP	30	Pulpotomy	GMTA	12.18.2013	10.1.2015	22 Months
40	VPT191	F	8	Caries	Molar	Mand	SIP	SAP	19	Pulpotomy	MTA	11.25.2013	4.5.2017	41 Months
41	VPT192	F	10	Caries	Molar	Mand	SIP	Normal	19	Pulpotomy	MTA	4.3.2014	8.12.2015	16 Months
42	VPT193	F	13	Caries	Molar	Max	SIP	SAP	2	Pulpotomy	MTA	9.3.2014	10.25.2016	25 Months
43	VPT195	F	11	Caries	Molar	Mand	SIP	SAP	30	Pulpotomy	MTA	10.8.2014	8.12.2019	58 Months
44	VPT197	M	7	Caries	Molar	Mand	SIP	Normal	19	Pulpotomy	MTA	11.6.2013	1.12.2018	50 Months
45	VPT198	F	13	Caries	Molar	Mand	AIP	Normal	30	Pulpotomy	MTA	1.22.2014	6.3.2015	17 Months
46	VPT200	F	8	Trauma/Fracture	Anterior	Max	SIP	Normal	8	Pulpotomy	WMTA	3.21.2014	5.26.2021	86 Months
47	VPT201	F	10	Caries	Molar	Max	AIP	Normal	14	Pulpotomy	MTA	6.5.2014	1.8.2016	19 Months
48	VPT202	F	8	Caries	Molar	Max	AIP	Normal	3	Pulpotomy	MTA	6.9.2014	2.24.2017	32 Months
49	VPT205	M	8	Caries	Molar	Mand	AIP	Normal	19	Pulpotomy	MTA	1.8.2010	2.4.2019	109 Months
50	VPT206	M	9	Caries	Molar	Max	AIP	SAP	14	Pulpotomy	MTA	10.2.2013	7.16.2014	9 Months
51	VPT207	F	6	Caries	Molar	Mand	SIP	SAP	19	Pulpotomy	MTA	10.30.2013	2.17.2016	19 Months
52	VPT208	M	8	Trauma/Fracture	Anterior	Max	SIP	Normal	9	Pulpotomy	WMTA	4.2.2014	11.18.2014	7 Months
53	VPT209	F	7	Trauma/Fracture	Anterior	Max	AIP	Normal	9	Pulpotomy	WMTA	12.22.2010	8.7.2013	32 Months

Appendix B: Evaluator Calibration

Patient ID#: VPT009 – **Tooth #21 Pulpotomy**



Evaluator Assessments

Case # & Tooth #:

1. VPT007 – Tooth #19:
   - PAI Score:
   - Root Status:
   - Final Assessment:
2. VPT008 – Tooth #20:
   - PAI Score:
   - Root Status:
   - Final Assessment:
3. VPT009 – Tooth #21:
   - PAI Score:
   - Root Status:
   - Final Assessment:
4. VPT010 – Tooth #28:
   - PAI Score:
   - Root Status:
   - Final Assessment:
5. VPT017 – Tooth #15:
   - PAI Score:
   - Root Status:
   - Final Assessment:

Assessment Key

PAI Score:
1 - Normal (no periapical bone loss evident)
2 - Small bony changes evident
3 - Bony changes with mineral loss, characteristic of AP
4 - AP with well-defined RL area
5 - Severe AP with radiating expansion of bony changes

Root Status:
1 - No continued root development
2 - Continued root development
3 - Complete root development/closure of apical foramen

Final Assessment:
1 - Healed
2 - Healing
3 - Not Healed

References

1 Sugars and dental caries. Available at: https://www.who.int/news-room/fact-sheets/detail/sugars-and-dental-caries. Accessed February 11, 2022, n.d.

2 Mathur Vijay Prakash, Dhillon Jatinder Kaur. Dental Caries: A Disease Which Needs Attention. Indian Journal of Pediatrics 2018;85(3):202–6. Doi: 10.1007/S12098-017-2381-6.

3 C Wells, C Dulong, S McCormack. Vital Pulp Therapy for Endodontic Treatment of Mature Teeth: A Review of Clinical Effectiveness, Cost-Effectiveness, and Guidelines [Internet]. Vital Pulp Therapy for Endodontic Treatment of Mature Teeth: A Review of Clinical Effectiveness, Cost-Effectiveness, and Guidelines 2019.

4 Cohenca Nestor, Paranjpe Avina, Berg Joel. Vital pulp therapy. Dental Clinics of North America 2013;57(1):59–73. Doi: 10.1016/J.CDEN.2012.09.004.

5 da Rosa W. L.O., Piva E., da Silva A. F. Disclosing the physiology of pulp tissue for vital pulp therapy. International Endodontic Journal 2018;51(8):829–46. Doi: 10.1111/IEJ.12906.

6 Ricucci Domenico, Siqueira José F., Li Yuanyuan, Tay Franklin R. Vital pulp therapy: histopathology and histobacteriology-based guidelines to treat teeth with deep caries and pulp exposure. Journal of Dentistry 2019;86:41–52. Doi: 10.1016/J.JDENT.2019.05.022.

7 AAE Position Statement on Vital Pulp Therapy. Journal of Endodontics 2021;47(9):1340–4. Doi: 10.1016/J.JOEN.2021.07.015.

8 Levin Linda G., Law Alan S., Holland G. R., Abbott Paul V., Roda Robert S. Identify and Define All Diagnostic Terms for Pulpal Health and Disease States. Journal of Endodontics 2009;35(12):1645–57. Doi: 10.1016/J.JOEN.2009.09.032.

9 Chen Eugene, Abbott Paul V. Dental pulp testing: a review. International Journal of Dentistry 2009;2009:1–12. Doi: 10.1155/2009/365785.

10 Witherspoon David E. Vital Pulp Therapy with New Materials: New Directions and Treatment Perspectives-Permanent Teeth. Journal of Endodontics 2008;34(7 SUPPL.). Doi: 10.1016/j.joen.2008.02.030.

11 Rechenberg D. K., Zehnder M. Call for a review of diagnostic nomenclature and terminology used in Endodontics. International Endodontic Journal 2020;53(10):1315–7. Doi: 10.1111/IEJ.13374.

12 Wolters W. J., Duncan H. F., Tomson P. L., et al. Minimally invasive endodontics: a new diagnostic system for assessing pulpitis and subsequent treatment needs. International Endodontic Journal 2017;50(9):825–9. Doi: 10.1111/IEJ.12793.

13 Gurcan A. T., Seymen F. Clinical and radiographic evaluation of indirect pulp capping with three different materials: a 2-year follow-up study. European Journal of Paediatric Dentistry 2019;20(2):105–10. Doi: 10.23804/EJPD.2019.20.02.04.

14 Ghoddusi Jamileh, Forghani Maryam, Parisay Iman. New approaches in vital pulp therapy in permanent teeth. Iranian Endodontic Journal 2013;9(1):15–22.

15 Torabinejad M., Parirokh M., Dummer P. M.H. Mineral trioxide aggregate and other bioactive endodontic cements: an updated overview – part II: other clinical applications and complications. International Endodontic Journal 2018;51(3):284–317. Doi: 10.1111/iej.12843.

16 Seale N. Sue, Glickman Gerald N. Contemporary Perspectives on Vital Pulp Therapy: Views From the Endodontists and Pediatric Dentists. Journal of Endodontics 2008;34(7 SUPPL.). Doi: 10.1016/j.joen.2008.02.034.

17 Parirokh M., Torabinejad M., Dummer P. M.H. Mineral trioxide aggregate and other bioactive endodontic cements: an updated overview - part I: vital pulp therapy. International Endodontic Journal 2018;51(2):177–205. Doi: 10.1111/IEJ.12841.

18 Camilleri Josette. Staining Potential of Neo MTA Plus, MTA Plus, and Biodentine Used for Pulpotomy Procedures. Journal of Endodontics 2015;41(7):1139–45. Doi: 10.1016/j.joen.2015.02.032.

19 Tran Xuan Vinh, Ngo Lan Thi Quynh, Boukpessi Tchilalo. Biodentine TM Full Pulpotomy in Mature Permanent Teeth with Irreversible Pulpitis and Apical Periodontitis. Healthcare (Basel, Switzerland) 2021;9(6). Doi: 10.3390/HEALTHCARE9060720.

20 Moinzadeh Amir T., Aznar Portoles Carlos, Schembri Wismayer Pierre, Camilleri Josette. Bioactivity potential of endo sequence BC RRM putty. Journal of Endodontics 2016;42(4):615–21. Doi: 10.1016/j.joen.2015.12.004.

21 Santos João Miguel, Marques Joana A., Diogo Patrícia, et al. Influence of Preoperative Pulp Inflammation in the Outcome of Full Pulpotomy Using a Dog Model. Journal of Endodontics 2021;47(9):1417–26. Doi: 10.1016/J.JOEN.2021.06.018.

22 Parirokh M., Torabinejad M., Dummer P. M.H. Mineral trioxide aggregate and other bioactive endodontic cements: an updated overview – part I: vital pulp therapy. International Endodontic Journal 2018;51(2):177–205. Doi: 10.1111/iej.12841.

23 Ward Jeff. Vital pulp therapy in cariously exposed permanent teeth and its limitations. Australian Endodontic Journal : The Journal of the Australian Society of Endodontology Inc 2002;28(1):29–37. Doi: 10.1111/J.1747-4477.2002.TB00364.X.

24 Tomson P. L., Lumley P. J., Smith A. J., Cooper P. R. Growth factor release from dentine matrix by pulp-capping agents promotes pulp tissue repair-associated events. International Endodontic Journal 2017;50(3):281–92. Doi: 10.1111/iej.12624.

25 Massler Maury, Pawlak Jack. The affected and infected pulp. Oral Surgery, Oral Medicine, and Oral Pathology 1977;43(6):929–47. Doi: 10.1016/0030-4220(77)90086-X.

26 Ørstavik Dag, Kerekes Kasmer, Eriksen Harald M. The periapical index: a scoring system for radiographic assessment of apical periodontitis. Endodontics & Dental Traumatology 1986;2(1):20–34. Doi: 10.1111/J.1600-9657.1986.TB00119.X.

27 Bukhari Sarah, Kohli Meetu R., Setzer Frank, Karabucak Bekir. Outcome of Revascularization Procedure: A Retrospective Case Series. Journal of Endodontics 2016;42(12):1752–9. Doi: 10.1016/j.joen.2016.06.021.

28 Cushley S., Duncan H. F., Lappin M. J., et al. Efficacy of direct pulp capping for management of cariously exposed pulps in permanent teeth: a systematic review and meta-analysis. International Endodontic Journal 2021;54(4):556–71. Doi: 10.1111/iej.13449.

29 Sabeti Mohammad, Huang Yujie, Chung Yoo Jung, Azarpazhooh Amir. Prognosis of Vital Pulp Therapy on Permanent Dentition: A Systematic Review and Meta-analysis of Randomized Controlled Trials. Journal of Endodontics 2021;47(11):1683–95. Doi: 10.1016/j.joen.2021.08.008.

30 Asgary Saeed, Eghbal Mohammad Jafar, Shahravan Arash, Saberi Eshaghali, Baghban Alireza Akbarzadeh, Parhizkar Ardavan. Outcomes of root canal therapy or full pulpotomy using two endodontic biomaterials in mature permanent teeth: a randomized controlled trial. Clinical Oral Investigations 2021. Doi: 10.1007/s00784-021-04310-y.

31 Ricucci Domenico, Loghin Simona, Siqueira José F. Correlation between clinical and histologic pulp diagnoses. Journal of Endodontics 2014;40(12):1932–9. Doi: 10.1016/j.joen.2014.08.010.

32 Keswani Deepa, Pandey Ramesh K., Ansari Afroz, Gupta Shalini. Comparative evaluation of platelet-rich fibrin and mineral trioxide aggregate as pulpotomy Agents in Permanent Teeth with Incomplete Root Development: A Randomized Controlled Trial. Journal of Endodontics 2014;40(5):599–605. Doi: 10.1016/j.joen.2014.01.009.

33 Ricucci Domenico, Siqueira José F., Li Yuanyuan, Tay Franklin R. Vital pulp therapy: histopathology and histobacteriology-based guidelines to treat teeth with deep caries and pulp exposure. Journal of Dentistry 2019;86:41–52. Doi: 10.1016/J.JDENT.2019.05.022.

34 Torabinejad Mahmoud, Parirokh Masoud. Mineral Trioxide Aggregate: A Comprehensive Literature Review-Part II: Leakage and Biocompatibility Investigations. Journal of Endodontics 2010;36(2):190–202. Doi: 10.1016/j.joen.2009.09.010.

35 Ruparel Nikita B., Teixeira Fabricio B., Ferraz Caio C.R., Diogenes Anibal. Direct effect of intracanal medicaments on survival of stem cells of the apical papilla. Journal of Endodontics 2012;38(10):1372–5. Doi: 10.1016/j.joen.2012.06.018.

36 Tronstad Leif, Barnett Frederic, Flax Michael. Solubility and biocompatibility of calcium hydroxide-containing root canal sealers. Dental Traumatology 1988;4(4):152–9. Doi: 10.1111/j.1600-9657.1988.tb00314.x.

37 Mente Johannes, Hufnagel Sarah, Leo Meltem, et al. Treatment outcome of mineral trioxide aggregate or calcium hydroxide direct pulp capping: Long-term results. Journal of Endodontics 2014;40(11):1746–51. Doi: 10.1016/j.joen.2014.07.019.

38 Lin Jia Cheng, Lu Jia Xuan, Zeng Qian, Zhao Wei, Li Wen Qing, Ling Jun Qi. Comparison of mineral trioxide aggregate and calcium hydroxide for apexification of immature permanent teeth: A systematic review and meta-analysis. Journal of the Formosan Medical Association 2016;115(7):523–30. Doi: 10.1016/j.jfma.2016.01.010.

Vita

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