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A Justification for the Trend Towards Indirect Pulp Therapy

Marissa Kuhnen
marissa.kuhnen@gmail.com

A Justification for the Trend Towards Indirect Pulp Therapy

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

By

Marissa Marie Kuhnen DMD
B.S., American University, 2004
D.M.D., Tufts School of Dental Medicine, 2009

Thesis Advisor: Patrice Wunsch, DDS, MS.
Director, Advanced Education in Pediatric Dentistry
Associate Professor, Department of Pediatric Dentistry

Virginia Commonwealth University
Richmond, Virginia
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Abstract

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Purpose: The purpose of this retrospective chart review was to determine how primary molars needing vital pulp therapy have been treated in the past four years at Virginia Commonwealth University (VCU) and to determine which treatments: indirect pulp therapy (IPT), formocresol pulpotomy, and ferric sulfate pulpotomy have been successful. **Methods**: AxiUm records that contained the procedure codes D3120 (Pulp Cap – Indirect) or D3220 (Therapeutic Pulpotomy) were totaled by year. Visit records were queried again to identify treatment failures i.e. extractions or pulpectomy. **Results**: In 2010, 52% of vital pulp therapies were ferric sulfate pulpotomies and in 2014 over 90% were indirect pulp therapy. Indirect pulp therapy had a 96.2% success rate, formocresol pulpotomy had a 65.8% success rate and ferric sulfate had a 62.9% success rate at three years (P<.0001). **Conclusions:** Indirect pulp therapy is a successful treatment option for the primary tooth with deep caries approaching the pulp.

Introduction

There are three techniques to vital pulp therapy that have been recently taught and utilized at VCU pediatric dentistry: 1) the formocresol pulpotomy 2) the ferric sulfate pulpotomy 3) indirect pulp therapy. With the advent of new research and a change in faculty, the hypothesis is that there has been a trend from the traditional formocresol pulpotomy, to the ferric sulfate pulpotomy, to now indirect pulp therapy. By examining the success and failure rates for each procedure, the VCU vital pulp therapy trend will either be justified or need modification.

The formocresol pulpotomy was developed in 1932 by Sweet and is still the most common treatment for teeth with caries approaching the pulp. The goal of the pulpotomy is to maintain the radicular pulp and remove the coronal pulp in an effort to maintain the tooth in the arch.[1] The current recommendation is to use a 1:5 dilution of Buckley's formocresol (19% formaldehyde).[2] By virtue of the formaldehyde and cresol moieties the solution has tissue fixative and antimicrobial properties that will fix and devitalize the irritated pulp.[3] The Buckley's full strength (19% formaldehyde, 35% cresol) is the formulation used at VCU. Formocresol studies show around a 92% short term (6-12 month) success and around a 70% long term (36-40 month) success.[4] Many residency programs (82%)[5] teach the formocresol pulpotomy and the majority of practitioners still use it.[6] At VCU it seems the formocresol pulpotomy was utilized more in the past, but currently more conservative therapies are favored.

The ferric sulfate pulpotomy was initially introduced to preserve the pulp by minimizing inflammation.[7] In contact with blood, a ferric ion protein complex is formed and the

membrane of this complex seals the cut blood vessels mechanically, producing hemostasis. It was thought that controlling pulpal hemorrhage with ferric sulfate may prevent the problems previously encountered by blood clot formation with calcium hydroxide.[7] Studies have shown varying degrees of clinical and radiographic success (74-100%),[1] and some studies report internal root resorption and calcific metamorphosis.[5] A 15.5 % ferric sulfate concentration is used at VCU.

The mineral trioxide aggregate (MTA) pulpotomy has a very high success rate (96-100%),[8] but due to the high cost of MTA, it is not used at VCU or many other residency programs for primary tooth pulpotomies.[5] In this study, the formocresol and ferric sulfate pulpotomies will be evaluated. Though chlorhexidine and Vitapex pulpotomies were completed, those treatments will not be included in the survival analysis.

Indirect pulp therapy has become the front runner in vital pulp therapy at VCU. It is a procedure performed in a tooth with a deep carious lesion approximating the pulp but without signs or symptoms of pulp degeneration. The caries on the lateral walls is removed while the caries closest to the pulp is left in an effort to avoid pulp exposure. It is then covered with a biocompatible material.[9] At VCU the biocompatible liner used is Vitrebond, a resin modified glass ionomer. Indirect pulp therapy usually shows success rates of 90% or greater no matter the technique, medicament, or follow up time period.[4] Indirect pulp therapy is becoming a more popular treatment option amongst practicing pediatric dentists, though the technique seems to be catching on at a slow pace.[5,6,10]

Regardless of the technique, there are several goals of vital pulp therapy: 1) to preserve space for the underlying permanent tooth, 2) to eradicate potential infection, or 3) to maintain the

primary tooth if no permanent successor exists.[1] The key to successful outcomes with any pulp therapy is accurate pulpal diagnosis. This can be particularly challenging with children, who are poor historians. Teeth diagnosed as having irreversible pulpitis may have: spontaneous throbbing, constant pain, advanced pulp degeneration, a percussion response, a radiolucency periapically or in the furcation, an abscess or fistula if the pulp is necrotic, internal or external root resorption, or mobility.[11] According to AAPD guidelines, treatment options for the non-vital primary tooth are: pulpectomy or extraction.[9] Teeth with irreversible pulpitis or a necrotic pulp were not considered in this study.

A history of provoked pain that is relieved by removal of the noxious stimuli is indicative of reversible pulpitis. These teeth are not painful to percussion and do not exhibit pathologic mobility or internal or external root resorption. Radiographs show decay close to the pulp and the absence of periapical or furcation radiolucencies. Teeth with reversible pulpitis have inflammation confined to the superficial layers of the coronal pulp and are good candidates for vital pulp therapies such as indirect pulp therapy and pulpotomies.[11] Only teeth with reversible pulpitis were examined in this study

The hypothesis is that VCU pediatric dentistry is doing less formocresol pulpotomies and more indirect pulp therapy. The study will determine whether that trend is justified or needs to be modified by examining success or failure rates of each of the three therapies. If the formocresol pulpotomy or ferric sulfate pulpotomy are more successful than hypothesized, then the curriculum will need to be adjusted. If indirect pulp therapy proves to be successful, then the trend is justified and perhaps more programs directors will use it clinically. (Dunston et al found

that only 30% of pediatric dentistry program directors recommended indirect pulp therapy when given the scenario of caries approaching the primary tooth pulp.) [6]

It is important that the most successful techniques are advocated in residency training. Practicing pediatric dentists utilize techniques learned in residency throughout their careers. If other treatment options prove to be more successful they should be taught and utilized.

Materials and Methods

The subjects for this study were identified in the following steps 1) screening and 2) eligibility.

The screening step was designed to all potential patients. An AxiUm (VCU's electronic dental record system) query with the following criteria was executed: date range = 2010 through 2014, treatment clinic = PEDO (6), and CDT procedure code = either D3120 (Pulp Cap – Indirect) or D3220 (Therapeutic Pulpotomy). This identified 3081 potential teeth. The second step excluded 503 patient records (983 teeth) who were not in the specified age range (age 2 to 14) or did not have treatment completed on primary molars (#A, B, I, J, K, L, S, T) resulting in 2,098 teeth. These 2,098 teeth were treated before June of 2014 and were included in analyses for the study. Procedures were completed either in the pediatric clinic under general anesthesia, oral sedation, nitrous oxide sedation with local anesthesia or in the operating room under general anesthesia. The treatment was performed by residents or VCU faculty.

To identify which material was used for the pulpotomies, a complete list of cases was given to the primary author, who went through the AxiUm database, inspected the treatment notes, and identified whether ferric sulfate or formocresol pulpotomies or "other" medicament was used. If there was a discrepancy in what was charged out versus what was in the clinical notes, that tooth was excluded from the study. If the clinical note did not specify what medicament was used, that tooth was also excluded from the study. Twenty six teeth were

excluded for the aforementioned reasons. There were 1555 indirect pulp therapies completed, 238 formocresol pulpotomies completed, 208 ferric sulfate pulptomies completed, and 71 “other” pulpotomy medicaments used. All procedures were tallied by year and recorded as a percentage.

A second AxiUm query used the patient chart number, treatment date, and tooth number to identify any subsequent treatment performed on that tooth and to identify the last patient visit to the VCU dental practices. Subsequent visit records were queried to identify any subsequent extractions of the tooth (CDT procedure code = D7140), or further nerve treatment: pulpectomy (CDT= D3221, or D3240). These were marked as a treatment failure. Treatment success/failures were tallied until June 14, 2014. A treatment success was indicated if there was no subsequent extraction or pulpectomy. The duration of a successful treatment was calculated by the number of days between the treatment and the last patient visit. The duration of an unsuccessful treatment was calculated by the number of days between the treatment and the extraction date, or additional treatment date.

A Kaplan-Meir survival analysis was used to compare if or when each treatment modality failed. Included in the survival analysis were ferric sulfate pulpotomies, formocresol pulpotomies, and indirect pulp therapy. “Other medicaments” were not included. In the survival analysis, treatment failures were uncensored and treatment successes were censored. Log rank test was used to determine if groups were significantly different. All analyses were performed using system analytical software (SAS) by the project biostatistician, Dr. Best.

The purpose of this retrospective study is to identify how reversible pulpitis in the primary posterior tooth has been treated over the past four years at VCU pediatric dentistry and to determine what treatment modalities (indirect pulp therapy, formocresol pulpotomy, or ferric

sulfate pulpotomy) have been successful. This project was approved under exempt status from the Virginia Commonwealth University Institutional Review Board (VCU IRB #: HM20000596).

Results

There are three major sections included in the results: A description of the patients and teeth, a description of the change in therapy from the ferric sulfate pulpotomy in 2010 to indirect pulp therapy in 2013-2014, and the success of the therapies (indirect pulp therapy, formocresol pulpotomy, and ferric sulfate pulpotomy) across time.

A total of 907 patients who were eligible for the study were treated between July 2010 and May 2014. Of the study population, 55% were male, 48% were African-American, and 6.7% were Caucasian (Table 1). There were a total of 2,072 teeth treated with vital pulp therapy, with approximately equal numbers of each of the eight primary molars: A, B, I, J, K, L, S, T. Tooth K was treated most often at 15.1%, with its antimere, tooth T at 14.2% (Table 2). Age range was 2-14 years of age with an average of age of 6.67 years (See Figure 1). Patients were from a low socioeconomic status and were considered high caries risk due to their young age and amount of dental caries. Patients were either treated in one of the VCU hospitals in the operating room under general anesthesia or in the pediatric clinic at VCU under general anesthesia, oral sedation, nitrous oxide sedation, or with no sedation and only local anesthesia. Treatment was completed by mostly faculty and pediatric dental residents, and less than 1% of procedures were completed by dental students.

Table 3 shows the number of patients that received vital pulp therapy treatment each year from July 2010 to May 2014 with a total of 907 patients. In 2013, 273 patients were treated with vital pulp therapy.

Table 4 shows which pulp therapy procedures have been completed in 2010, 2011, 2012, 2013, and 2014. The "other" column in Table 4 includes cases where chlorhexidine or Vitapex or a combination of ferric sulfate and chlorhexidine was used. In 2010, 52% of vital pulp therapy procedures were ferric sulfate pulpotomies, while 38% were indirect pulp therapy, and only 5% were formocresol pulptomies. In 2011, 54% of vital pulp therapy were indirect pulp therapies, while 28% were formocresol pulpotomies and 15% were ferric sulfate pulpotomies. In 2012, 83% of vital pulp procedures were indirect pulp therapies, while 14% were formocresol pulpotomies, and about 4% of teeth were either treated with ferric sulfate or another medicament. In 2013 and 2014 over 90% of teeth that needed vital pulp therapy received indirect pulp therapies. A total of 1555 indirect pulp therapy, 238 formocresol pulpotomies, and 208 ferric sulfate pulpotomy procedures have been completed and 71 "other" medicaments have been used. Included in the "other medicaments" were 4 Vitapex pulpotomies and 10 chlorhexidine pulpotomies. In 2010 the predominant treatment was therapeutic pulpotomy using ferric sulfate but by 2014, it was a rarity. This change was statistically significant (chi-square $P < .0001$). This trend is depicted graphically in Figure 2.

The primary aim of the study was to determine the success rate of the three main therapies: indirect pulp therapy, therapeutic pulpotomy using formocresol, and therapeutic pulpotomy using ferric sulfate. The 71 "other" treatments were excluded from the 2072 vital pulp therapy teeth for the survival analysis, therefore N=2001. In total, 6/1555 (0.38%) indirect pulp therapy failed, 9/238 (3.7%) formocresol pulpotomies failed, and 26/208 (12.5%) ferric

sulfate pulpotomies failed between May 2010 and June 2014. Not included in the analysis were 2/10 (20%) chlorhexidine pulpotomy failures and 0/4 Vitapex pulpotomy failures. Failure rates for indirect pulp therapy, formocresol pulpotomy, and ferric sulfate pulpotomy appear to be low and similar when time is not considered, however Kaplan-Meier survival analysis across time clearly showed that the three treatments did not have an equal success ($P < .0001$, Table 5 and Figure 3).

Table 5 shows that the 281 indirect pulp therapies still at risk after one year had only seen 3 prior failures, for a 99.3% success rate. This rate appeared similar to the 98.9% one year survival proportion for the 54 formocresol pulpotomies cases and this seemed higher than the 87.2% success rates of the 70 ferric sulfate pulpotomies. By 2 years, the success rate of the therapeutic pulpotomies (85.9 % for formocresol and 75.6 % ferric sulfate) was substantially lower than the 98.8% success rate of indirect pulp therapy. And, by 3 years, the 96.2% success rate for indirect pulp therapy was clearly higher than the 63–66% success rate for therapeutic pulpotomies.

Figure 4 shows that there was no significant difference in success rates between first and second molars for indirect pulp therapy or pulpotomy ($P > 0.6$, Figure 4). There were approximately an equal number of failures for first versus second primary molars.

Discussion

The purpose of this retrospective study is to identify how reversible pulpitis in the primary posterior tooth has been treated over the past four years at VCU pediatric dentistry and to determine what treatment modalities (indirect pulp therapy, formocresol pulpotomy, or ferric sulfate pulpotomy) have been successful. In 2010, 52% of vital pulp therapy procedures were ferric sulfate, while in 2014 only 2% of vital pulp procedures were ferric sulfate. In 2010, 38% of vital pulp therapy procedures were indirect pulp therapy while in 2014 about 91% of vital pulp therapies were indirect pulp therapy. The formocresol pulpotomy saw most use in 2011 with 28% of vital pulp therapies. In summary, four years ago, VCU was doing mostly ferric sulfate pulpotomies, and today over 90% of vital pulp therapy is indirect pulp therapy (See Table 4 and Figure 2).

Similar trends are demonstrated at other institutions. Dunston reported that in 2005, 83% of programs taught or used the indirect pulp therapy technique and Walker reported in 2013 that 18% of program directors completely eliminated formocresol from the curriculum.[5, 6] In 2009, Chaollai et al examined what was being taught in the United Kingdom and Ireland, it was found that 10/14 schools taught indirect pulp therapy and the most commonly used medicament was calcium hydroxide. All 14 schools taught the pulpotomy and the most popular medicament (13/14) was ferric sulfate, followed by formocresol (3/14). Interestingly, several schools reported

that they taught different techniques to undergraduate dental students versus residents.[12] The article did not specify which techniques were taught to which level.

Explanations for these trends can be mostly attributed to where and when faculty trained. Ferric sulfate was popular in the 1990's and 2000's as a safe alternative to the formocresol pulpotomy. During the 2000's, faculty members who received their training in pediatric dentistry at VCU preferred the ferric sulfate pulpotomy. In 2010, many ferric sulfate pulpotomies were completed. However, with emerging research especially studies with 2 to 3 year follow up, the ferric sulfate pulpotomy was found to cause internal resorption, pulp canal obliteration, and subsequent failures.[13] Many faculty went back to the formocresol pulpotomy in 2011. Also in 2011, a new faculty member joined the staff from the University of Maryland, where indirect pulp therapy was taught to be the preferred method for vital pulp therapy over the pulpotomy treatment. Dr. Coll, who has reported favorable outcomes with indirect pulp therapy, was one of her mentors. Therefore, in 2011, VCU was also doing many indirect pulp therapies. In 2011, 53% of vital pulp therapies were indirect pulp therapy, while 15% were ferric sulfate pulpotomies, and 28% were formocresol pulpotomies. After 2011, VCU was doing more indirect pulp therapy and less pulpotomy therapy. By 2014, 91% of vital pulp therapy was indirect pulp therapy (See Table 5 and Figure 2).

Although many of VCU's full time faculty prefers the indirect pulp therapy, many of the adjunct or part time faculty who also work in private practice, prefer the formocresol or ferric sulfate pulpotomy over indirect pulp therapy. Some of the part time faculty reported that they tried ferric sulfate in the past but due to failures ended up reverting back to formocresol. Additionally, part time faculty have stated that formocresol has worked relatively well for them; they do not see a need to change their technique. Another part time faculty member said he was

"not comfortable with indirect pulp therapy because he did not like leaving caries in the tooth". Traditionally, dentists are taught in dental school to remove decay, therefore many practitioners feel that leaving decay is a disservice to the patient. Other adjunct faculty have mentioned that they do not get reimbursed for the indirect pulp therapy, and therefore do not do them. Perhaps if insurance companies reimbursed for indirect pulp therapy, it would be utilized more often.

Formocresol use has been controversial over the past few decades, some regarding formaldehyde as a carcinogen causing leukemia and nasopharyngeal cancer.[14] While others argue that formaldehyde is ubiquitous in our daily lives and if the formocresol pulpotomy is done correctly with a squeezed cotton pellet, the estimated amount of formaldehyde is 0.02 to 0.1mg, a minimal amount compared to a child's natural daily exposure.[15] Zarazar suggests that doing one formocresol pulpotomy on a child does not exhibit statistically significant mutagenic activity but more research needs to be done in scenarios where several formocresol pulpotomies are completed on one individual.[16]

Seale found that 18% of pediatric dentists agree that formocresol being a carcinogen contraindicates its use, but 78% feel that it will eventually no longer be used not because of its danger to patients but due to the controversy surrounding its use. When asked "if cost were not an issue which is the recommended medicament for pulpotomy in the primary teeth", MTA was the overwhelming winner.[17] In a 2008 meta-analysis several articles reviewed show MTA's clinical and radiographic success ranges from 93% to 100%.[1] Unfortunately, due to MTA's current high cost many residency programs including VCU do not use MTA for the primary tooth pulpotomy.

Table 5 and Figure 3 show that indirect pulp therapy remains successful (96.2%) over a three year time span, whereas, ferric sulfate and formocresol therapies are successful initially, there success wanes after three years. Survival analysis indicates a 65.8% survival after three years with formocresol and 62.9 % survival with ferric sulfate after three years. This difference is clinically significant P<.0001. The results are similar to other studies. Vij et al showed a 94% success rate at 40 months for indirect pulp therapy using glass ionomer and a 70% success rate for formocresol pulpotomies.[18] Farooq et al showed 93 % success after 4.2 years using glass ionomer for indirect pulp therapy. While formocresol had a 74% success rate after 3.9 years.[19] Casas et al found that 33% of teeth treated using ferric sulfate pulpotomy should be extracted immediately at 3 year follow up.[13] This is similar to the 62.9% three year survival rate for ferric sulfate pulpotomies that was found in this study.

Landau and Johnsen (1988) used ferric sulfate, a hemostatic agent, to control pulpal hemorrhage before applying calcium hydroxide to pulptomized monkey teeth.[20] The authors thought that controlling pulpal hemorrhage with ferric sulfate may prevent the problems previously encountered by blood clot formation with calcium hydroxide.[7,21] In contact with blood, a ferric ion protein complex is formed and the membrane of this complex seals the cut blood vessels mechanically, producing hemostasis.[20] Early short term studies showed ferric sulfate pulpotomy success.[20] Fei et al reported 100% clinical success at 12 months. However, long term studies are less optimistic.[13] Casas reported a probability of survival for FS molars at 36 months was 0.62, which is similar to the three year results of this study.[13] Ferric sulfate failures were attributed to internal and external resorption and pulp canal obliteration.[13,22] Resorption is thought to be caused by an inflammatory response, the very cause ferric sulfate was meant to prevent.

Perhaps it is not the ferric sulfate that caused the failures but the base material placed afterwards. Garcia-Godoy have found that ZOE is irritating to the pulp.[20] IRM contains ZOE. In this study, the base material was not considered. However, in a formocresol pulpotomy, when the pulp tissue is fixed, the pulp would be unaffected by a base that was not inert, like ZOE, whereas in the ferric sulfate pulpotomy, the tissue is not fixed and the base is in direct contact with the pulp.[20] It would be worthwhile to investigate the type of base that was used in the instances of ferric sulfate pulpotomy failure.

Ranly suggests an increase in formocresol pulpotomy failure rates because the pulp is not given the chance to completely mummify in the one appointment formocresol pulpotomy. Historically, formocresol pulpotomies were completed in multiple visits so that the entire pulp was completely mummified. Multi-visit pulpotomies were very successful.[7] According to Ranly doing the formocresol pulpotomy in one visit leaves the pulp in a half vital, half necrotic and chronically inflamed state, which in turn makes the tooth prone to failure. Also not leaving the formocresol pellet in the tooth for the recommended 5 minutes [2, 23, 24] may also lead to treatment failure.

It is important to obtain hemostasis prior to application of the formocresol pellet. Practitioners may be tempted to rely on the formocresol or any other medicament for that matter, to obtain hemostasis. However, pulp tissue that is bleeding uncontrollably without medicament is probably irreversibly inflamed. Additional treatment, such as a pulpectomy or extraction, is likely indicated.[25]

Once the infected layer of carious dentin is removed, the affected layer is treated with a biocompatible material such as glass ionomer. It is thought that indirect pulp therapy with glass ionomer is successful because of the antimicrobial effect of fluoride on mutans streptococci. The

bacteria are deprived of nutrients[18] and thus the bacterial load decreases with a shift toward less cariogenic microflora. [26] Also glass ionomer has the effect of drying out of the moist soft leathery decay, [18] the pulp is sealed and able to recover. Calcium hydroxide is traditionally the material of choice in deep carious treatment because of its alkaline biocompatible properties and the induction of tertiary dentin. However, resin modified glass ionomer (RMGI) has been found to have comparable success rates to calcium hydroxide but unlike calcium hydroxide RMGI is better at preventing microleakage. [26]

Franzon and Marchi propose that re-hardening of dentin occurs independently of the use and type of capping material so long as there is an adequate seal. Mineral gain is the biological response of the pulp. [27,28] Furthermore, Opal and Massler agree that the pulp's reaction to dental caries is productive not degenerative and sclerosis of the underlying dentin and reparative dentin is the rule not the exception.[29] However, the capping material does provide an important seal so that the pulp can heal. The capping material creates an undesirable, nutrient poor, microenvironment for the trapped bacteria.[29,30] Opal proposes that the benefit of materials such as calcium hydroxide and glass ionomer is that the initial low pH setting has a superficial solubilizing effect on dentin immediately after placement. As a result bioactive molecules such as transforming growth factor could induce odontoblasts to produce intratubular and reactionary dentin in order to decrease dentin permeability and provide a barrier against invading bacteria.[29, 30]

In addition to having an adequate seal with a biocompatible material, case selection or proper diagnosis is also very important.[29, 31]Any vital pulp therapy can fail because of incorrect pulpal diagnosis. Waterhouse suggests that there may be an exception with the formocresol pulpotomy; with a 5 minute application of 20% dilution of Buckley's formocresol, even a non-

vital pulp has a good prognosis due to the devitalizing nature of formocresol[3] suggesting that diagnosis is not as important when using formocresol. In this study, 50% of the indirect pulp therapies that failed, did so within the first year (Table 5). Perhaps these teeth were instances of pulpal misdiagnosis or perhaps the diagnosis was unclear. Sometimes the pulpal diagnosis is not obvious, in which case Coll suggests a pretreatment glass ionomer temporary restoration for one to three months. Not only does the glass ionomer temporary restoration inhibit caries progression, it can also aid in pulpal diagnosis. Teeth pretreated with glass ionomer were more accurately diagnosed with correct pulpal diagnosis then when pretreatment temporary restorations were not completed. [31] The interim restoration allows time for the pulp to form a fistula or some obvious radiographic lesion indicating the pulp is irreversibly involved. [31] If the pulp is not irreversibly inflamed then the temporary restoration can be removed and vital pulp therapy can be initiated. The pretreatment temporary restorations also improved the success of vital pulp therapy procedures especially on teeth with proximal lesions.[31]

It is important to consider all diagnostic tools when determining pulpal status. Radiographs, symptoms, and clinical presentation ought to be reviewed.[9] However, even after careful review of diagnostic aids, the correlation between histologic findings and clinical symptoms is poor.[26,32] Gruythuysen contends that once dentin has been affected pulpal inflammation is inevitable. Subjacent to deep caries, the pulp has chronic inflammatory exudates (lymphocytes, macrophages, plasma cells) indicating that pulpitis has developed even in the absence of pain.[26] Fortunately, the young, vascular primary tooth withstands this inflammation and has the capacity to heal. Histologically inflamed teeth can survive for extended periods of time.[33] Perhaps, the inflamed coronal pulp should not necessarily be considered a forerunner to necrosis or irreversible inflammation, but a state of potential regeneration and repair.[26]

If marginal breakdown is present, Coll and Kassa suggest that pulp inflammation is usually extensive, and perhaps vital pulp therapy should not be considered.[31,34] Moreover, in Gopinath's study, primary second molars with more than 2/3 caries involvement and symptoms of pain, histologically showed inflammation of both coronal and radicular pulp tissues. Consequently, pulpectomies were treatment planned. [35]

In general, in the United States, indirect pulp therapy has been carried out in one step. One step is more cost effective, less time consuming, and could potentially be less traumatic to the patient especially if behavior is less than optimal. However, Scandinavian countries traditionally utilize a stepwise excavation approach, [36] where the caries is removed in two separate appointments placing RMGI or calcium hydroxide or both after the first appointment. Both techniques have their advantages, however, Orhan found that there was no significant difference between one and two visit indirect pulp therapy in terms of pulp exposure and success rate.[37] At VCU the one step approaching is typically taken, where the indirect pulp therapy and crown are placed in the same appointment. However, recently, for many of our patients who have to wait until an operating room is available, sedative fillings are temporarily placed. Typically, a glass ionomer or a RMGI is placed after minimally invasive caries excavation. Therefore, a modified version of the stepwise approach is utilized for our patients that are waiting to go to the operating room. As mentioned previously this pretreatment temporary can also be useful in pulpal diagnosis if the inflammatory status of the pulp is not clear.

In this study there was no difference in success rate for any pulp therapy procedure in primary first or second molars (See Figure 4). There were roughly equal number of failures in primary first and second molars. Another study found first primary molars treated with indirect pulp therapy were significantly more likely to fail than second primary molars.[38] Vij et al

showed that primary first molars had a combined indirect pulp therapy or formocresol success rate of 76%, which was lower than the indirect pulp therapy or formocresol success rate of 91% in the primary second molars.[18] There was no explanation provided in this article, however in another article by Coll it is suggested that primary first molars demonstrate more interproximal caries.[31] Teeth with deep interproximal caries, as opposed to deep occlusal caries, generally have more pulpal inflammation, and subsequently fail more often. Therefore, vital pulp therapy procedures completed on primary first molars are more likely to fail because they tend to have more proximal caries and pulpal inflammation.[31]

A major limitation to the study was that some of the patients who underwent treatment did not return for follow up, so it is not known whether treatments (indirect pulp therapy or pulpotomy) failed or survived. As time progressed, there was less data available because of patient compliance and therefore, the confidence interval is broad (0-100) (Table 5). Future studies should follow teeth that have had regular recall visits for long term follow up.

Another limitation was a large variation in caries depth for some of the teeth treated with indirect pulp therapies. Some teeth had decay approaching the pulp while other teeth had minimal decay. A tooth with minimal caries is going to have a high chance of remaining vital even without an indirect pulp therapy procedure. There is growing consensus that the residual dentin thickness (the depth of unaffected hard tissue between the base of the caries lesion and the pulp periphery) may be the most predictive measure of likely pulpal reactions. [29, 31, 34] In this study, proximal lesions were also not differentiated from occlusal lesions. It has been suggested that proximal lesions in conjunction with caries that extend beyond 50% of dentin thickness show severe inflammatory changes.[34] Opal contends that 0.25-0.50mm of sound dentin provides a safeguard for a speedy recovery of the dental pulp to health.[29] Cavities placed closer to the pulp

appear to injure underlying odontoblasts, reducing their number and capacity to form reactionary dentin.[29] A subsequent study is underway that will exclude teeth that had indirect pulp therapy with only minimal cares i.e. caries that is only 1/3 into dentin or less.

In this study only teeth that were extracted or had a pulpectomy were counted as a failure. However, there were teeth that came out prematurely that were not counted as a failure. There were teeth that were planned for extraction but since the patient did not return for the extraction appointment, that tooth was not considered a failure. There were radiographic failures that were not considered a failure. Conversely, there were some teeth that were extracted, and therefore considered a failure that some practitioners would consider a success. For example, a pulpotomized tooth that lasts several years and is extracted at the time of intended exfoliation may be considered a success. A few teeth were extracted because the tooth was about to exfoliate and root tips remained. In one scenario the crown fell off and the remaining tooth was extracted and therefore considered a failure.

The vast majority of teeth were restored with a stainless steel crown (SSC), especially those that were treated with pulpotomies. There were a small number of indirect pulp therapy teeth that were restored with resin composite. In general teeth that were not restored with a crown also had minimal caries into dentin. In future studies, teeth with minimal caries should be excluded, however, several sources state that the type of restoration (SSC or composite) does not matter so long as there is an adequate seal.[9,18] Vital pulp therapy procedures restored with poorly sealed restorations that allow bacterial invasion will fail.

The results of this study indicate that indirect pulp therapy is a successful treatment option for the reversibly inflamed tooth. The department is justified in using it with frequency. Primary and young immature permanent teeth have the remarkable ability to heal without much

human intervention.[39] Perhaps practitioners underestimate the pulps' ability to heal, and should utilize a more conservative approach. Hume humorously stated that dentists should modify their 200 year old philosophy that caries should be treated like gangrene by extracting or excavating and filling.[29] More aggressive treatment options should not be discredited, the pulpotomy certainly has its place, a pulp exposure would certainly justify the pulpotomy procedure. However, clinicians should consider MTA or perhaps the formocresol pulpotomy if the tooth needs to last for several years. Ferric sulfate pulpotomies could be used successfully in the short term. Perhaps with this and other studies that show indirect pulpotomy success, other residency programs and eventually practitioners will utilize indirect pulp therapy more frequently.

Conclusions

The purpose of this retrospective study was to identify how reversible pulpitis in the primary posterior tooth has been treated over the past four years at VCU pediatric dentistry, and also to determine which treatments modalities (indirect pulp therapy, formocresol pulpotomy, or ferric sulfate pulpotomy) have been successful. The following conclusions can be made from this study:

1. In 2010, 52% of vital pulp therapies were ferric sulfate pulpotomies. In 2013 and 2014 over 90% of vital pulp therapies were indirect pulp therapy. Formocresol pulpotomy saw most use in 2011 at 28%.
2. Indirect pulp therapy had a 96.2% success rate, while the formocresol pulpotomy had a 65.8% success rate and ferric sulfate had a 62.9% success rate at three years. This difference was significant $P < .0001$.

Considering the results, it has been concluded that the trend towards favoring indirect pulp therapy for primary posterior teeth needing vital pulp therapy is justified and that the vital pulp therapy curriculum at VCU pediatric dentistry does not need to be modified at this time.

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Table 1. Demographic Characteristics of Patients (N=907)

Characteristic	N	%
Sex		
Female	410	45.2
Male	497	54.8
Race/Ethnicity*		
African-American	236	47.9
Asian	8	1.6
Caucasian	181	36.7
Hispanic	56	11.4
Other	12	2.4

Table 2. Teeth Treated in the Study

Tooth	N	%
A	233	11.2
B	205	9.9
I	220	10.6
J	260	12.5
K	312	15.1
L	285	13.8
S	262	12.6
T	295	14.2

Total: 2,072 teeth

Table 3. Number of Patients by Year (N=907)

Year	N	%
2010	107	11.8
2011	229	25.2
2012	192	21.2
2013	273	30.1
2014	106	11.7

Note that the AxiUm database began in July, 2010 and that patients seen through May 2014 were included in the study.

Table 4. Number of Procedures by Year

		Therapeutic Pulpotomy		
Year	Pulp Therapy - Indirect	Formocresol	Ferric sulfate	Other*
2010	88 (38%)	11 (5%)	120 (52%)	10 (4%)
2011	253 (54%)	131 (28%)	72 (15%)	12 (3%)
2012	387 (83%)	64 (14%)	8 (2%)	7 (2%)
2013	603 (91%)	28 (4%)	2 (0%)	29 (4%)
2014	224 (91%)	4 (2%)	6 (2%)	13 (5%)
Total	1555 (75%)	238 (11%)	208 (10%)	71 (3%)

Table 5. Kaplan-Meier Survival Analysis Results

Treatment	Time (years)	Survival (%)	95% CI		Number Failures	Number Censored	Number At risk
D3120	0	100.0			0	713	1555
D3220FC	0	100.0			0	106	238
D3220FS	0	100.0			0	76	208
D3120	1	99.3	97.8	100	3	558	281
D3220FC	1	98.9	96.9	100	1	78	54
D3220FS	1	87.2	62.1	100	11	128	70
D3120	2	98.8	96.3	100	1	173	105
D3220FC	2	85.9	58.3	100	5	21	28
D3220FS	2	75.6	27.8	100	8	12	50
D3120	3	96.2	88.7	100	2	68	34
D3220FC	3	65.8	0.0	100	3	21	4
D3220FS	3	62.9	0.0	100	7	20	26

* Groups significantly different by the log-rank test (df = 2, chi-square = 58.1, P < .0001)

Figure 1. Age Distribution of Patients

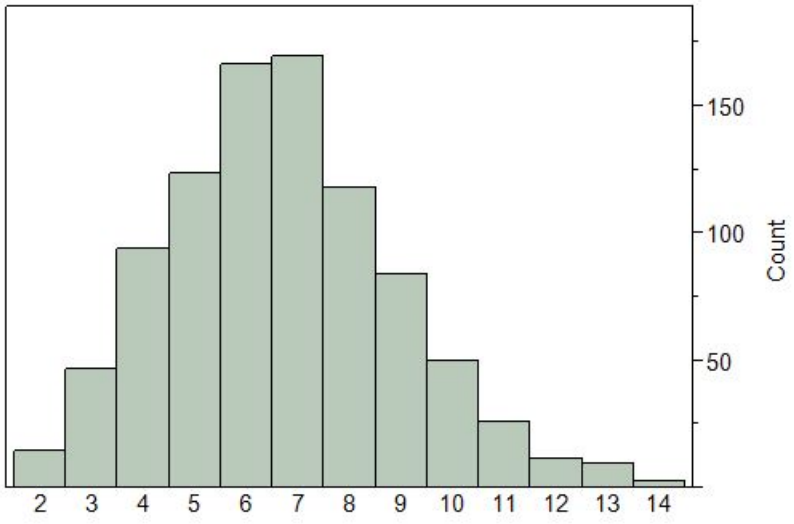


Figure 2. Percentage of Procedures by Year

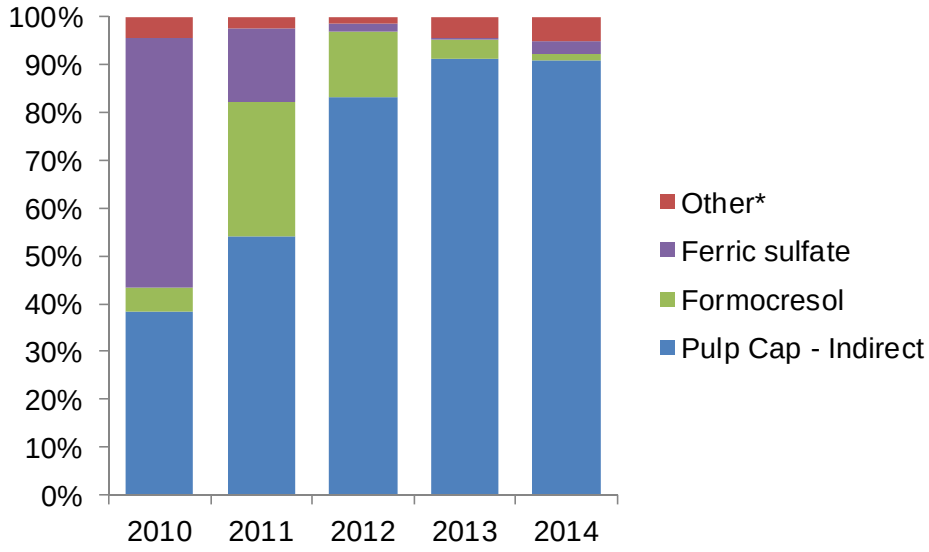
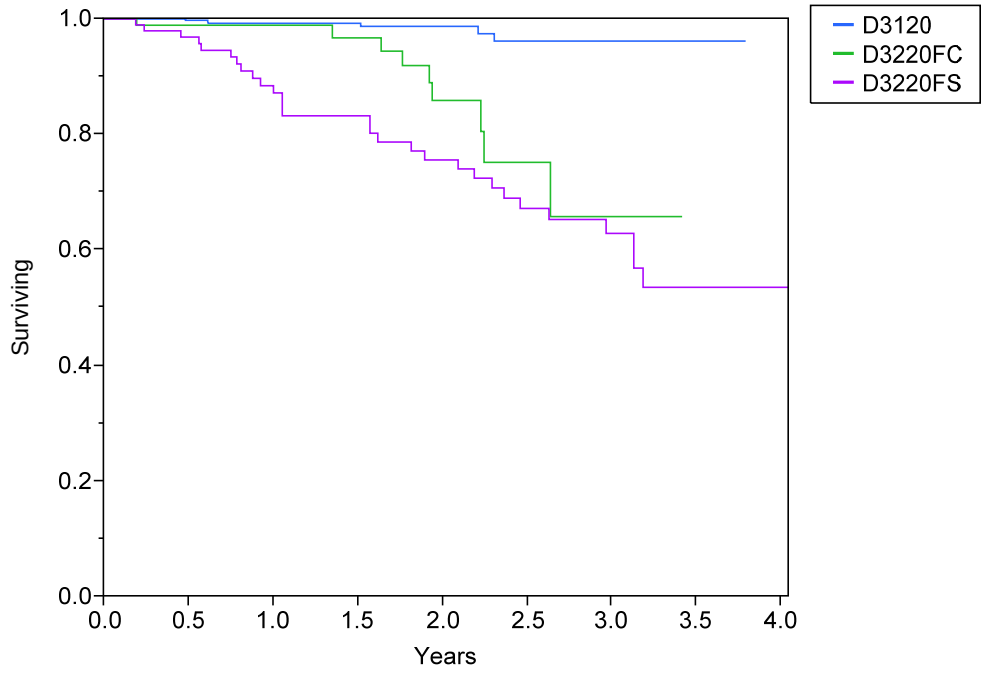
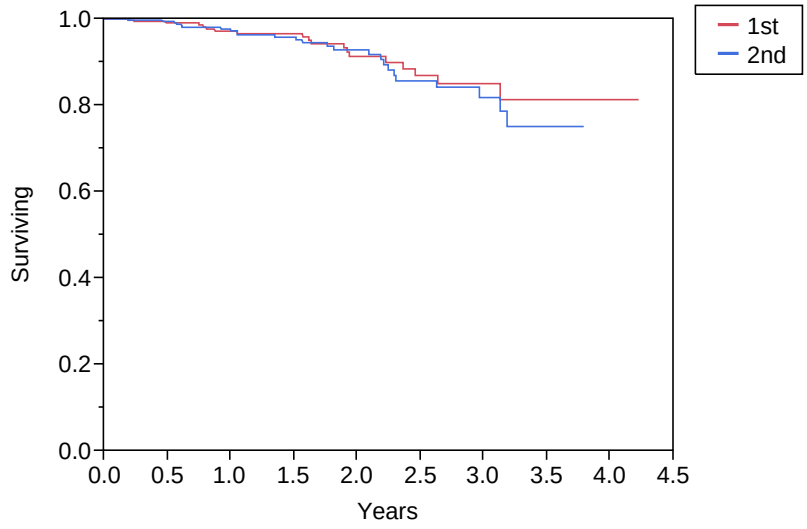


Figure 3. Kaplan-Meier Survival Analysis Results



* Groups significantly different by the log-rank test (df=2, chi-square=58.1, P < .0001)

Figure 4. Kaplan-Meier Survival Analysis by Tooth type



*Groups were not significantly different (P>0.6)

Vita

Marissa Kuhnen was born on December 31, 1981 in Livingston, New Jersey. She was raised in Warren, Pennsylvania. She graduated magna cum laude with a Bachelor of Science in biochemistry from American University in 2004. After college, Marissa conducted cancer research for one year at National Institute of Dental and Craniofacial Research (NIDCR) in Bethesda, Maryland. While at NIDCR, Marissa was authored in the publication “Intermolecular Complementation Achieves High-Specificity Tumor Targeting by Anthrax Toxin”, which is in Nature Biotechnology, May 2005. Marissa graduated dental school in 2009 from Tufts School of Dental Medicine in Boston, MA. Following graduation Marissa completed a certificate in Advanced Education in General Dentistry through the Lutheran Medical Center at the Winslow, AZ site. Marissa continued to work as a general dentist for three years on the Navajo Indian Reservation in Arizona. Marissa will complete her Pediatric Dentistry training at Virginia Commonwealth University in June 2015.