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Fit to be Tied: Social Network Structures and Evaluation Apprehension

Andrew L. Nicholson

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A Retrospective Clinical Study to Evaluate Treatment Outcomes of Vital Pulp
Therapy with ProRoot® Mineral Trioxide Aggregate, Endosequence® Root Repair
Material, and Biodentine®

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Thesis Submitted to the
School of Dentistry of Robert C. Byrd Health Sciences Center
at West Virginia University
in partial fulfillment of the requirements
for the degree of

Masters of Science
in
Endodontics

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ABSTRACT

A Retrospective Clinical Study to Evaluate Treatment Outcomes of Vital Pulp Therapy with ProRoot® Mineral Trioxide Aggregate, Endosequence® Root Repair Material, and Biodentine®

Nathaniel Nicholson D.D.S.

The aim of this study was to evaluate success rates of vital pulp therapy cases completed exclusively by endodontic residents at West Virginia University School of Dentistry with 3 different bioactive calcium silicate cements. The materials used were ProRoot® Mineral Trioxide Aggregate (MTA) white, Endosequence® Root Repair Material (ERRM), and Biodentine®. Failures were also examined to observe trends toward failure associated with multiple factors.

All follow-up examinations included a clinical and radiographic evaluation, which included multiple examiners that read each radiograph. Associations between procedure failure rates and the factors of interest were examined through non-parametric tests due to the small number of failures relative to the overall sample size. Fisher's exact tests were used to investigate associations between failure rate and each categorical factor. Wilcoxon rank sum tests were employed to assess associations between procedure failure rates and the continuous factors of patient age and follow-up time.

A total of 130 cases were completed by endodontic residents. Fifty cases were successfully recalled, and 41 cases met the inclusion criteria after a retrospective chart review. All cases were completed between 2010 and 2013. The age of patients ranged from 7-58 years with an average age of 14.3 years. The follow-up time for successful cases ranged from 160 to 1000 days with an average of 730 days. Failure follow-up ranged from 7-38 days with an average of 24 days. The overall success rate of the 41 cases was 87.8%. Those patients receiving ERRM materials had over twice the odds of failure compared to those patients receiving ProRoot® MTA. (OR: 2.29 (0.32,16.51)). ERRM materials included both ERRM putty (8 patients) and ERRM syringeable (1 patient). Those patients with trauma-related procedures had over three times the odds of failure compared to those patients with caries/decay-related procedures. (OR: 3.22 (0.44, 23.65)). Also, one out of the four patients who received cotton and Triage® instead of immediate restoration were reported as failed cases. Nearly every patient with a failed procedure was older than the median age of patients that had a successful case. None of the factors examined were statistically significant.

Vital pulp therapy in this study had a success rate of 87.8% with an average of 730 days follow-up. While each of our conservative statistical tests did not indicate statistical significance, they are potentially clinically relevant. The factors of age, cases completed with ERRM, trauma vs. caries, and immediate restoration vs. temporizing should be examined in future studies.

Dedication

I would like to dedicate this master's thesis to my wife, Kayleigh, and my parents, Les and JoAnn. They have stood behind me and encouraged me throughout these past 2 years. They have been very understanding of my time commitments to this degree. They have helped me whenever I asked without question. I would not have survived without their help.

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List of Symbols, Abbreviation, or Nomenclature

BMP – Bone Morphogenic Protein

ERRM – Endosequence® Root Repair Material, also known as bioceramics

IL – interleukin

IRM® - Intermediate Restorative Material

MTA – Mineral Trioxide Aggregate

NaOCl – sodium hypochlorite

SCAP – stem cells of the apical papilla

SoD = School of Dentistry

Super EBA™ – Super Ethoxy Benzoic Acid

TNF- α – Tumor Necrosis Factor-Alpha

WVU = West Virginia University

Chapter I: Introduction

Background

Vital pulp therapy involves a dental procedure that aims to maintain the vitality of the dental pulp with no concomitant inflammation. These procedures include pulp capping, pulpotomy, partial pulpotomy, and indirect pulp capping (which will not be included in this paper). The American Association of Endodontists' *Glossary of Endodontic Terms*¹ defines these as follows: "pulp cap - treatment of an exposed vital pulp by sealing the pulpal wound with a dental material such as calcium hydroxide or mineral trioxide aggregate to facilitate the formation of reparative dentin and maintenance of a vital pulp"; "pulpotomy (pulp amputation) - the removal of the coronal portion of a vital pulp as a means of preserving the vitality of the remaining radicular portion..."; "partial pulpotomy (shallow pulpotomy; Cvek pulpotomy) - the removal of a small portion of the vital coronal pulp as a means of preserving the remaining coronal and radicular pulp tissues."¹ The currently available treatment options for children with large carious lesion(s) approximating the pulp chamber with a pre-operative diagnosis of normal pulp or reversible pulpitis include pulp cap, partial pulpotomy, and pulpotomy, depending, on the amount of pulpal inflammation present at the time of the procedure.

The purpose of vital pulp therapy is to maintain the vitality of the dental pulp affected by caries, trauma, mechanical exposure, or developmental abnormalities. If the dental pulp maintains vitality in a tooth still developing, roots of the tooth will to continue to mature in

thickness and in length. If the dental pulp maintains its vitality in a tooth that already has fully developed roots, root canal therapy may be avoided in the future. Caplan² et al found that the prognosis for root canal filled teeth in terms of survival is significantly lower than non-root filled teeth.

There are many pulp capping materials available on the market today. This study focused on those used by the West Virginia University School of Dentistry, Department of Endodontics. A past endodontic resident at the school completed his master's thesis³ in 2012 using ProRoot® Mineral Trioxide Aggregate (MTA) exclusively for pulp caps that he performed during his residency. Subsequent residents used both Endosequence® Root Repair Material (ERRM) and Biodentine®, in addition to the continued use of MTA. There are currently no published studies with Biodentine® or ERRM with regards to follow-up from vital pulp therapy from caries or trauma.

MTA is manufactured under the name ProRoot® MTA (Figure 1) by a division of Dentsply International Inc. known as DENTSPLY Tulsa Dental Specialties. The manufacturer lists indications for its use as a retrofilling material for apicoectomy, for apexification, to repair root perforations and internal resorption, and for pulp caps (Dentsply Tulsa Dental Specialties 2010). MTA has been well studied since it first appeared in the literature, with two articles beginning in 1993.^{4,5}

Figure 1. Dentsply Tulsa Dental ProRoot® MTA

There have been several studies in the literature regarding the biocompatibility of MTA. Kettering⁶ et. al. used the Ames mutagenicity test and found MTA not mutagenic. Asrari⁷ et. al. used murine cerebral cortical cells and found that MTA (freshly mixed or set) was the only material found not to be neurotoxic in the group of materials tested. Masuda⁸ et. al. found microcirculation was restored in a study involving rabbit ear chambers 4 weeks after MTA was placed. Yasuda⁹ et. al. studied rat dental pulp cell cultures, and found MTA was not cytotoxic after 72 hours, and that it also stimulated dental pulp cells, significantly increasing mineralization. He also found that MTA increased bone morphogenic protein-2 (BMP-2), as contrasted to Dycal®, which decreased BMP-2 production and increased cell death.

In a meta-analysis, MTA was called the “ideal material” and was found more biocompatible than amalgam, IRM®, and Super EBA™. ¹⁰

Figure 2. Brassler Endosequence® Root Repair Material (syringeable)

Figure 3. Brassler Endosequence® Root Repair Material (putty)

ERRM is manufactured by Brassler Inc. and marketed as Endosequence® Root Repair Material (ERRM) in both putty (Figure 2) and syringeable (Figure 3) forms. The manufacturer claims it can be used for repair of root perforations and resorption, root end filling during apical surgery, apexification, and pulp capping.¹¹

Multiple studies have shown similar cytotoxicity of ERRM when compared to MTA.¹²⁻¹⁴ Ciasca¹³ et al found that ERRM putty and MTA had minimal levels of cytotoxicity. They also found that the expression of IL-1 β , IL-6, and IL-8 was detected in all samples studied, with minimal TNF- α expression in-vitro. Alanezi¹² et al found no significant difference in cell viability

with grey MTA, white MTA, and ERRM, in-vitro. Dalmás¹⁴ et al found no significant difference in cell viability of ProRoot® MTA, MTA-Angelus®, and ERRM. However, there was a statistically significant difference negatively associated with viability of human fibroblasts with ERRM, in-vitro.

Figure 4. Septodont Biodentine®

Biodentine® (Figure 4) is marketed by Septodont as, “The first all-in-one bioactive and biocompatible dentin substitute to use wherever dentin is damaged,” and “Dentin in a capsule.”¹⁵ Septodont states that Biodentine® can be used in the crown or in the root of a tooth. For use in the crown of a tooth, the manufacturer claims it can be used as a base under composite resins or inlays and onlays, as a temporary restoration, used in a “sandwich technique” when restoring deep and/or large carious lesions, for treatment of cervical decay, for pulp capping, and for pulpotomy procedures. For use in the roots of the teeth, it is claimed

that it can be used for repair of perforations, internal or external resorption, apexification, and for retrofills for apicoectomy procedures.¹⁶

An in-vitro study by Zhou¹⁷ et. al. found human gingival fibroblasts had a similar reaction to MTA and Biodentine®. Through the use of flow cytometry, both materials were found to be less cytotoxic than glass ionomer.

A human study recently published by Nowicka¹⁸ et. al. compared the differences between the dental pulp responses between MTA and Biodentine®. The study involved mechanical exposure of maxillary and mandibular third molar teeth in patients ranging from 19-28 years with these teeth being pre-planned for extraction for orthodontic considerations. Pulp were mechanically exposed and capped with either one of the two materials. At 6 weeks, all teeth were observed to have vital pulps when examined histologically. This study showed no significant difference between the two materials (histologically), and both materials were well tolerated by the pulp.

Zanini¹⁹ et. al. used immortalized murine pulp (OD-21), which were cultured with and without Biodentine®. This study found Biodentine® induced cell differentiation into odontoblast-like cells, while also stimulating biomineralization.

Shayegan²⁰ et. al. studied histological pulp response in primary pig teeth after pulpotomy with Biodentine®, white MTA, or formocresol. The authors observed responses of pulp capping with Biodentine®, white MTA, or calcium hydroxide. Using 180 teeth, which were

sectioned at 7, 28, and 90 days after the procedure, they found more hard tissue formation and less pulpal inflammation in Biodentine® and white MTA when compared to formocresol for pulpotomy procedures. They also found Biodentine® samples to be forming more hard tissue after 7 days compared to calcium hydroxide for pulp capping. They concluded that both white MTA and Biodentine® were biocompatible for these procedures (pulp cap and pulpotomy).

Once calcium silicate cement material has been placed over an exposed pulp, research has demonstrated a dentinal bridge forming between material and pulp tissue.^{18,21} Histological studies²¹ have shown pulps covered with traditional calcium hydroxide form a dentinal bridge that often has tunnel defects that can allow ingress of bacteria into the pulp, causing continued pulpal inflammation. Studies with MTA and Biodentine®¹⁸ have shown an absence of these tunnel defects and a continuous formation of dentin-like bridges. This finding has been seen in both animal and human studies.^{18,21}

Statement of the Problem

The aim of this study was to evaluate vital pulp therapy cases completed exclusively by endodontic residents at West Virginia University School of Dentistry, using 3 different bioactive calcium silicate cements. The materials used were ProRoot® Mineral Trioxide Aggregate (MTA), Endosequence® Root Repair Material (ERRM), and Biodentine®. Failures were also examined to observe trends associated with multiple factors. Also, the amount of pulp space calcification was examined radiographically at follow-up.

Significance of the Study

There are currently no studies in the literature that evaluate success rates of vital pulp therapy procedures completed exclusively by endodontic residents. Also, there are no studies evaluating success and failure comparing ERRM to Biodentine® when used to treat carious or traumatic exposures of the pulp. An endodontic department is in the unique position of treating referral patients from a wide patient population coming from a state wide and varied pool of participants.

Without adequate follow-up examinations, treatment outcomes cannot be evaluated. The only adequate method to determine success or failure is with sequential examination, including radiographic comparison.

Questions to be Answered

- 1) What, if any, difference can be determined about the success of vital pulp therapy using MTA, ERRM, or Biodentine®?
- 2) Are there any specific factors associated with failure of vital pulp therapy?
- 3) Are success rates with endodontic residents performing vital pulp therapy similar to other studies in the literature?
- 4) What amount of pulp space calcification is observed radiographically following vital pulp therapy?

Assumptions

- 1) Vital pulp therapy is gaining wide acceptance.
- 2) Newer calcium silicate cements that can be used for vital pulp therapy are increasingly becoming available.
- 3) Vital pulp therapy has a relatively high success rate as determined by past studies.
- 4) A dentin like-bridge is formed after application of calcium silicate cements to pulp exposures.
- 5) Removal of only inflamed pulp tissue leaving healthy uninflamed pulp tissues will lead to success.
- 6) Calcium silicate cements are bioactive.
- 7) Hemostasis was obtained in each case completed.

Limitations

- 1) Patient compliance with follow-up appointments is poor.
- 2) There were only a small number of cases that met the inclusion criteria (n=41).
- 3) Procedures were not randomized.
- 4) There were a similar number of cases completed using each calcium silicate cement.
- 5) Subjective operator notes were relied upon for retrospective chart review.
- 6) Pre-operative diagnosis with children is frequently difficult.
- 7) Assuming apex and/or apices of roots of teeth are closed by appearance on periapical radiograph, which is not definitive for the buccal-lingual dimension.
- 8) Not all cases were restored immediately after vital pulp therapy procedure.

- 9) No standardization of radiographic interpretation.
- 10) Pulp testing can be subjective, especially on children.

Delimitations

- 1) A clinical and radiographic follow-up exam was completed.
- 2) Hemostasis was obtained with a sterile cotton pellet moistened with NaOCl 2.5 – 3.0%
- 3) Rubber dam isolation was used on all cases.

Chapter 2: Review of Literature

A randomized clinical trial, the largest to date with respect to pulp capping, was conducted by Hilton²² et. al for the Northwest Practice-based Research Collaborative in Evidence-based Dentistry (NWP). MTA and calcium hydroxide were randomly selected for use in 35 practices. MTA was used exclusively in 19 of the practices while calcium hydroxide was used in 16 of the practices. Three hundred seventy-six pulp caps were completed; only one pulp cap per patient was included in the study. Age of subjects ranged from 8-90 years with the average age being 18 years. Recalls ranged from 0.2 – 33.5 months for MTA, and 0.2 to 30.9 months for calcium hydroxide. No pre-operative pulp testing was completed, and observation of bleeding from the site of pulpal exposure determined vitality. The investigators excluded patients with a history of signs of irreversible pulpitis. After exposure of the pulp, each operator rinsed the area with water, followed by application of a 5.25% sodium hypochlorite soaked pellet for several minutes, until hemostasis was achieved. The operators used a 1 step protocol approximately 90% of the time, a rubber dam was in place prior to exposure about 19% of the time, and approximately 89% of the time, the exposure was carious in nature. One brand of pulp capping material was randomly assigned to each participating office in the study. Regardless of material, after pulp caps were placed, a thin layer of Vitrebond™ was flowed over the capping material. The tooth was then restored with composite, amalgam, or some other permanent or temporary restorative material. On recall, each site conducted a clinical exam that included pulp vitality testing and periapical radiograph. If the patient couldn't make the recall, a phone interview was completed. The probability of failure for MTA was determined to

be 19.7%, while calcium hydroxide was found to be 31.5% at the 24 month period, and with the results being found to be statistically significant.

Barnkgel²³ et. al. completed a study in Syria, where 11 MTA pulpotomies were performed in permanent teeth after carious pulp exposure. Recalls ranged from 24 to 42 months with age ranging at the time of treatment from 27 to 54 years. Pre-operative diagnosis was listed as reversible pulpitis and normal apical tissues. Rubber dam isolation was used for all cases. The authors reported that their normal protocol in treating mature symptomatic teeth with deep carious lesions was indirect pulp cap, but if during the procedure an exposure occurred, root canal therapy was then initiated. Ten of the patients in the treatment period of the study agreed to pulpotomy treatment. After exposure of the pulp, the operators removed the coronal pulp tissue and used a sterile cotton pellet for 5 minutes to obtain hemostasis. The operators utilized a 2-visit protocol, where the pulp was covered with 2 to 3 mm of MTA at the time of exposure. A wet cotton pellet was placed over the MTA and the tooth was temporized with Litark® (Lascod, Italy). At the second visit, two days later, the temporary restoration was removed along with the cotton pellet and the tooth was permanently restored with polycarboxylate cement and amalgam. Two of the teeth were treated with full coverage crowns. On recalls, the investigators conducted a clinical examination, which included vitality testing in the form of electric pulp test, and a radiographic examination performed at 1, 3, 6 months, and then every 6 months after that. Recalls ranged from 24-42 months with a mean of 30.5 months. All 11 cases were successful.

An observational study was conducted by Bogen²⁴ et. al., with 53 pulp caps completed in permanent teeth. Of that number, 48 were available for recall. The observational period ranged between 1 to 9 years, with an age range at the time of treatment being from 7 to 45 years. Pre-operative diagnosis was normal pulp or reversible pulpitis. Rubber dam isolation was used for all cases. A 2-visit protocol was used and subject teeth were temporized with unbonded composite resin (Clearfil Photocure®) at the first visit after placement of MTA. Either irrigation or a saturated cotton pellet of 5.25% to 6.0% sodium hypochlorite was used on the pulp exposure site for both hemostasis and disinfection. Solution was applied for 5 to 10 minutes prior to pulp capping. Approximately 1.5 to 3 mm thickness of MTA was placed over exposure sites. On recall, interviews were conducted with patients, cold tests were performed, and radiographic examinations were completed. In this particular study, it was concluded that 97.96% of the teeth pulp capped had a favorable outcome.

In a randomized clinical trial by El Meligy²⁵ and Avery, 15 patients received both MTA pulpotomy and calcium hydroxide pulpotomy on contralateral permanent teeth. The investigators were able to recall all 15 patients at 3, 6, and 12 month intervals. The age of the patients ranged from 6-12 years, all teeth had incomplete root formation, and pulp exposures were the result of caries or trauma. Pulpal diagnosis for all teeth was normal pulp and rubber dam isolation was employed for all cases. For MTA cases, a 2-visit protocol was utilized, where, following MTA placement, a wet cotton pellet was placed covering the site, and the tooth was then temporized with IRM®. One week later, temporary restorations were removed along with all cotton and each tooth was then restored with either resin in the anterior or amalgam in the

posterior. For calcium hydroxide cases, a 1-visit protocol was used, where a paste was made by mixing saline and calcium hydroxide powder USP. This mixture was directly placed over pulp stumps and then covered with zinc oxide eugenol. Each tooth was similarly restored with either resin in the anterior or amalgam in the posterior. Hemostasis was obtained with cotton pellet soaked in saline. At recall visits, two blinded examiners as to which tooth received which treatment performed a clinical exam and obtained appropriate radiographs. MTA success rate was noted to be 100% and calcium hydroxide success rate was recorded at 87%, but there was no significant difference found between the 2 materials. This study also noted calcific metamorphosis seen in 4 MTA cases and 2 calcium hydroxide cases.

In a retrospective study by Miles²⁶ et. al., 75 MTA pulp caps in permanent teeth were completed, and all 51 patients in the study returned for recall. Pulp caps were performed by students at The University of the Pacific School of Dentistry under the supervision of either restorative or endodontic faculty, all of whom had been previously calibrated with regards to the same selection criteria and technique. Recalls ranged from 12-27 months, with the age range at the time of treatment being 21-85 years. As per the protocol, pre-operative diagnosis was required to be “normal pulp”, but some students failed to follow the specific guidelines for tooth selection. Pre-operative pulp testing does not appear to be completed in those cases. Rubber dam isolation was not mentioned in the paper, but is assumed since this study took place at an accredited dental school. The authors reported using 2.5% sodium hypochlorite cotton pellets on sites of the exposure, but also stated that some operators used cotton pellets wet with sterile saline. A 1-visit protocol was employed where MTA was mixed with local

anesthetic solution (Lidocaine 2% 1:100,000 with epinephrine) and placed in a thin layer over the exposure site. The MTA was then covered with Vitrebond™ after which the subject teeth were restored with amalgam, composite or glass ionomer. On recall, the investigators completed interviews with patients and conducted percussion testing, cold and/or electric pulp testing, and radiographic examination. The one year survival was rate was noted to be 67% and the two year survival rate was 56%. Of particular note, the authors admitted there was considerable variation in technique.

In a case series outcome assessment by Witherspoon,²⁷ Small, and Harris, the three authors completed a total of 23 cases. Pulpotomies were performed after carious or traumatic pulpal exposures on permanent teeth, with 19 of the patients available for recall. Recalls ranged from 6 to 53 months, with an age range at the time of treatment of 7 to 16 years. Rubber dam isolation was utilized for all cases. Unlike other studies found in the literature on this topic, a unique finding of this investigation was that the pre-operative diagnosis was listed as irreversible pulpitis. The operators used 6% sodium hypochlorite as an irrigant and irrigated with 2 mL of the agent for 1 minute over the pulp exposure sites instead of using sodium hypochlorite saturated cotton pellets. A 2-visit protocol was used, where in at the first visit, approximately a 2 mm thickness of MTA was placed directly against the pulp and a temporary restoration was placed. Next, the patients were referred back to their treating dentist for definitive restoration. On recalls, interviews with patients were conducted, percussion and cold tests were done, and radiographs were obtained. Results were categorized at follow-ups as healed (15 out of 19), healing (3 out 19), or persistent disease (1 out 19).

A prospective clinical study was conducted by Barrieshi-Nusair²⁸ and Qudeimat. One of the authors completed 31 cases using partial pulpotomies after carious pulp exposures on first permanent molars, with 28 presenting for recall. Recalls ranged from 12 to 26 months, with an age range at the time of treatment of 7.2 to 13.1 years. Pre-operative diagnosis was listed as reversible pulpitis and normal apical tissues. All teeth were isolated prior to start of each procedure, but the authors did not state specifically or not whether rubber dam isolation was used. After exposure of the pulp, the operator surgically removed 2 to 4 mm of pulp tissue and flushed each pulp exposure site with sterile saline until hemostasis was obtained. The operator used a 1-visit protocol, where the pulp was covered with 2 to 4 mm of MTA followed by a layer of Vitrebond™, followed by a layer of light cured glass ionomer, with each tooth finally restored with either amalgam or glass ionomer buildup with stainless steel crown. On recall, clinical examination was performed and included vitality testing and a radiographic evaluation. Twenty-two teeth appeared normal clinically and radiographically, but 6 teeth did not respond to vitality testing. Those 6 appeared normal on radiograph and clinical symptoms were absent.

A randomized clinical trial was conducted by Qudeimat²⁹, Barrieshi-Nusair, and Owais, where MTA and calcium hydroxide were randomly selected for use in 64 partial pulpotomies after carious pulp exposures on first permanent molars. Fifty-one cases were available for recall. Recalls ranged from 25.4 to 45.6 months, an age range at the time of treatment of 6.8 to 13.3 years. Pre-operative diagnosis was inferred to be either normal pulp or reversible pulpitis as described in the selection criteria of the study, but not irreversible pulpitis. After exposure of the pulp, the operator removed 2 to 4 mm of pulp tissue and flushed the exposure site with

sterile saline until hemostasis was achieved. The operators used a 1-visit protocol, where pulp exposure sites were randomly selected to be covered with either a layer of MTA (32 cases) or a layer of non-setting calcium hydroxide (Hypocal), followed by a layer of setting calcium hydroxide (Dycal®) (32 cases). A layer of Vitrebond™ was then applied, followed by a layer of light cured glass ionomer, and finally a restoration of either amalgam or a glass ionomer buildup and stainless steel crown. On recall, clinical examination was conducted, which included sensitivity testing and a radiographic examination. The authors listed a 91% success rate for calcium hydroxide and a 93% success rate for MTA, with no significant difference observed between the 2 groups. Of particular note, the discussion section of this study noted that rubber dam isolation was used for 55% of the cases, and that all cases that failed were isolated with cotton rolls and a saliva ejector.

A retrospective, case controlled study by Mente³⁰ et. al., studied MTA and calcium hydroxide for 167 pulp caps after carious exposures on permanent teeth. Procedures were performed by supervised dental students and experienced dentists, with 122 cases being recalled. Recalls ranged from 12 to 80 months, with an age range at the time of treatment of 8-78 years. Clinical signs and symptoms were recorded prior to treatment, but a definitive clinical pre-operative diagnosis may not have been made prior to treatment. All teeth were treated with rubber dam isolation for the entire procedure. Each operator used a 1-visit protocol in the majority of cases, but 3 teeth were temporarily restored with IRM® at the time of treatment and subsequently restored with resin as soon as possible thereafter. After exposure of the pulp, a cotton pellet soaked in 0.12% chlorhexidine solution was placed until hemostasis was

achieved. Since this was a retrospective study, randomization of pulp capping materials was not recorded. Each pulp exposure was covered with “small portions” of MTA (ProRoot® MTA) or non-setting calcium hydroxide (Hypocal SN), followed by a layer of glass ionomer (Vitrebond™). Finally, each tooth was restored with composite resin. On recall, symptoms were noted and a complete clinical exam was performed, including cold and percussion testing, and radiographic examination. Results indicated that 86 cases were successful but 36 cases were noted as failures. In the MTA group, 54 (78%) cases were successful with 15 (22%) cases noted as failures. In the calcium hydroxide group, 32 (60%) cases were successful, with 21 (40%) cases seen as failures. These results were statistically significant.

A clinical assessment by Farsi³¹ et. al., studied the use of MTA for 30 pulp caps after carious exposures on permanent molar teeth. Recalls ranged from 6 to 24 months, with an age range at the time of treatment of 9-12 years. Clinical signs and symptoms were recorded prior to treatment. Pre-operative diagnosis was listed as reversible pulpitis, and all teeth responded normally to percussion and palpation evaluation. All teeth were isolated with rubber dam isolation prior to start of procedure. The operator used a 2-visit protocol in all cases, and teeth were temporized with a wet cotton pellet and IRM® at the time of treatment. All teeth were restored with resin after 2 weeks for intermediary screening for symptoms of irreversible pulpitis. Upon exposure of the pulp, a cotton pellet soaked in saline was used to obtain hemostasis at the exposure site. A requirement of the study was that hemorrhage be achieved in 5-10 minutes. Each pulp exposure was then covered with MTA (ProRoot® MTA). On recall, the investigators completed a clinical exam which included cold and percussion testing, along

with digital palpation and a radiographic examination. At 6 month recall, 4 cases out of 30 were observed to have slight sensitivity to cold testing, but none reported sensitivity to percussion or palpation. Radiographic follow-up yielded no periapical findings of significance. At the 12 month follow-up, 2 cases had lingering pain to cold that required root canal therapy, and these subjects were removed from the study. At 18 and 24 month recalls, the remaining 28 cases tested normally to clinical tests and were seen to have undergone root development. This study reported a 93.3% (28 out of 30) success rate after 24 months.

Table 1. MTA Vital Pulp Therapy studies in the Literature

Author	# of cases	Age Range (years)	Treatment	Pulp Exposure	Pre-op Pulp Diagnosis	Hemostasis method	# of visits	Recall Range (months)	Success (%) (MTA only)
Hilton ²²	195	8-90	Direct Pulp Cap	Caries/ non-caries	Normal or Reversible	Sodium hypochlorite 5.25% cotton pellet	1 – 90% of time	0.2 – 33.5	19.7*
Farsi ³¹	30	9-12	Direct Pulp Cap	Caries	Reversible	Saline cotton pellet	2	6-24	93.3
Mente ³⁰	6993	8-78	Direct Pulp Cap	Caries	Not always recorded	Chlorhexidine cotton pellet	1	12-80	78
Bogen ²⁴	48	7-45	Direct Pulp Cap	Caries	Normal or Reversible	Sodium hypochlorite 5.25-6% flush or soaked cotton pellets	2	12-108	97.96
Miles ²⁶	51	12-27	Direct Pulp Cap	Caries	Normal or unknown	Sodium hypochlorite 2.5% pellets or sterile saline pellets	1	21-85	1y: 67** 2y: 56**
Qudeimat ²⁹	32	6.8-13.3	Partial Pulpotomy	Caries	Normal or reversible	Sterile Saline flush	1	25.4 - 45.6	93
Barrieshi-Nusair ²⁸	28	7.2-13.1	Partial Pulpotomy	Caries	Normal or Reversible	Sterile Saline flush	1	12-26	100***
Witherspoon ²⁷	19	7-16	Pulpotomy	Caries / Trauma	Symptomatic Irreversible Pulpitis	Sodium Hypochlorite 6% flush	2	6-53	94.7
Barngkgei ²³	11	27-54	Pulpotomy	Caries	Reversible	Cotton Pellet	2	24-42	100
El Meligy ²⁵	15	6-12	Pulpotomy	Caries/ Trauma	Normal	Saline cotton pellet	2	12	100

*: probability of failure (not success %)

**: 1 and 2 year survival rate

***: six cases in age range of 7.2 to 9.3 years didn't respond to cold, but asymptomatic, no percussion or palpation sensitivity, and appeared normal radiographically

Chapter III: Test of the Investigation

Sample Description

The Institutional Review Board (IRB) at West Virginia University granted an exemption for this protocol after the application process. The IRB protocol tracking number is 1401170812A001; see p. 73 of this document for a copy of the approval letter.

Patients in the study were from multiple sources, including from private general practices, private pediatric dental practices, the Urgent Care Department of West Virginia University (WVU) School of Dentistry (SoD), the Restorative Departments at WVU SoD, and Pediatric Dentistry Department at WVU SoD.

A total of 130 cases of vital pulp therapy were completed between the dates of 8/1/2010 to 9/20/2013 at West Virginia University SoD in the Department of Endodontics by a number of the endodontic residents. Fifty patients were recalled at least one time, but of those, only 41 cases met the inclusion criteria. Ages ranged from 7-58 years with an average age of 14.3 years and median age of 14.5 years. There were 17 males and 24 females.

Research Design

Inclusion criteria:

Carious lesion exposing pulp on excavation of decay or trauma resulting in exposure or mechanical Exposure

Permanent teeth only

Pre-operative pulpal diagnosis of Normal pulp, Reversible Pulpitis, or Symptomatic irreversible pulpitis

Periapical diagnosis of Normal Apical Tissues or Symptomatic Apical Periodontitis

No sinus tract(s)

No swelling

Pulp Cap(s), Partial Pulpotomy, or Complete Pulpotomy

MTA, Endosequence Root Repair Material in putty or flowable forms, or Biodentine® must be capping or pulpotomy material

Previous Restoration in tooth or No previous restoration

Previous pulp exposures or no previous pulp exposure

Sodium Hypochlorite pellet used for hemostasis

Any age included

Able to obtain hemostasis during procedure

Intrapulpal injection or no intrapulpal injection for local anesthesia

Pre-operative radiograph consistent with absence of periapical pathology

Apex open or closed per radiograph

Clinical and Radiographic follow-up of atleast 5 months

Exclusion Criteria

Pulpal Diagnosis of Pulp Necrosis

Apical Diagnosis of Asymptomatic Apical Periodontitis, Chronic Apical Abscess, or Condensing Ostitis

Pre-operative radiolucency at any apex

Indirect Pulp Caps

Pulp Caps with calcium hydroxide

Unable to obtain hemostasis within 10 minutes

Clinical Protocols for Treatment

Pre-treatment Procedures:

Prior to a treatment, patient interview was conducted, both clinical and radiographic exams were performed, and all pertinent symptoms were recorded. Patient interview for symptoms included questions regarding spontaneous pain, including pain that kept the patient awake at night, hot or cold sensitivity, chewing sensitivity, or a past history of pain. The clinical exam consisted of percussion testing, digital palpation over apices of the roots, periodontal probing, and thermal testing with cotton pellets saturated in Endo Ice®. The radiographic examination focused on the apices of the tooth in question, and the tooth was included only if there was an absence of periapical pathology (Figures 5 and 6). Normal apices were defined as either apically developing roots or closed apices without thickening of the PDL space. A pre-operative pulpal diagnosis was made that was either normal pulp, reversible pulpitis, or irreversible pulpitis, with an apical diagnosis of either normal apical tissues or symptomatic

apical periodontitis. Options were reviewed with the parent(s) or guardian(s), and informed consent was obtained prior to the start of the procedure.

Figure 5. Radiographs of Teeth Not Meeting Inclusion Criteria.

These radiographs show a radiolucency at the apices of teeth #19 consistent with periapical pathology. These teeth received vital pulp therapy, but did not meet the inclusion criteria in this study.

Figure 6. Radiographs of Teeth Meeting Inclusion Criteria.

These radiographs show a radiolucency (left #19 and right #18) at the apices consistent with normal root formation. These teeth met the inclusion criteria for inclusion in this study.

Treatment Procedures:

Local anesthetic, with either Septocaine® 4% with 1:200,000 epinephrine or Lidocaine 2% with 1:100,000 epinephrine, was administered and profound anesthesia of the tooth

undergoing treatment was obtained prior to beginning any procedures. Some of the procedures were completed using supplemental nitrous oxide sedation or in the operating room under general anesthesia for patient management considerations. Rubber dam was applied and a rubber dam sealant, such as OpalDam® (Ultradent Products Inc.) or Cavit™ (3M™ ESPE™) was applied if the rubber dam was seen to be leaking saliva after placement (Figure 7). Each tooth was treated in the normal operative manner with initial removal of all decay accomplished using air driven high speed handpiece with sterile friction grip burs under water spray (water from the faucet in a bottle on the dental unit with an A-dec ICX® Water Tablets added). Additional decay was removed with round burs without water spray in slow speed handpiece, either electric or air driven, or by using spoon excavators prior to entering the pulp chamber. Every effort was made to remove all circumferential decay over the pulp that would lead to pulp exposure. Some operators used Snoop™ (Pulpdent® Corporation) caries detecting dye to aid in caries removal. Any size of pulpal exposure was included in the study.²⁶ Pulpal hemostasis was obtained with pressure from a sterile cotton pellet soaked with sodium hypochlorite ~3% (half concentration from Clorox® brand 6.15% bottle) (Figure 11). Hemostasis was obtained within 5 to 10 minutes (Figure 10), but if hemorrhage continued, additional pulp tissue was removed until complete hemostasis was obtained (Figures 12 and 13). In some cases, a complete pulpotomy was required to obtain the necessary level of hemostasis. If pulp hemostasis was not seen after 10 minutes during a pulpotomy procedure, root canal therapy was initiated and that tooth was not included in this study.²⁴ Using the air/water syringe, the preparation was then both rinsed and dried or air dried only.

Figure 7. A tooth isolated with rubber dam and Opal Dam® Rubber dam Sealant

Figure 8. A tooth isolated with Wedjets® Dental Dam Isolating Cord

Figure 9. Initial pulpal hemorrhage

Figure 10. Pulpal hemostasis obtained

Figure 11. Obtaining Hemostasis with a 2.5% Sodium Hypochlorite Cotton Pellet

Figure 12. Hemostasis Not Obtained After Removing Cotton Pellet

Figure 13. After Removing More Pulp Tissue, Hemostasis Obtained

One of the three investigational materials was chosen to cover the each pulp exposure. As previously noted, MTA, ERRM, and Biodentine® were the materials included in this study. When MTA was used, it was prepared by mixing with sterile water to the desired consistency and then delivered to and placed over exposure site (Figure 14). When ERRM was used in the syringeable form, it was syringed directly over the area. In putty form, it was placed over the exposure site and tamped down with a sterile instrument or a cotton pellet moistened with sterile water (Figure 14). When Biodentine® was used, 5 drops of liquid were placed into the prepared capsule as delivered from the manufacturer and then triturated for 30 seconds. The resulting mass was retrieved from the capsule and then placed over the exposure site with a hand instrument of the operator's choice (Figure 14). The thickness of the material, as with all materials covering the pulp, was typically anywhere from 1-3 mm in depth, depending on operator preference and size of preparation.

Figure 14. MTA, ERRM, and Biodentine® in Place
(MTA on left, ERRM in the middle, and Biodentine® on the right)

All pulp capping or pulpotomy materials were immediately covered with glass ionomer (3M Vitrebond™ or Fuji Triage®) and then restored with composite resin (Figure 15) (Dentsply Caulk TPH®3 Micro Matrix Restorative), amalgam (Kerr Tytin™), or glass ionomer (Fuji Triage®) with an appropriate matrix (Tofflemire matrix and band, Triodent™ sectional matrix, or Auto Matrix®) of operator's choice, if required. Occlusion was assessed on each tooth and was either lightened or the tooth was completely removed from occlusal contact. Post-operative instructions were given, along with emergency phone numbers, and the importance of follow-up was stressed to the patient and/or parents/guardians. All patients were dismissed in good condition.

Figure 15. Sequence from Pulp Cap to Restoration. Pulp exposure after hemostasis obtained (upper right), Biodentine® placed (upper left), Vitrebond™ placed over Biodentine® (lower left), and restoration with composite resin (lower right)

Three cases, where MTA was used, and one case, where ERRM in the putty form, were temporized with a cotton pellet moistened with sterile water and Fuji Triage® Glass Ionomer. One case, where Biodentine® was used, the pulp was not only capped but the tooth was also restored with the same material. If the tooth was temporized, patients were instructed to return to their general dentist for proper restoration as soon as possible, or were instructed to

return for restoration. In one case, the patient returned to the school for temporary removal and restoration.

Follow-up:

Follow-up appointments were made by mailing a recall card and/or letter to the specific address on file given when the patient was registered on the first day of treatment. If the initial letter was returned and a forwarding address was found on the envelope, the new address was used for a second attempt at contacting the patient. Multiple phone calls were attempted to the phone numbers on file.

The majority of patients were appointed for recall examination at the West Virginia University School of Dentistry, Department of Endodontics. Two follow-ups were completed at a private endodontic practice due to the fact the patients involved in the study lived or attended school close to that particular office. A clinical and radiographic examination was completed at follow-up visits. Clinical examination consisted of percussion and thermal sensitivity testing, palpation evaluation, periodontal probing, and mobility status. The radiographic examination (Figures 16 and 17) specifically focused on the apices of the treated teeth along with morphological changes seen in the pulp chambers. Radiographic appearance was compared to pre-operative film at the time of evaluation. Pulpal and periapical diagnoses were made at the time of follow-up. Parent and/or guardians were informed of findings, and recommendations for further treatment were made, if needed.

Figure 16. Radiographs Showing Continued Root Development Tooth #18 -
Follow-up 11 months (left is pre-operative film and right is follow-up film)

Figure 17. Radiographs Showing Continued Root Development Tooth #31-
Follow-up 18 months (left is pre-operative film and right is follow-up film)

Methodology/Data Collection

The WVU School of Dentistry's AxiUm Dental software was used to search for patients listed as having had a pulp cap or pulpotomy (partial or complete) procedure completed between the dates of 8/1/2010 to 9/20/2013. A search for the dental codes D3110, which per *Current Dental Terminology*³² is "pulp cap - direct" and D3120 "therapeutic pulpotomy" was

conducted utilizing this database. Codes D3351, D3352, and D3353 were also searched, due to the fact that they were sometimes erroneously used for recording pulp capping and pulpotomy procedures. Only endodontic residents with a graduated or graduating year of 2012, 2013, 2014, and 2015 were included as providers. Residents prior to these classes were not included. Some pulp caps were included for patients that were treated in the student clinic, but only when an endodontic resident completed the pulp cap for the student.

The treatment notes of each patient were examined individually by the author alone. The notes were either in paper chart form that had been scanned into the school database, or those on the AxiUm system beginning in late 2011. Notes were examined for clinical findings pre-operatively and at subsequent follow-up visits, along with treatment steps and procedures. All data were placed into a spreadsheet located on a secured server at the SoD. If a piece of the data was not listed in the chart, it was recorded as “NR” (not recorded) in the spreadsheet. If something was missing from the chart, the previous operator was contacted to discover the reason for omission.

Some charts did not include some of the factors examined in this study. A pre-operative pulpal diagnosis or list of symptoms was sometimes omitted, if a previous pulp exposure had occurred by the referring practitioner. If a list of symptoms was listed and/ or included spontaneous pain or being kept awake at night, the author assumed symptomatic irreversible pulpitis for the pre-operative pulpal diagnosis. If the notes did not include if there was a previous pulp exposure and there was a temporary restoration or permanent restoration

approximating the pulp horn per radiograph, the referral was called to see if had been recorded it in their notes as an occurrence.

All radiographs were examined by the author (an endodontic resident) and the Chairman of the Department of Endodontics at West Virginia University SoD. If there was disagreement in apical findings or whether the apex/apices appeared open radiographically, a consensus was made together.

Ten factors were studied. These factors were age, gender, tooth location, tooth type, apex development per radiograph, reason for exposure, prior restoration, prior pulp exposure, procedure used, material used over pulp, and temporary or permanent restorative material used. Tooth location was maxillary or mandibular tooth as noted. For apex development per radiograph, this finding was based on pre-operative assessment of the radiograph for either open or closed apex/apices. Pulp exposures were due to caries, trauma, or pre-eruptive intracoronary resorption. Prior restoration was either previous restoration in the tooth or no previous restorations in the tooth prior to vital pulp therapy. Procedures used included direct pulp cap, partial (Cvek) pulpotomy, or pulpotomy. Materials in direct contact with the pulp were either MTA, ERRM, or Biodentine® (these materials were never used in combination). In direct contact with the calcium silicate materials, a layer of glass ionomer was placed. Finally, permanent restorations placed were either composite resin or amalgam. In those cases that were completed in 2 steps, Fuji 2® (resin modified glass ionomer) or Triage® (glass ionomer) served until the second visit when they were replaced with composite or amalgam. In those

cases where a stainless steel orthodontic band had been cemented with Ketac™ Cem and closed with Triage® in the access portion, patients were scheduled with their regular provider for placement of permanent crown. Biodentine® was used to restore one tooth as a temporary restoration, with the intention of it being replaced with composite, but the patient returned for recall with it still in place. Multiple cases were closed with a wet cotton pellet covered with Triage® and referred back to their regular provider for definitive restoration. Once the patient was referred back to their dentist, it was out of control of this study. Time frame and placement of restoration is unknown.

The category of pre-operative pulpal diagnosis was not studied due to the fact that 13 cases lacked a recorded diagnosis in the chart or couldn't be assumed given the lack of a list of symptoms.

Statistical Analysis

Associations between procedural failure rate and the factors of interest were examined through non-parametric tests due to the small number of failed cases relative to the overall sample size. Fisher's exact tests were used to investigate associations between failure rate and each categorical factor. Wilcoxon rank sum tests were employed to assess associations between procedure failure rate and the continuous factors of patient age and follow-up time. All statistical analyses were performed in R 3.1.0.³³

Materials

Three calcium silicate cements that are claimed to be bioactive were used for vital pulp therapy, and included ProRoot® MTA (in white formulation), Endosequence Root Repair Material, and Biodentine®.

MTA's ingredients are listed by the manufacturer to be 75% Portland cement, 20% Bismuth Oxide, and 5% calcium sulfate dihydrate or gypsum. MTA is mixed with sterile water and takes approximately 4 hours to set, with a working time of approximately 5 minutes. Working time can be increased if the mixture is covered with moistened gauze to prevent water from evaporating.^{34,35}

ERRM ingredients are calcium silicates, zirconium oxide, tantalum oxide, calcium phosphate monobasic and filler agents. ERRM comes in 2 forms, syringeable or in a jar of material that is putty-like in consistency. ERRM is ready to use directly out of the package with no mixing required prior to placement. Set time is approximately 2 hours.^{11,36}

Biodentine® is composed of tricalcium silicate powder that is mixed at the time of the procedure with an aqueous calcium chloride solution containing other excipients. Once the 2 components are placed into a mixing capsule, the combination is triturated for 30 seconds.¹⁶ Biodentine® has an advantage over MTA and ERRM in that it has a quicker setting time of approximately 10-12 minutes.¹⁵

Results

There were 41 cases in total, with 5 failures. The success rate was determined to be 87.8%, with a resultant failure rate of 12.2%. The longest follow-up for successful cases ranged from 160 to 1000 days with an average of 730 days (2 years). The longest follow-up for failed cases ranged from 7 days to 38 days with an average of 24 days.

All 10 factors examined were not statistically significant at the 0.05 level (see Table 2). Nearly all patients with failed procedures were found to be older than the median age of patients with successful outcome, suggesting procedure failure might occur more frequently in older patients. Previous pulp exposure and previous filling prior to vital pulp therapy showed no significant difference.

This study had relatively low power due to the small number of procedural failures and overall sample size. All 10 factors were found to be statistically non-significant. A power analysis wasn't completed, but it can be assumed that 41 cases with 5 failures are an insufficient number of cases to find factors for failure. Several trends were observed that are potentially clinically relevant and should be further explored. Those patients receiving ERRM materials had over twice the odds of procedural failure compared to those patients receiving ProRoot® MTA. (OR: 2.29 (0.32,16.51)). ERRM materials included both ERRM putty (8 patients) and ERRM syringeable (1 patient). Those patients with trauma-related procedures had over three times the odds of procedural failure compared to those patients with caries/decay-related exposures. (OR: 3.22 (0.44, 23.65)). One out of the four patients who was treated with

cotton and Triage® instead of immediate restoration was reported as a failed procedure.

Nearly every patient with a failed procedure was older than the median age of patients that had a successful procedure, suggesting procedural failure might occur more frequently in older patients (Figure 18). While each of our conservative statistical tests did not indicate statistical significance at the 0.05 level, these findings may provide factors to consider for future research involving these dental procedures. For results categorized by factor with their respective p-value and odds ratio, see Table 2. For results pertaining to patient age, gender, pre-operative pulp diagnosis, reason for exposure, if trauma how many days until treated, procedure used, calcium silicate material used, restoration placed, longest follow-up, amount of pulp chamber calcification per periapical radiograph, and whether successful or not, see Table 3. See Table 5 (in appendix) for clinical data collected prior to statistical analysis.

Pulp space calcification was evaluated by radiographic analysis by visual evaluation comparing post-operative and follow-up radiographs. Pulp space calcification was considered to be more than just dentinal bridge formation adjacent to the calcium silicate cement. Significant decrease in pulp space size observed radiographically was recorded as slight, moderate, or severe calcification. Cases without any pulp space calcification were found to be 32 (78%), slight calcification, was 4 (9.8%), moderate calcification, 3 (7.3%), severe calcification, was 1(2.4%) case, and in 1 case (2.4%), no follow-up radiograph was available (received root canal therapy outside of school 1 week later). The 4 failed cases had either no pulp space calcification (3 cases) or unknown calcification. This was examined for statistical significance

with success and failure using a Fisher's exact test and the p-value was 0.316, which was not statistically significant. See Table 4.

Figure 18. Distribution of Successes by Age

Table 2. Results Categorized by Factors

	Success (n)	Failure (n)	Odds Ratio	P-Value
Gender				
1) Male	1) 15	1) 2	1.0697	1.0000
2) Female	2) 21	2) 3		
Tooth Location				
1) Maxillary	1) 22	1) 2	2.3571	0.6327
2) Mandibular	2) 14	2) 3		
Tooth Type				
1) Anterior	1) 7	1) 2	0.3621	0.2994
2) Posterior	2) 29	2) 3		
Apex Development per Radiograph				
1) Open	1) 19	1) 4	0.2794	0.3629
2) Closed	2) 17	2) 1		
Reason for Exposure				
1) Caries	1) 29	1) 3	3.2222	0.3474
2) Trauma	2) 6	2) 2		
Prior Restoration				
1) Yes	1) 12	1) 3	0.3431	0.3365
2) No	2) 24	2) 2		
Prior Pulp Exposure				
1) Yes	1) 30	1) 4	1.5000	1.0000
2) No	2) 5	2) 1		
Procedure Used				
1) Pulp Cap	1) 25	1) 4	1 vs 2) 1.2500 2 vs 3) NC 1 vs 3) NC	1.0000
2) Partial Pulpotomy	2) 5	2) 1		
3) Pulpotomy	3) 6	3) 0		
Biocompatible Material Used				
1) ProRoot® MTA	1) 24	1) 3	1 vs 2) 2.2857 2 vs 3) NC 1 vs 3) NC	0.3474
2) ERRM	2) 7	2) 2		
3) Biodentine®	3) 5	3) 0		
Restoration Material				
1) Amalgam	1) 4	1) 1	NC	0.6230
2) Composite	2) 25	2) 3		
3) Fuji 2®	3) 1	3) 0		
4) Triage®	4) 0	4) 1		
5) SSB & Triage®	5) 1	5) 0		
6) Biodentine®	6) 1	6) 0		
7) Cotton and Triage®	7) 3	7) 1		

P-values were determined by Fisher's exact test

NC = Not calculated (due to zero cell count)

Table 3. Results of Vital Pulp Therapy with Pre-operative Diagnosis (when recorded) and Factors Examined

Patient #	Age at Txt	Gender	Tooth #	Pre-op Pulp Dx	Reason for Pulp Exposure	Days after trauma tooth was treated	Procedure	Material	Restoration	Longest Follow-up time (days)	F.U X-ray Pulp Space calcification	Success / Failure
1	9	F	30	NR	CA	N/A	DPC	MTA	C&T	922	SL	S
2	11	F	30	NR	CA	N/A	DPC	MTA	AM	497	SL	S
3	12	F	30	SIRP	CA	N/A	DPC	MTA	R	1000	M	S
4	14	F	18	RP	CA	N/A	DPC	MTA	AM	474	N	S
5	16	F	31	RP	CA	N/A	DPC	MTA	R	16	N	F
6	15	M	18	RP	CA	N/A	DPC	MTA	AM	361	N	S
7	20	F	19	NR	CA	N/A	DPC	MTA	R	428	SL	S
8	9	F	3	NR	CA	N/A	DPC	MTA	R	833	SL	S
9	17	F	12	RP	CA	N/A	DPC	MTA	R	438	N	S
10	16	M	30	RP	CA	N/A	DPC	MTA	R	364	M	S
11	16	M	31	RP	CA	N/A	PY	MTA	R	936	N	S
12	25	F	9	NR	TR	1	PP	MTA	R	31	N	F
13	9	F	14	NR	CA	N/A	DPC	MTA	R	499	N	S
14	16	M	19	NR	CA	N/A	DPC	MTA	AM	278	N	S
15	9	F	8	NR	TR	0	PP	MTA	R	533	N	S
16	7	M	8	NR	TR	NR	PP	MTA	R	564	N	S
17	8	F	19	RP	CA	N/A	PP	MTA	R	305	SV	S
18	9	F	8	NR	TR	1	DPC	MTA	R	711	N	S
19	9	F	9	NR	TR	1	DPC	MTA	R	711	N	S
20	16	M	31	RP	CA	N/A	PY	MTA	C&T	744	N	S
21	7	F	19	RP	CA	N/A	DPC	MTA	R	814	N	S
22	16	M	18	RP	CA	N/A	DPC	MTA	AM	28	N	F
23	11	M	8	RP	TR	6	PP	ERRM-P	R	447	N	S
24	58	F	19	NR	CA	N/A	DPC	ERRM-P	F2	560	N	S
25	12	M	31	NP	PIR	N/A	PY	MTA	SSB	397	N	S
26	10	M	30	NP	CA	N/A	DPC	ERRM-P	R	396	N	S
27	19	F	9	RP	TR	2	DPC	ERRM-P	R	38	N	F
28	13	M	3	RP	CA	N/A	DPC	BD	R	236	N	S
29	9	F	9	RP	TR	2	PY	ERRM-S	R	238	N	S
30	11	M	14	RP	CA	N/A	DPC	ERRM-P	C&T	7	UK	F
31	9	M	3	RP	CA	N/A	DPC	BD	R	202	N	S
32	8	F	3	NP	CA	N/A	DPC	MTA	C&T	202	N	S
33	31	M	19	RP	CA	N/A	DPC	BD	T	274	N	S
34	10	F	18	NP	CA	N/A	PY	ERRM-P	R	337	N	S
35	16	F	18	SIRP	CA	N/A	DPC	BD	R	321	N	S
36	10	M	19	RP	CA	N/A	DPC	ERRM-P	R	221	N	S
37	16	F	9	NR	CA	N/A	DPC	ERRM-P	R	219	N	S
38	13	M	19	NP	CA	N/A	DPC	BD	BD	215	M	S
39	23	F	15	NP	CA	N/A	PP	MTA	R	204	N	S
40	8	F	19	SIRP	CA	N/A	PY	MTA	R	174	N	S
41	17	M	30	NP	CA	N/A	DPC	MTA	R	160	N	S

Table 3 Abbreviations:

Dx = diagnosis, Txt = treatment, F.U. = follow-up, M = male, F = female, NR = not recorded, SIRP = symptomatic irreversible pulpitis, RP = reversible pulpitis, NP = normal pulp, CA = caries, TR = trauma, PIR = pre-eruptive intracoronal resorption, Y = yes, N= no or none, DPC = direct pulp cap, PP = partial (Cvek) pulpotomy, P = pulpotomy, MTA = ProRoot® MTA white, ERRM-P =Endosequence Root Repair Material putty, ERRM-S = Endosequence Root Repair Material syringeable, BD = Biodentine®, R = composite resin, A = amalgam, F2 = Fuji 2® resin-modified glass ionomer, T = Triage®, SSB = stainless steel orthodontic band cemented with Ketac™ Cem and access filled with Triage®, BD = Biodentine® (whole restoration), C&T = cotton and Triage®, N/A=not applicable, SL = slight, M = moderate, SV = severe, UK = unknown, S = success, F = failure

Table 4. Pulp Space Calcification and Success or Failure

	Success	Failure
None	28	4
Slight	4	0
Moderate	3	0
Severe	1	0
Unknown	0	1

Discussion

Obtaining recalls was found to be a challenge for a number of reasons. There were over 20 incidents in which patients failed recall appointments. A total of 92 letters were mailed, and out of this number, 13 were returned as undeliverable as addressed. A total of 44 patients could not be reached by direct phone contact (left voicemail and never received reply, no answer, number disconnected, etc).

Some suspected reasons for failure to contact patients included those patients that were in collection, patient's relocation, phone numbers disconnected, and lack of perceived need for follow-up, especially when asymptomatic. Some suspected reasons for multiple

appointment failures / cancellations were severe inclement weather, poor dental IQ, unable to afford transportation, or different patient priorities.

The trend of additional variable failures with traumatic exposures to the pulp can possibly be explained by that this added another factor to the determination of the ultimate outcome of pulp survival. During any trauma, teeth may possibly be subjected to subluxation, intrusion or other movement, which could lead to a decreased success rate versus those pulps that were only cariously exposed. Vascular supply to the pulp may or may not have been disrupted during impact. Prognosis determination of traumatically injured tooth, even without pulp exposure, is a study topic all on its own.

Rubber dam was used on all cases in this study. Significantly, Qudeimat²⁹ et. al. found all cases of vital pulp therapy that had failed were isolated with cotton rolls only during treatment.

This study included 1 pulpotomy case, where during the treatment procedure, the patient experienced significant pain. Treatment was being performed on a lower first molar and an intrapulpal injection was administered to achieve direct pressure anesthesia. In one study by Teixeira³⁷ et. al., the investigators found no statistical difference in the success rate of calcium hydroxide pulpotomies where intrapulpal injections with lidocaine were administered, as compared to those cases that did not receive intrapulpal injections. That study is consistent with the findings in the current study.

Multiple studies have shown that sodium hypochlorite has no known detrimental effects to pulpal tissue when used for hemostasis or disinfection. Katoh³⁸ et. al. observed histologically that 6% NaOCl applied to pulpal tissue, when compared to non-treated controls, showed similar healing patterns. There were no signs of tissue necrosis, and it was also reported that the adjacent layer of pulp tissue was disinfected and pulp tissue bleeding was controlled. Akimoto³⁹ et. al. used 2.5% NaOCl for hemorrhage control in a study investigating the use of bonding agents placed against mechanical pulp exposures in primates. The investigators that found bridge formation and odontoblastoid cell formation were not inhibited. They also found it not toxic to pulp cells and that it did not inhibit pulpal healing. However, this particular study only sampled specimens up to 97 days. Hafez⁴⁰ et. al. used 3% NaOCl prior to bonding agent application to mechanical pulp exposures in primates, and histologically found no pulp necrosis up to 27 days later. The researchers concluded that in terms of toxicity and pulpal healing with relation to pulp tissue, sodium hypochlorite 3% did not affect these parameters. A recent study by Martin⁴¹ et. al. found that dentin treated with 0.5 %, 1.5% and 3% sodium hypochlorite demonstrated similar viability of stem cells of the apical papilla (SCAP). A 6% concentration had a larger decrease in SCAP viability. In this study, a concentration of 2.5 to 3% sodium hypochlorite was used, which is consistent with being favorable to stem cells.

In this study and after placement of the calcium silicate cement, 3M Vitrebond™ Glass Ionomer was placed over all unset material. Eid⁴² et. al. showed the placement of glass ionomer cement immediately after MTA placement had minimal effect on the MTA in terms of hardness.

Pulp chamber calcification, which in this study was considered more than dentinal bridge formation, occurred in 8 cases (20% of cases), was absent in 32 cases (78%), and in 1 case (2.4%) was unknown. Only one case out of 8 was considered severe. El Meligy²⁵ and Avery found calcific metamorphosis occurred in 4 cases (26%) of the teeth treated with MTA and in 2 cases (13%) of teeth treated with calcium hydroxide. Calcific metamorphosis is usually considered severe calcification, but El Meligy didn't define the amount of calcification that constituted calcific metamorphosis. He also mentioned that this is not an unforeseen finding, because these materials are already known to cause hard tissue formation. Similarly to the current study, calcific metamorphosis did not affect the success of treatment.

The earliest follow-up used in this study was 5 months. Matsuo⁴³ et. al. in a study of pulp capping with carious pulp exposures, found similar success rates at 3, 6, 9, 12, and 18 months follow-up periods, but found higher success rates at later follow-ups, in particular 21 and 24 months.

Multiple teeth treated with MTA in this study appeared gray in color on follow-up, but this was not observed in any teeth treated with ERRM or Biodentine®. A case report/clinical technique by Belobrov⁴⁴ et. al. showed a case of tooth #8 in a 12 year old female that had experienced a complicated crown fracture. The patient was subsequently treated with a Cvek pulpotomy where ProRoot® White MTA was utilized as the pulp capping material. At follow-ups, this tooth appeared grayish in color, despite the use of white MTA. The tooth reportedly tested normally to CO₂ and was asymptomatic at each follow-up. After 17 months, the operator

reentered the operative site and observed a dentin bridge had formed, then proceeded to remove the MTA and proceeded with internal bleaching. This technique was seen to be successful in removing the grayish color and returning the tooth to its normal shade. This same technique might be used on other cases of vital pulp therapy on anterior teeth which have been treated with white MTA. In the current study, there were multiple patients that, when recalled and whom had been treated with MTA, were observed to have this discoloration. One minor patient was offered Belobrov's technique to remove discoloration, but the parent declined. Cases with ERRM and Biodentine® were not observed to have discoloration at recall.

Follow-up exams found that several teeth had received crowns after the vital pulp therapy procedure had been completed. Upon observation of complete root formation and closure, further pulpal treatment is not warranted. Exceptions to this could include cases that need a post for retention of core build-up, those cases that become symptomatic, or those cases that display signs of pathology, either clinically or radiographically.

Dr. Hargraves⁴⁵ reports sending endodontic residents to patients' homes for follow-up radiographic examination utilizing a "Nomad", a handheld, portable radiograph system (personal communication). This device was used in conjunction with digital radiographic sensors to obtain radiographs outside of the clinical setting. A gift card valued at an amount that varied depending upon the length of the recall period was awarded to patients that agreed to participate in the examination.

Dr. Friedman,⁴⁶ who is associated with the Toronto Studies on outcomes from endodontic therapy, reported that patients are paid with \$100+ gift cards for participating in recall examinations.

In order to obtain an increase recall rate in future studies, investigators might look into similar creative ways of increasing the rate of recall examinations to better influence statistical analysis.

Chapter IV: Summary and Conclusions

Vital pulp therapy cases completed by endodontic residents at West Virginia University School of Dentistry had a success rate of 87.8% with an average follow-up of 2 years for successful cases. The failure rate was seen to be 12.2% with average follow-up of only 24 days. If a failure is to occur, it is likely to happen rapidly, usually within one month. While each of the conservative statistical tests did not indicate statistical significance, these tests are potentially clinically relevant and provide guidance for future studies. The factors of age, cases completed with ERRM, trauma vs. caries, and immediate restoration vs. temporizing should be examined. Future studies should strive for an increased follow-up rate to increase the power of the topic of study. It can be concluded that vital pulp therapy should be considered a viable treatment alternative to root canal therapy given proper diagnosis and proper procedural delivery.

Work Cited

1. American Association of Endodontists. *Glossary of endodontic terms*. 7th ed. Chicago, IL: ; 2012.
http://www.nxtbook.com/fx/save/dbindex.php?book_id= NXT fb7abda2dd226423b4ca8ed95b9f0192&sid=e1b24ac7ba71fe3117ebe79e1d1f293b&pdf=1. Accessed May 5, 2013.
2. Caplan DJ, Cai J, Yin G, White BA. Root canal filled versus non-root canal filled teeth: A retrospective comparison of survival times. *J Public Health Dent*. 2005;65(2):90-96.
3. Petley P. *A retrospective clinical study to evaluate mineral trioxide aggregate (MTA) as a direct pulp capping agent in a one-visit protocol*. Master's Thesis ed. Morgantown, WV: West Virginia University Libraries; 2012:34.
4. Lee SJ, Monsef M, Torabinejad M. Sealing ability of a mineral trioxide aggregate for repair of lateral root perforations. *J Endod*. 1993;19(11):541-544. doi: 10.1016/S0099-2399(06)81282-3.
5. Torabinejad M, Watson TF, Pitt Ford TR. Sealing ability of a mineral trioxide aggregate when used as a root end filling material. *J Endod*. 1993;19(12):591-595. doi: 10.1016/S0099-2399(06)80271-2.
6. Kettering JD, Torabinejad M. Investigation of mutagenicity of mineral trioxide aggregate and other commonly used root-end filling materials. *J Endod*. 1995;21(11):537-542. doi: S0099-2399(06)80980-5 [pii].
7. Asrari M, Lobner D. In vitro neurotoxic evaluation of root-end-filling materials. *J Endod*. 2003;29(11):743-746. doi: S0099-2399(05)60366-4 [pii].
8. Masuda YM, Wang X, Hossain M, et al. Evaluation of biocompatibility of mineral trioxide aggregate with an improved rabbit ear chamber. *J Oral Rehabil*. 2005;32(2):145-150. doi: JOR1397 [pii].
9. Yasuda Y, Ogawa M, Arakawa T, Kadowaki T, Saito T. The effect of mineral trioxide aggregate on the mineralization ability of rat dental pulp cells: An in vitro study. *J Endod*. 2008;34(9):1057-1060. doi: 10.1016/j.joen.2008.06.007 [doi].

10. Fernandez-Yanez Sanchez A, Leco-Berrocal MI, Martinez-Gonzalez JM. Metaanalysis of filler materials in periapical surgery. *Med Oral Patol Oral Cir Bucal*. 2008;13(3):E180-5.
11. Brassler USA. *Endosequence*® Root repair material [information for use]. Information for Use Web site. http://www.brasselerusa.com/brass/assets/file/B_3238A_RRM%20DFU.pdf. Published 2009. Updated 2009. Accessed May/5, 2013.
12. Alanezi AZ, Jiang J, Safavi KE, Spangberg LS, Zhu Q. Cytotoxicity evaluation of endosequence root repair material. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2010;109(3):e122-5. doi: 10.1016/j.tripleo.2009.11.028; 10.1016/j.tripleo.2009.11.028.
13. Ciasca M, Aminoshariae A, Jin G, Montagnese T, Mickel A. A comparison of the cytotoxicity and proinflammatory cytokine production of EndoSequence root repair material and ProRoot mineral trioxide aggregate in human osteoblast cell culture using reverse-transcriptase polymerase chain reaction. *J Endod*. 2012;38(4):486-489. doi: 10.1016/j.joen.2011.12.004; 10.1016/j.joen.2011.12.004.
14. Damas BA, Wheeler MA, Bringas JS, Hoen MM. Cytotoxicity comparison of mineral trioxide aggregates and EndoSequence bioceramic root repair materials. *J Endod*. 2011;37(3):372-375. doi: 10.1016/j.joen.2010.11.027; 10.1016/j.joen.2010.11.027.
15. Septodont. *Biodentine* [sell sheet]. http://www.septodontusa.com/sites/default/files/Biodentine_SellSheet.pdf. Updated 2013. Accessed May/5, 2013.
16. Septodont. *Biodentine* [package insert]. <http://www.septodontusa.com/sites/default/files/Biodentine%20IFU.pdf>. Updated 2012. Accessed May 5, 2013.
17. Zhou HM, Shen Y, Wang ZJ, et al. In vitro cytotoxicity evaluation of a novel root repair material. *J Endod*. 2013;39(4):478-483. doi: 10.1016/j.joen.2012.11.026; 10.1016/j.joen.2012.11.026.

18. Nowicka A, Lipski M, Parafiniuk M, et al. Response of human dental pulp capped with biodentine and mineral trioxide aggregate. *J Endod*. 2013;39(6):743-747. doi: 10.1016/j.joen.2013.01.005; 10.1016/j.joen.2013.01.005.
19. Zanini M, Sautier JM, Berdal A, Simon S. Biodentine induces immortalized murine pulp cell differentiation into odontoblast-like cells and stimulates biomineralization. *J Endod*. 2012;38(9):1220-1226. doi: 10.1016/j.joen.2012.04.018 [doi].
20. Shayegan A, Jurysta C, Atash R, Petein M, Abbeele AV. Biodentine used as a pulp-capping agent in primary pig teeth. *Pediatr Dent*. 2012;34(7):e202-8.
21. Asgary S, Eghbal MJ, Parirokh M, Ghanavati F, Rahimi H. A comparative study of histologic response to different pulp capping materials and a novel endodontic cement. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2008;106(4):609-614. doi: 10.1016/j.tripleo.2008.06.006 [doi].
22. Hilton TJ, Ferracane JL, Mancl L, Northwest Practice-based Research Collaborative in Evidence-based Dentistry (NWP). Comparison of CaOH with MTA for direct pulp capping: A PBRN randomized clinical trial. *J Dent Res*. 2013;92(7 Suppl):16S-22S. doi: 10.1177/0022034513484336 [doi].
23. Barnkgkei IH, Halboub ES, Alboni RS. Pulpotomy of symptomatic permanent teeth with carious exposure using mineral trioxide aggregate. *Iran Endod J*. 2013;8(2):65-68.
24. Bogen G, Kim JS, Bakland LK. Direct pulp capping with mineral trioxide aggregate: An observational study. *J Am Dent Assoc*. 2008;139(3):305-15; quiz 305-15.
25. El-Meligy OA, Avery DR. Comparison of mineral trioxide aggregate and calcium hydroxide as pulpotomy agents in young permanent teeth (apexogenesis). *Pediatr Dent*. 2006;28(5):399-404.

26. Miles JP, Gluskin AH, Chambers D, Peters OA. Pulp capping with mineral trioxide aggregate (MTA): A retrospective analysis of carious pulp exposures treated by undergraduate dental students. *Oper Dent*. 2010;35(1):20-28. doi: 10.2341/09-038CR1; 10.2341/09-038CR1.
27. Witherspoon DE, Small JC, Harris GZ. Mineral trioxide aggregate pulpotomies: A case series outcomes assessment. *J Am Dent Assoc*. 2006;137(5):610-618.
28. Barrieshi-Nusair KM, Qudeimat MA. A prospective clinical study of mineral trioxide aggregate for partial pulpotomy in cariously exposed permanent teeth. *J Endod*. 2006;32(8):731-735. doi: 10.1016/j.joen.2005.12.008.
29. Qudeimat MA, Barrieshi-Nusair KM, Owais AI. Calcium hydroxide vs mineral trioxide aggregates for partial pulpotomy of permanent molars with deep caries. *Eur Arch Paediatr Dent*. 2007;8(2):99-104.
30. Mente J, Geletneky B, Ohle M, et al. Mineral trioxide aggregate or calcium hydroxide direct pulp capping: An analysis of the clinical treatment outcome. *J Endod*. 2010;36(5):806-813. doi: 10.1016/j.joen.2010.02.024; 10.1016/j.joen.2010.02.024.
31. Farsi N, Alamoudi N, Balto K, Al Mushayt A. Clinical assessment of mineral trioxide aggregate (MTA) as direct pulp capping in young permanent teeth. *J Clin Pediatr Dent*. 2006;31(2):72-76.
32. American Dental Association. *CDT 2013*. ADA; 2013.
33. R Core Team (2014). R: A language and environment for statistical computing. r foundation for statistical computing, vienna, austria. URL <http://Www.R-project.org/>.
34. Dentsply International Tulsa Dental Specialties. *Proroot® MTA root canal repair material* [MSDS]. http://www.tulsadentalspecialties.com/Libraries/Tab_Content_-_Accessories/MSDS_Proroot_MTA_Gray_1-28-10.sflb.ashx. Updated 2010. Accessed May/2013, 2013.

35. Dentsply Tulsa Dental Specialties. *Proroot® MTA root canal repair material* [directions for use].
http://www.tulsadentalspecialties.com/Libraries/Tab_Content_-_Accessories/ProRoot_MTA_White_DFU_2010-06.sflb.ashx. Updated 2010. Accessed May/2013, 2013.
36. Brassler USA. *Endosequence® Root repair material* [MSDS].
http://www.brasslerusa.com/brass/assets/file/B_3238B_RRM%20MSDS.pdf. Updated 2009. Accessed May/5, 2013.
37. Teixeira LS, Demarco FF, Coppola MC, Bonow ML. Clinical and radiographic evaluation of pulpotomies performed under intrapulpal injection of anaesthetic solution. *Int Endod J*. 2001;34(6):440-446.
38. Katoh M, Kidokoro S, Kurosu K. A study on the amputation of pulp using sodium hypochlorite (NaOCl). *Jpn J Pediatric Dent*. 1978;16:107-116.
39. Akimoto N, Momoi Y, Kohno A, et al. Biocompatibility of clearfil liner bond 2 and clearfil AP-X system on nonexposed and exposed primate teeth. *Quintessence Int*. 1998;29(3):177-188.
40. Hafez AA, Cox CF, Tarim B, Otsuki M, Akimoto N. An in vivo evaluation of hemorrhage control using sodium hypochlorite and direct capping with a one- or two-component adhesive system in exposed nonhuman primate pulps. *Quintessence Int*. 2002;33(4):261-272.
41. Martin DE, De Almeida JF, Henry MA, et al. Concentration-dependent effect of sodium hypochlorite on stem cells of apical papilla survival and differentiation. *J Endod*. 2014;40(1):51-55. doi: 10.1016/j.joen.2013.07.026; 10.1016/j.joen.2013.07.026.
42. Eid AA, Komabayashi T, Watanabe E, Shiraishi T, Watanabe I. Characterization of the mineral trioxide aggregate-resin modified glass ionomer cement interface in different setting conditions. *J Endod*. 2012;38(8):1126-1129. doi: 10.1016/j.joen.2012.04.013 [doi].

43. Matsuo T, Nakanishi T, Shimizu H, Ebisu S. A clinical study of direct pulp capping applied to carious-exposed pulps. *J Endod*. 1996;22(10):551-556. doi: S0099-2399(96)80017-3 [pii].
44. Belobrov I, Parashos P. Treatment of tooth discoloration after the use of white mineral trioxide aggregate. *J Endod*. 2011;37(7):1017-1020. doi: 10.1016/j.joen.2011.04.003; 10.1016/j.joen.2011.04.003.
45. Hargraves K. Personal communication. . March 6, 2014.
46. Friedman S. Personal communication. . October 24, 2013.

Appendix

Case #25 (by Dr. Nicholson – Pre-eruptive Intracoronal Resorption)

Pre-op PA #31

Pre-op Bitewing #31

Pre-op Photo (note hole poked with explorer)

Initial Opening

Further Enamel Opening

Thin Walls

Pulp Exposure

Orthodontic Band Cemented after wall broke

Re-accessed through Ketac™ Cem

Pulpotomy and Hemostasis

ProRoot® MTA placed

Vitrebond™ Placed

Post-op #31

1 year 1 month follow-up (still in orthodontic band and Triage® from post-op)

1 year 1 month follow-up (note hole in Triage®)

1 year 6 months follow-up Tooth #31 (still in orthodontic band & film from current GP prior to crown placement)

Case #34 (by Dr. Nicholson)

Pre-op Radiograph #18

Pre-op Photo #18

Initial Hemorrhage

Hemostasis (4 pulp horns exposures)

Biodentine® Placed

Vitrebond™ Placed and Leaking Blood

Complete Pulpotomy with Hemostasis

ERRM Putty Placed

Vitrebond™ in Place

Resin Restoration Placed

Post-op #18

Follow-up (11 months) #18 - note continued root formation

Case #3 (by Dr. Petley)

Pre-op #30

Post-op #30

Follow-up 2 years 9 months Tooth #30 (longest follow-up of study)

Follow-up 2 years 9 months Photo #30

Case #18 & 19 (by Dr. Petley)

Pre-op #8 and 9

Post-op #8 and 9

Follow-up 2 years Teeth #8 and 9

Clinical Photos #8 and 9 showing gray color on Facial and Lingual surfaces respectively

Case #21 (by Dr. Petley)

Pre-op #19

Post-op #19

Follow-up #19 (2 years 3 months)

Follow-up BWX #19 (2 years 5 months)

Table 5. Data from Chart Review for Statistics

Case #	Age at Txt	Gender	Tooth #	Tooth Location	Tooth Type	Apex per x- ray	Reason for exposure	Prior Restoration	Prior Pulp Exposure	Procedure	Material	Restoration	Longest Follow-up time (days)	F.U X-ray Pulp calcification	Success / Failure
1	9	F	30	MD	PT	CL	CA	Y	N	DPC	MTA	C&T	922	SL	S
2	11	F	30	MD	PT	CL	CA	N	N	DPC	MTA	AM	497	SL	S
3	12	F	30	MD	PT	CL	CA	Y	N	DPC	MTA	R	1000	M	S
4	14	F	18	MD	PT	CL	CA	N	N	DPC	MTA	AM	474	N	S
5	16	F	31	MD	PT	CL	CA	N	N	DPC	MTA	R	16	N	F
6	15	M	18	MD	PT	OA	CA	N	N	DPC	MTA	AM	361	N	S
7	20	F	19	MD	PT	OA	CA	N	N	DPC	MTA	R	428	SL	S
8	9	F	3	MX	PT	OA	CA	Y	Y	DPC	MTA	R	833	SL	S
9	17	F	12	MX	PT	CL	CA	N	N	DPC	MTA	R	438	N	S
10	16	M	30	MD	PT	CL	CA	Y	Y	DPC	MTA	R	364	M	S
11	16	M	31	MD	PT	CL	CA	Y	N	PY	MTA	R	936	N	S
12	25	F	9	MX	AT	CL	TR	N	N	PP	MTA	R	31	N	F
13	9	F	14	MX	PT	OA	CA	Y	NR	DPC	MTA	R	499	N	S
14	16	M	19	MD	PT	CL	CA	N	N	DPC	MTA	AM	278	N	S
15	9	F	8	MX	AT	OA	TR	N	N	PP	MTA	R	533	N	S
16	7	M	8	MX	AT	OA	TR	N	N	PP	MTA	R	564	N	S
17	8	F	19	MD	PT	OA	CA	N	N	PP	MTA	R	305	SV	S
18	9	F	8	MX	AT	CL	TR	N	N	DPC	MTA	R	711	N	S
19	9	F	9	MX	AT	CL	TR	N	N	DPC	MTA	R	711	N	S
20	16	M	31	MD	PT	OA	CA	Y	Y	PY	MTA	C&T	744	N	S
21	7	F	19	MD	PT	OA	CA	N	N	DPC	MTA	R	814	N	S
22	16	M	18	MD	PT	CL	CA	Y	N	DPC	MTA	AM	28	N	F
23	11	M	8	MX	AT	CL	TR	N	N	PP	ERRM-P	R	447	N	S

24	58	F	19	MD	PT	CL	CA	Y	N	DPC	ERRM-P	F2	560	N	S
25	12	M	31	MD	PT	OA	PIR	N	N	PY	MTA	SSB	397	N	S
26	10	M	30	MD	PT	CL	CA	N	N	DPC	ERRM-P	R	396	N	S
27	19	F	9	MX	AT	CL	TR	Y	N	DPC	ERRM-P	R	38	N	F
28	13	M	3	MX	PT	OA	CA	N	N	DPC	BD	R	236	N	S
29	9	F	9	MX	AT	OA	TR	N	N	PY	ERRM-S	R	238	N	S
30	11	M	14	MX	PT	OA	CA	Y	Y	DPC	ERRM-P	C&T	7	UK	F
31	9	M	3	MX	PT	OA	CA	Y	N	DPC	BD	R	202	N	S
32	8	F	3	MX	PT	OA	CA	N	N	DPC	MTA	C&T	202	N	S
33	31	M	19	MD	PT	CL	CA	N	N	DPC	BD	T	274	N	S
34	10	F	18	MD	PT	OA	CA	N	N	PY	ERRM-P	R	337	N	S
35	16	F	18	MD	PT	CL	CA	N	N	DPC	BD	R	321	N	S
36	10	M	19	MD	PT	OA	CA	Y	Y	DPC	ERRM-P	R	221	N	S
37	16	F	9	MX	AT	CL	CA	N	N	DPC	ERRM-P	R	219	N	S
38	13	M	19	MD	PT	CL	CA	Y	N	DPC	BD	BD	215	M	S
39	23	F	15	MX	PT	CL	CA	Y	Y	PP	MTA	R	204	N	S
40	8	F	19	MD	PT	OA	CA	N	N	PY	MTA	R	174	N	S
41	17	M	30	MD	PT	CL	CA	N	N	DPC	MTA	R	160	N	S

Table 5 Abbreviations: Dx = Diagnosis, Txt = Treatment, F.U. = follow-up, M = male, F = female, MX = maxillary, MD = mandibular, AT = anterior, PT = posterior, CL = closed apex/apices, OP = open apex/apices, CA = caries, TR = trauma, PIR = pre-eruptive intracoronal resorption, Y = yes, N= no or none, DPC = direct pulp cap, PP = partial (Cvek) pulpotomy, P = pulpotomy, MTA = ProRoot® MTA white, ERRM-P =Endosequence Root Repair Material putty, ERRM-S = Endosequence Root Repair Material syringeable, BD = Biodentine®, R = composite resin, A = amalgam, F2 = Fuji 2 resin-modified glass ionomer, T = Triage®, SSB = stainless steel orthodontic band cemented with Ketac™ Cem and access filled with Triage®, BD = Biodentine® (whole restoration), C&T = cotton and Triage®, N/A=not applicable, SL = slight, M = moderate, SV = severe, UK = unknown, S = success, F = failure

Acknowledgement Letter Exempt Initial Protocol Review

To Michael Bagby
From WVU Office of Research Integrity and Compliance
Approval Period 04/24/2014 **Expiration Date** 02/26/2017
Subject **Acknowledgement Letter Exempt Initial Protocol Review**
Protocol Tracking 1401170812A001
Title A Retrospective Clinical Study to Evaluate Treatment Outcomes of Vital Pulp Therapy with ProRoot Mineral Trioxide Aggregate, Endosequence Root Repair Material, and Biodentine

The above-referenced study was reviewed by the West Virginia University Institutional Review Board IRB and was granted exemption in accordance with 45 CFR 46.101.

- The amendment wording is: Just needed to add 2 statisticians for data analysis before they can look at the data. Names: 1) John Honaker 2) Dorthy L. Long

Documents for use in this study have been acknowledged and validated and are available in the WVUkc system in the Notes and Attachments section of your protocol.

If you have any questions, please contact the IRB at 304 293 7073.

Thank you.

A handwritten signature in purple ink that reads 'Barbara A. White'.

Board Designee Barbara White

Letter Sent By Barbara White on 04/24/2014 at 13:54:03-04:00

Once you begin your human subject research, the following regulations apply:

1. Any modifications to the study protocol must be reviewed and acknowledged by the IRB prior to implementation.
2. You may not use a modified form until it has been acknowledged by the IRB.