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Vital Pulp Therapy Survivability Based on Radiographic Depth of Caries

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Vital Pulp Therapy Survivability Based on Radiographic Depth of Caries

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

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Abstract

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Purpose: The purpose of this retrospective chart review was to determine if the survival of two methods of vital pulp therapy (VPT) were influenced by the pre-operative radiographic depth and location of caries. **Methods:** Electronic patient records (axiUm®) that contained the procedure codes D3120, Indirect Pulp Therapy (IPT), or D3220, Therapeutic Pulpotomy (TP), were queried. Qualifying charts' pre-operative and post-operative radiographs were viewed in MiPACS® by two raters. Visit records were queried again to identify any other treatment failures. **Results:** A total of 568 primary molars met the eligibility criteria. There was a difference in survival depending upon the treatment procedure ($P < .0001$), with D3220 having a significantly higher failure rate than D3120. In the 182 total cases with caries 2/3 to encroaching the pulp, therapy success was greater with IPT ($P < .0001$). **Conclusion:** IPT results in longer overall clinical success even at the deepest level of caries.

Introduction

From 2011-2015, two techniques to vital pulp therapy (VPT) that have been taught and clinically applied at Virginia Commonwealth University (VCU) Pediatric Dentistry: 1) the therapeutic pulpotomy (TP) and 2) indirect pulp therapy (IPT). In evaluation of recent research performed at VCU, it has been shown that VCU has trended from the utilizing the formocresol pulpotomy, to ferric sulfate pulpotomy, to indirect pulp therapy and with the latter having the highest overall success rates of the three.[1] This retrospective study will review if radiographic depth and location of caries affects the outcome of TP and IPT treatments.

One of the most challenging aspects in considering VPT is making an accurate diagnosis. Children are typically not reliable for an accurate description on the history of pain with a tooth. Hence clinical and radiographic signs are the main criteria dentists use to diagnose such lesions. In determining a diagnosis the best way to determine the difference between reversible and irreversible pulpitis is whether the pain is provoked or unprovoked. If the symptoms arise when provoked, this would indicate that the pulp is in a transitional state and the changes are reversible. If a tooth is asymptomatic and appears normal radiographically, or has symptoms consistent with a diagnosis of reversible pulpitis without radiographic pathology and has enough tooth structure to allow successful restoration, two viable options exist for vital pulp therapy: IPT or the TP. The most important aspect of VPT regardless of which treatment option is chosen, is to maintain the vitality of the pulp. However, if the tooth pain has ever woken the child up, or

hurts spontaneously in the middle of the day without stimulation, the changes to the pulp are now irreversible and would require a pulpectomy or extraction.

As mentioned previously, sometimes making an accurate diagnosis becomes difficult due to an unreliable history of symptoms from the patient or caregiver. One method to aid the provider in making a more accurate diagnosis is to perform a procedure referred to caries control. With this procedure, one will place an interim restoration (IR), ideally glass ionomer, and then wait one to three months. If the tooth remains asymptomatic, the diagnosis of reversible pulptitis can be confirmed and less aggressive vital pulp therapies such as IPT can be more confidently performed.[2] In this time the IR acts to dry out the remaining infected dentin, which decreases the likelihood of a pulp exposure upon completing IPT.[3] Also, by placing an IR, if the tooth becomes symptomatic the practitioner can reach a diagnosis of irreversible pulpitis and treat accordingly.

IPT is a procedure performed in a tooth with a deep carious lesion approximating the pulp but without signs or symptoms of pulpal degeneration. Seale suggests that the decision to treat with IPT should be made prior to initiation of the prep to avoid an accidental microexposure which would lead to a failed procedure.[4] The superficial caries is dentin that has become necrotic. It contains the highest number of bacteria and is referred to as infected dentin.[5,6] This level of carious dentin is removed. The next layer of carious dentin is decalcified and with a small amount of bacteria which is referred to as the affected dentin.[5,6] This layer is left in the deepest portion of the cavity, surrounding the pulp, to avoid pulp exposure and is covered with a biocompatible material. This provides an opportunity for affected dentin to remineralize. Across the literature, IPT shows success rates of 90% or greater no matter the technique, medicament, or time periods. IPT is also more cost effective as the pulp chamber is not being entered.[7-9]

With the TP procedure, the very nature of the pulp, once exposed, aids in determining the most appropriate treatment for that tooth. The characteristics of the exposed pulp such as the amount and color of hemorrhage and ability to control the hemorrhage prior to administering a medicament, will finalize the diagnosis as either reversible or irreversible pulpitis, hence guiding the provider to the most appropriate treatment.[10] If the pulpal tissue is healthy, many medicaments have been utilized over the year as agents to aid in maintaining the vitality of the pulp.

Formocresol was the gold standard for many years consistently providing success rates between 74%-96%.[7,9,11] Formocresol acts as an agent that fixes the most coronal portion of the radicular pulp tissue which allowing the most apical portion to remain vital.[12] However, concerns with formocresol carcinogenic potential that both researchers and practitioners have been searching for a safe substitute.[13] A 1978 study raised more fear of the potential long term consequences of the use of formocresol, when elevated levels of formaldehyde demonstrated that it was being systemically spread after a pulpotomy.[14] Despite all the potential side effects of formocresol, only 5% of pediatric dentists and 18% of endodontists believed that its use should be discontinued.[15]

More recently, ferric sulfate came onto the scene and clinically had success with rates as high as 93%. However, over time it's radiographic success did not hold up to that of Formocresol.[11] Calcium Hydroxide was also utilized for a time, proving to have the lowest success rates, consistently around 50%, and per Huth's systematic review it is not recommended as a medicament for TP.[9]

In recent years Mineral Trioxide Aggregate (MTA) has become an important medicament in TP of a primary molar. It is a material that is non-carcinogenic and acts to create a dentinal

bridge between the healthy remaining pulps and the restoration of the tooth.[16] MTA is utilized in TP and has had a reported 100% success rate both clinically and radiographically.[17] Recent articles suggest that MTA is a viable substitution for a pulpotomy instead of formocresol or ferric sulfate.[18]

Radiographs are an important diagnostic tool utilized by pediatric dentists in the decision making process for treatment planning teeth with carious lesions. The use of radiographs has been employed to determine depth of caries in primary molars based on the greyness of the dentin in relationship to cavitation.[19] The most accurate view of the proximity of the carious lesion to the pulp is through the bitewing radiograph, since it taken at a more perpendicular relationship to the long axis to the tooth thus avoiding the tendency of superimposing the carious lesion over the pulp chamber region.

However, limitations arise when interpreting radiographs. Radiographs show both the location and depth of caries. However, the extent of the carious lesion is often underestimated because a minimum of 30% demineralization of enamel or dentin is necessary in order for the lesion to be radiographically visible.[20] While depth of caries can sometimes be estimated based on a clinical exam, a radiographic examination is necessary to determine proximity of caries to the pulp and thus the appropriate pulpal therapy.

Due to the aforementioned limitations of radiographic depth, Gopinath states that the only way to correctly assess the inflammatory status of the pulp in children is an evaluation of the histopathology of the pulp.[21] Kassa et al., determined that in primary teeth, caries originating from the proximal surfaces and are at least 50% through the dentin lead to significantly increased inflammation of the pulpal tissue.[22] Gopinath determined that caries whether it originated from the occlusal or proximal surfaces that once the lesions progresses to 2/3 through the dentin both

types of lesions will exhibit histologic inflammation of the pulpal tissue.[21] Coll et al., found a statistically significant difference in clinical success rates of VPT between teeth with proximal lesions versus those with non-proximal lesions.[2]

A study conducted by Bjørndal L, et al defined carious lesions based on depth and activity and its relationship to pulpal regeneration.[23] It notes that the specific depth of a carious lesion is seldom mentioned in clinical studies and that understanding the lesion depth can benefit a provider when determining treatment and predicting outcomes.[23] Gopinath VK and Anwar K recently conducted a study correlating histological, clinical and radiographic caries. It was determined that caries extending between 80-100% of the dentin left a residual dentinal thickness between 0.25-1.0mm.[21] The presence of bacteria in cavities with a remaining dentin thickness (RDT) less than 0.25 mm stimulates a more severe pulp inflammatory reaction than in similar cavity preparations in the absence of bacteria.[24] The RDT has a protective role in that a RDT below 0.25 results in a significant decrease in the number of odontoblasts observed with a consequential reduction in tertiary dentin formation and therefore, the greater the RDT, the better the protection of the pulp. [24]

By examining depth of caries in relationship to the success and failure rates for each procedure, the VCU vital pulp therapy trend will either be justified or need modification. The purpose of this retrospective case series analysis is to evaluate the preoperative bitewing radiographs of patients treated with either the TP procedure (D3220) or the IPT procedure (D3120) performed in the VCU Department of Pediatric Dentistry Practice, and determine which therapy based on depth of caries has been most successful.

Methods

In this study, an axiUm report was run to collect data on all D3120 and D3220 codes completed at the VCU pediatric dental clinic. The inclusion criteria of patient age 1-12 years old, having radiographs, being restored with a Stainless Steel Crown (SSC), and having a follow-up exam or treatment was then applied to these codes.

In order to properly evaluate the radiographs, the examiners must have an understanding of what definition we will be using to determine caries depth. Molina J.R. et al., outlined a method of calibration that will be replicated in this study.[25] Two dentists affiliated with the pediatric department underwent calibration sessions on the radiographic depth of caries. A third independent dentist randomly selected 30 radiographs of various depths in which one of the two procedures have procedures had been performed. In a study conducted by Nielsen LL, et al, a scoring system was instituted amongst the examiners to determine cavity depth based on radiographic findings.[26] A similar style was utilized in this study as examiners classified lesions as having no caries (0), being one-third of the way through dentin (1), one-third to two-thirds of the way through dentin (2) or two-thirds through dentin to approximating the pulp (3). The 3 evaluators independently looked at, and gave a score for each of the 30 teeth. In order to properly calibrate examiners, three such sessions were held. Inter-rater reliability is held to a high standard because correlation and kappa coefficients are higher for digitalized radiographs than traditional radiographs.[27]

After calibration was completed, a Red Cap system was implemented for the two independent dentists to evaluate radiographs, and answer related questions. Each tooth with the code D3120 or D3220 required having radiographs in MiPacs (electronic digital radiograph system), the radiographs must have been diagnostic, and they must have been taken less than 6 months prior to the treatment date in order for that tooth to receive a score. Raters then used a split screen on the computer to evaluate a radiograph and enter the data into the REDCap database. In order to determine intra and inter-rater reliability each rater saw 30 of his or her own scored radiographs twice and there were 30 that both raters viewed.

In order to be eligible for the study a patient must have met all of the following criteria:

- Be treated in the VCU Pediatric Dentistry practice between 2010 and April of 2015,
- Be between 1 year and 12 years of age at time of treatment,
- Treatment Code=D3120 (Pulp Cap – Indirect) or Treatment Code=D3220 (Therapeutic Pulpotomy),
- Treatment on primary molars (A, B, I, J, K, L, S, T),
- Accompanied by a pre-treatment radiograph (D0210 (intraoral complete series), D0272H (Bitewing – 2 horizontal films), or D0274H (Bitewing- 4 horizontal films), that occurred the day of, or prior to completion of the dental treatment codes.
- And have been seen at least once in a subsequent visit up to 36 months post treatment.

Failure of treatment will be identified on post-treatment radiographs, if they exist. The treatment codes for the post-operative radiographs were:

- No radiographic failure (treatment success)
- Periapical radiolucency
- Interradicular radiolucency
- Internal resorption
- External resorption
- Additionally the database also identified: No DIAGNOSTIC radiographs available

Failure of treatment will also be identified by the following post-treatment procedure codes:

- D7140 (extraction erupted tooth)
- D7111 (coronal remnants)

- D3221 (Pulpal Debridement)

Caries determination

The level of pre-treatment caries was determined by an examination of the radiographs taken up to 90-days before treatment. Caries level was recorded by one of two practitioners as: 0=No evident caries, 1=less than 1/3 through dentin, 2=1/3-2/3 through dentin, 3=2/3-approximating the pulp. Each practitioner was randomly assigned half of the patients to rate. In order to estimate the level of reproducibility of these measurements, each practitioner was randomly assigned 20 patients to rate twice, and both practitioners were randomly assigned 20 patients to each rate. These duplicate ratings were done blindly—all of the ratings were assigned in a random order and the duplicates were placed in this random ordering so that the raters would be unlikely to know if they had previously rated a patient. And, since the assigned patients of one rater were unknown to other rater, the raters were blind to the occasions when they were both rating the same patient. At the time of the assignments of patients to raters, it was unknown whether diagnostic radiographs would be available, and so it was anticipated that some patients would not be evaluable.

The two practitioners agreed on the level of caries in 74% of the teeth with diagnostic radiographs available (Table 1). This raw level of agreement is inflated by the fact that each of the 4 caries levels is not of equal likelihood to occur. Thus, the Kappa coefficient is a chance-corrected level of agreement. Using the requirement that an exact match is required for agreement to be declared, the Kappa coefficient of agreement is moderate (52%, 95% CI = 30% to 74.3%). Using a more relaxed requirement for agreement—exact agreement counts as 1, agreement within 1 unit counts as 2/3, and agreement to within 2 units counts as 1/3—the weighted Kappa coefficient of agreement is 65% (95% CI = 48.2% to 82.1%).

Rater 1 evaluated 26 teeth twice and determined exactly the same level of caries 85% of the time (Kappa = 74.6%, weighted Kappa = 78.0%). Rater 2 evaluated 34 teeth twice and determined exactly the same level of caries 70.6% of the time (Kappa = 55.9%, weighted Kappa = 64.3%).

Statistical methods

Results are summarized as counts and percentages or means and standard deviations, as appropriate. The values to be compared are further described with 95% confidence intervals. In order to test for a difference between IPT and TP survival and to determine if the difference is associated with depth of caries or location Kaplan-Meier survival analysis was used to compare each of the groups individually (i.e., treatment procedure, depth of caries, tooth location, and age). The log-rank chi-square test was used to compare group in the Kaplan-Meier analyses. Any factor associated with differences (at $P<0.2$) will be included in a Weibull parametric survival analysis. Interactions between treatment procedure and depth of caries, and treatment procedure and caries location will be considered. Any effects remaining significant in the multivariable model (at $P < 0.05$) were being described.

Results

In this section, we begin with a description of the patients and teeth included in the study. Then the two treatment groups are compared, to identify imbalance of factors that may be related to treatment success. In the final analysis portion, the findings are first broken down into the results of unadjusted analyses—looking at one-factor-at-a-time differences. And finally, all potential differences are integrated into an adjusted analysis and the effects of the various factors are illustrated.

Description of patients

A total of 260 children met the eligibility criteria and 47.7% (125) of them had only one tooth treated. There were 52.7% who were female and 47.3% who were male, there was no difference between the treatment groups (P>0.9). In 31% of the cases, the race/ethnicity of the patient was not specified, 33% were African-American, and 23% were white (P>0.5). The IPT patients were an average of 5.1 years of age (SD=1.97) and the TP patients were an average of 5.71 years of age (SD=2.09), a significant difference (t-test P=0.0331), indicating TP was being performed on older kids. The IPT patients had an average follow-up of 457 days (SD=340) and the TP patients had an average follow-up of 593 days (SD=317), a significant difference (t-test P=0.0021), indicating that children who received a TP returned to VCU for a longer time period than those with treated with ITP.

Description of treated teeth

The 568 primary molars treated by the two treatment methods are described in Table 4. There was no difference in treatment procedure depending upon the tooth (chi-square P = 0.47). When and whether pre-treatment images were available is shown in Table 5. Table 6 shows the depth of caries that was assessed for each procedure. Caries depth was not comparable between treatments (P < .0001). In the case of molars treated by TP, 72% had caries approximating the pulp whereas in the IPC molars only 40% had caries to this depth. Table 7 shows the location of caries that was assessed for each procedure. Caries location was also not comparable between treatments (P = .0062). In the case of molars treated by TP, the three locations were approximately equally likely whereas in the IPC molars 48% had occlusal caries.

Treatment failure was identified by two methods. One method was a radiographically identified failure (Table 8). The other method was to query all the follow-up procedures performed and identify tooth-associated procedures that would identify a failure. There were 23 of these cases, as described in Table 9. Note that there were no subsequent failures identified by D3120 or D3220. A complete list of all failure types is shown in
Table 10. The final designation of a failure is either the frank failures identified by a subsequent D7111 or D7140 or as one of the radiolucency or resorption codes, whichever came first. Using this scheme, there were 78 total failures; 6/416 (0.01%) in the IPT group and 72/152 (47.4%) in the TP group.

Statistical comparisons of groups

In order to screen for potential group differences, four Kaplan-Meier survival analyses were performed using time-to-failure (in days) as the outcome, or if no failure occurred, time-to-last follow-up as the (censored) outcome. The first factor screened for potential differences in

survival time was the two procedures. There was clearly a difference in survival depending upon the treatment procedure (log-rank chi-square = 92.8, P < .0001, Figure 1). TP had a significantly higher failure rate, surviving an average of 2.4years, as versus the 2.9 year survival average for IPT.

The second unadjusted survival analysis compared survival between the groups identified by the depth of caries. Not every case had radiographs where caries were able to be evaluated, but in the 517 instances where this information was available, there was evidence for a relationship between survival and caries level (procedure (log-rank chi-square = 15.6, P < .0013, Figure 2). In the 98 cases of caries less than 1/3 through the dentin, their average survival was 3.16 years. In the 162 cases of caries between 1/3 and 2/3 through the dentin, the survival averaged 3.06 years. In the 252 cases of caries approximating the pulp, the survival averaged 2.82 years. There was not enough data to estimate survival for the 5 cases with no caries.

The location of the caries was not statistically related to survival time (log-rank chi-square = 2.6, P = 0.4550).

Since age is a continuous variable, its relationship with tooth survival was assessed using a Weibull parametric survival analysis. Unadjusted for other differences, there is some evidence for a relationship between age and survival (likelihood ratio chi-square=2.65, P < 0.1038). This trend towards higher survival in younger individuals may be seen in the Kaplan-Meier plot where the green-shaded younger children appear to have higher survival and the orange-shaded older children appear to fail earlier (Figure 7).

Each of the preceding analyses looked at the effect of a single characteristic on the survival outcome of the treated molars when all of the other characteristics are ignored. An adjusted analysis determines the effect of a single characteristic on the survival outcome of the

treated molars after adjusting for the effect of all of the other characteristics. A survival analysis that included all four characteristics indicated that the following factors were significantly related to survival: Treatment procedure (chi-square = 86.1, P < .0001), Caries location (chi-square = 9.6, P = 0.0082), and Age in months (chi-square = 4.6, P = 0.0321). Caries depth was not found to be significantly related to tooth survival (chi-square = 1.3, P = 0.7227) after the other factors were accounted for in the analysis.

Since caries depth was the primary focus of the study, two secondary analyses were also considered. The first considered whether the effect of caries depended upon the treatment group. An interaction test indicated that it did not (chi-square = 3.8, P = 0.2791), Figure 5. The top panel indicates how similar the IPC groups are and how similar the TP groups are. The bottom panels indicate that there remains a significant procedure difference within each of the caries depth groups (all P < .0001). The next analysis considered whether the effect of caries depended on the location of the caries. An interaction test indicated that it did not (chi-square = 2.5, P = 0.7751); there is no evidence for survival differences due to the depth of caries.

To illustrate the combined effects of treatment procedure and caries location, Figure 6 shows the Kaplan-Meier plot for all cases where caries location was characterized. As may be seen, in the IPC cases (red lines in the figure) there is insufficient data to characterize the caries location difference (P = 0.1482). For the TP cases, there is a significant difference between the three caries location groups (P = 0.0182). Teeth with interproximal caries survived an average of 2.22 years (SE = 0.23, median survival = 2.15 years) and teeth with occlusal caries survived an average of 2.20 years (SE = 0.18, median survival = 2.22 years). Teeth with multisurface caries locations had better survival, surviving an average of 2.79 years (SE = 0.15, median survival = 2.62 years). This pattern of better survival in molars with multisurface caries locations was also

evident in the IPC cases where none of the 93 IPC molars with multiple caries failed; all of the observed failures were in IPC molars with interproximal caries (4 failures out of 98) and in IPC molars with occlusal caries (2 failures out of 180).

Therefore, the final survival analysis model that describes the survival time of treated teeth indicates that there is a significant treatment difference ($P < .0001$), with the TP group having a higher likelihood of failure. Additionally, within all treatment groups there is a likelihood of failure with an increase in age and if the caries location is either occlusal or interproximal (but not both).

Discussion

The purpose of this retrospective study is to determine if there is a difference in survivability of the two VPT treatment options, IPT or TP, based on depth and location of caries. Kuhnen et al initiated a retrospective study which showed that at VCU Pediatric Dental Clinic in 2010 TP was the treatment of choice for VPT 61% while 38% was IPT. In 2014, following the literature, this trend shifted such that 91% of VPT completed at VCU was IPT.[1]

Regardless of the depth of caries, IPT survived longer and had both a higher clinical and radiographic success rate than TP. IPT demonstrated a 99.3% clinical success rate and 98.8% radiographic success rate, meanwhile, TP demonstrated a 86.9% clinical success rate but only a 50.6% radiographic success rate. TP had an average survival of 2.4 years, while IPT survived for 2.9, this difference is statistically significant at $P<.0001$. These results are similar to many published articles; Farooq et al showed a 93% success rate for IPT at 4.2 years and a 74% success rate for TP at 3.9 years.[28]

Over the course of five years, IPT has proven to be a very successful treatment option at VCU, even in the deepest carious lesions, Figure 5. The theory surrounding its success is based on the healing potential of the young immature pulp due to an increase in vasculature. [29] Upon leaving the remaining affected caries as opposed to exposing the pulp, prevents new sources of bacteria and foreign materials from contacting the vital pulp. When the IPT medicament is placed and then sealed over with a definitive restoration, it has two distinct effects on the affected dentin. First, it removes organic substrates the remaining bacteria utilized to survive.

[29]Second, the characteristics of the affected dentin shift from a state of demineralization to that of a remineralized, sclerotic state, regardless of which medicament is used. [30] According to Opal, sclerotic dentinal tubules, by the nature of their make-up, can physically prevent the movement of bacteria toward the pulp.[29]

As mentioned above, after adjusting for differences due to treatment procedure and caries location, patient age is related to survival (P = 0.0250). To illustrate the magnitude of this factor, we generated predicted survival proportions for the three significant factors (treatment, caries location, patient age) and plotted them, as shown in Figure 7. Although this figure only shows the results for the most common caries location, occlusal caries, the magnitude of the effect of age is the same in the other locations. The points in the top portion of the figure correspond to the expected results for IPC and the points in the lower portion of the figure correspond to the worse survival proportions corresponding to TP. In each group, the younger children (green dots) have better survival than that expected in older children (orange dots). Age based differences within the IPT group rather than the TP group may be due to normal exfoliation of the primary teeth or maturation of the primary molar. A TP that undergoes internal resorption or asymptomatic interradicular radiolucency will experience premature exfoliation regardless of age.

No differences were found based on location of caries, Figure 3. Previous research shows that deep carious lesions originating interproximally will cause a higher degree of pulpal inflammation and may in turn result in a higher percentage of failures.[2] Due to such a high percentage of overall combined clinical and radiographic failures, roughly 15-20% more than reported across most literature, these high failure rates may be masking an association.[17]

In determining caries depth, 5 of the 568 teeth, 0.008%, treated showed no signs of radiographic caries, depth= 0, in extending into dentin, Table 6. Since the qualification of this study required the radiograph be taken within 6 months of the treatment date, it is possible that some of these lesions did advance into dentin in the time between the exam date and treatment date. Another interesting finding was that there were significantly more teeth treated with IPT at a shallower depth of caries, depth = 1, than those treated with TP (9:1 ratio). It is possible that with many different practitioners treating the teeth over 5 years that each individual's assessment of where the pulp is could be different, since affected dentin is left. Similarly to those treated with no radiographic caries, the long period accepted between date of radiograph and date of treatment could have allowed for caries progression to proceed closer to the pulp. A final explanation could be that the lesions extended closer to the pulp than the radiographic may have indicated. Radiographs require 30-40% demineralization prior to becoming visually evident on the radiograph.[20] Finally, since a radiographic is a two dimensional image of a three dimensional object, it is possible that some occlusal caries could have actually been buccal or lingual caries that extended close to the pulp from its respective location.

Four methods of radiographic failure are included to determine if changes within the pulp of the tooth occurred in the absence of clinical signs and symptoms. The most common radiographic change is interradicular radiolucency accounting for 34.7% of the radiographic failures over both treatment groups, followed by periapical radiolucency at 23.6%, internal resorption at 20.8% and finally external resorption at 13.9%, Table 10. Six teeth, 8.3%, show no sign of radiographic failure, yet experienced clinical failure requiring extraction.

Although not all radiographic failures led to clinical failures, the decision to enter the pulp and complete a TP led to different changes radiographically than the more minimally

invasive treatment of IPT. Teeth that received IPT did not show any signs of inflammatory resorption radiographically, Table 11. The medicaments utilized directly on the remaining pulpal tissue may cause an unfavorable reaction to the TP treatment. The guidelines state that successful VPT should show no signs of external root resorption or supportive bone loss. [31] However, it also states that internal resorption should be monitored closely and if any signs or symptoms arise, to treat the affected tooth.[31] This recommendation is based on the concept that internal resorption arises as from chronically inflamed vital pulp.[32] Inflammatory cells within the vasculature of the pulp are drawn to the area where an irritating material is in direct contact with healthy pulpal tissue. This leads to an increase in odontoclastic activity and inflammatory resorption.[24]

A limitation of this study and possible reason the failure rate for TP's is higher than reported literature is because there was not standardized technique utilized in completing the procedure. Over the course of the five years this retrospective study covers, 25 different residents and 12 different faculty members all completed VPT codes. This led to great variability in medicament used (formocresol, ferric sulfate, Vitapex, calcium hydroxide, and chlorhexidine). Even if only one method of TP was utilized, such as formocresol, in a survey by Dunston, he found great variation in techniques amongst AAPD members.[33]

A major limitation of this study includes patient compliance. While it was attempted to administer very strict inclusion criteria to the teeth selected for radiographic evaluation, over half of the IPT and TP procedures completed from 2010-2015 were excluded from the study due to a lack of follow up in any manner. Despite the high percentage of patients (71.3%) who never returned for a follow-up appointment, a sufficient sample size was obtained from 260 patients who returned. Another limitation of this study involves a non-standardized method of treatment. While many of the patients included in this study were treated in the operating room, some were

treated in the chair and some were treated under sedation. There was no way to control for patient behavior and if any procedures were completed under duress. Also, since patient selection criteria was based on follow-up and not depth of caries, some teeth exhibiting shallow decay radiographically were included because they were treated as either a IPT or TP. In the case of IPTs, it is possible that for some it may only have been a liner. Future research may involve a prospective study in which these aforementioned limitations can be controlled.

A final limitation is the nature of human differences and error in evaluating radiographs. Although we calibrated prior to viewing the radiographs, and throughout the study had both inter-rater and intra-rater reliability tests run, if a lesion was borderline between any of the 3 depths, one rater may view things as always being shallower, while another may perceive the exact same lesions as deeper. Although there is no way to account for human error without exact measurements of each tooth, in the future, a higher Kappa Coefficient may be desirable.

Dunston and Coll in 2005 surveyed both predoctoral pediatric directors at dental schools, and Diplomats of the AAPD to determine if the teaching and practicing of VPT therapy had changed since 1997.[33] Similar to the trend seen at VCU from 2010-2014, IPT has increased in both lecture and clinical settings from 70% to 83%. TP was still taught and used universally at 100% of the programs. Although the trend in academia has shifted toward the more clinically successful IPT, AAPD Diplomats in practice remain at only a 71% utilization rate.[33]

Future research at VCU could focus on a prospective study in which specific lesions are chosen to improve upon the limitations of this study. Research could also be completed to determine how effective sedative interim restorations completed at VCU have been in the past.

Conclusion

The purpose of this retrospective chart review was to determine if the survival of two methods of vital pulp therapy (VPT) was influenced by the pre-operative radiographic depth and location of caries. The following conclusions can be reached based on this study:

1. Even in the deepest carious lesions, IPT survives longer and has a higher success rate than TP.
2. No definitive decisions can be made on success rates based on the location of carious lesions.
3. The younger a patient is at the time the VPT procedure is completed, the longer it lasts and has a higher success rate.

Considering these results, and that the clinical and radiographic indications for choosing to treat a tooth with IPT or TP are exactly the same, pediatric dentists should highly consider utilizing IPT over TP even when a carious lesion is close to the pulp.

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Tables

Table 1. Between Rater Agreement

	Rater 2				
Rater 1	0 No evident caries	1 (less than 1/3 through dentin)	2 (1/3-2/3 through dentin)	3 (2/3-approximating the pulp)	Total
0 No evident caries	0	1	0	0	1
1 (less than 1/3 through dentin)	0	2	2	0	4
2 (1/3-2/3 through dentin)	0	2	4	0	6
3 (2/3-approximating the pulp)	0	0	4	19	23
Total	0	5	10	19	34
Exact agreement (%)	73.5	95% CI			
Simple Kappa (%)	52.1	(30.0 to	74.3)		
Weighted Kappa (%)	65.2	(48.2 to	82.1)		

Table 2. Within Rater Agreement

	Rater 1 (second)				
Rater 1 (first)	0 No evident caries	1 (less than 1/3 through dentin)	2 (1/3-2/3 through dentin)	3 (2/3-approximating the pulp)	Total
0 No evident caries	0	0	0	0	0
1 (less than 1/3 through dentin)	0	4	0	0	4
2 (1/3-2/3 through dentin)	1	2	4	1	8
3 (2/3-approximating the pulp)	0	0	0	14	14
Total	1	6	4	15	26
Exact agreement (%)	84.6	95% CI			
Simple Kappa (%)	74.6	(54.0 to	95.3)		
Weighted Kappa (%)	78.0	(59.1 to	96.9)		

	Rater 2 (second)				
Rater 2 (first)	0 No evident caries	1 (less than 1/3 through dentin)	2 (1/3-2/3 through dentin)	3 (2/3-approximating the pulp)	Total
0 No evident caries	0	0	0	0	0
1 (less than 1/3 through dentin)	0	8	3	1	12
2 (1/3-2/3 through dentin)	0	3	6	2	11
3 (2/3-approximating the pulp)	0	0	1	10	11
Total	0	11	10	13	34
Exact agreement (%)	70.6	95% CI			
Simple Kappa (%)	55.9	(33.2 to	78.6)		
Weighted Kappa (%)	64.3	(44.2 to	84.4)		

Table 3. Demographic characteristics (N=260)

	Procedure			
Characteristic	IPT	TP	Total	Percent
Sex				
Female	92	45	137	52.7
Male	83	40	123	47.3
Total	175	85	260	
chi-square P=0.9553				
Race/ethnicity				
(not specified)	60	21	81	31.2
AFRAM	57	29	86	33.1
ASIAN	3	1	4	1.5
CAUC	36	24	60	23.1
HISP	16	7	23	8.8
OTHER	3	3	6	2.3
Total	175	85	260	
chi-square P=0.5266				
Age (years)				
1	0	2	2	0.8
2	8	2	10	3.8
3	34	8	42	16.2
4	30	16	46	17.7
5	38	11	49	18.8
6	21	14	35	13.5
7	20	14	34	13.1
8	16	9	25	9.6
9	3	7	10	3.8
10	3	2	5	1.9
11	2	0	2	0.8
Total	175	85	260	
chi-square P=0.0262				

Table 4. Teeth Treated (N=568)

	Treatment		
Tooth	IPT	TP	Total
A	51	12	63
B	36	15	51
I	43	10	53
J	52	16	68
K	70	25	95
L	56	26	82
S	53	22	75
T	55	26	81
Total	416	152	568

Notes:

Table 5. Pre-treatment imaging

	Treatment		
Pre-Tx image	IPT	TP	Total
no pre-treatment images	17	8	25
day of treatment	262	100	362
no more than 3mo prior	123	41	164
6-no more than 6mo prior	14	3	17
Total	416	152	568

Notes

Table 6. Depth of Caries by Treatment Group

	Treatment	
Caries depth	IPC	TP
No evident caries	5	0
Less than 1/3 through dentin	89	9
1/3-2/3 through dentin	132	30
2/3-approximating the pulp	150	102
(unknown)	40	11

Chi-square = 46.5, $p < .0001$ (excluding unknowns)

Table 7. Location of Caries by Treatment Group

	Treatment	
Caries location	IPC	TP
No evident caries	5	0
Occlusal	180	47
Interproximal	98	43
Multisurface	93	51
(unknown)	40	11

Chi-square = 12.4, P = 0.0062 (excluding unknowns)

Table 8. Radiographic failure by Treatment Group

	Treatment		
Outcome	IPT	TP	Total
.	141	27	168
No radiographic failure (treatment success)	237	40	277
Periapical radiolucency	2	15	17
Interradicular radiolucency	2	23	25
Internal resorption	0	15	15
External resorption	0	10	10
No DIAGNOSTIC radiographs available	34	22	56
Total	416	152	568

Table 9. Frank failures by Treatment Group

	Treatment		
Failure procedure	IPT	TP	Total
D7111	1	0	1
D7140	2	20	22
Total	3	20	23

Table 10. Failures by Procedure Code, Radiographic Outcome, and Extraction Procedure

Procedure	Radiographic Outcome	Procedure outcome	Frequency	Percent
D3120	.		141	24.82
D3120	0-No radiographic failure (treatment success)		235	41.37
D3120	0-No radiographic failure (treatment success)	D7111	1	0.18
D3120	0-No radiographic failure (treatment success)	D7140	1	0.18
D3120	1-Periapical radiolucency		1	0.18
D3120	1-Periapical radiolucency	D7140	1	0.18
D3120	2-Interradicular radiolucency		2	0.35
D3120	?-No DIAGNOSTIC radiographs available		34	5.99
D3220	.		26	4.58
D3220	.	D7140	1	0.18
D3220	0-No radiographic failure (treatment success)		37	6.51
D3220	0-No radiographic failure (treatment success)	D7140	3	0.53
D3220	1-Periapical radiolucency		10	1.76
D3220	1-Periapical radiolucency	D7140	5	0.88
D3220	2-Interradicular radiolucency		19	3.35
D3220	2-Interradicular radiolucency	D7140	4	0.7
D3220	3-Internal resorption		13	2.29
D3220	3-Internal resorption	D7140	2	0.35
D3220	4-External resorption		10	1.76
D3220	?-No DIAGNOSTIC radiographs available		17	2.99
D3220	?-No DIAGNOSTIC radiographs available	D7140	5	0.88

Table 11. Failures by treatment type

	Treatment		
Reason	IPT	TP	Total
Periapical radiolucency	1	12	13
Interradicular radiolucency	2	19	21
Internal resorption	0	13	14
External resorption	0	10	10
D7111	1	0	1
D7140	2	20	20
Total	6	72	78

Figures

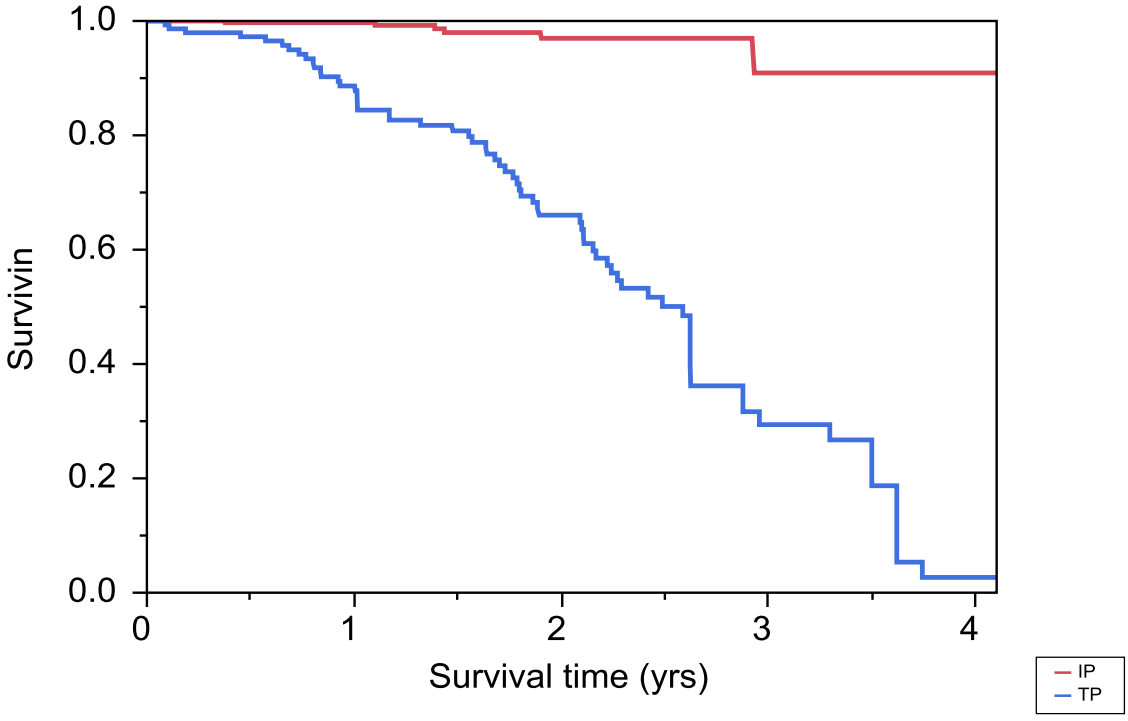


Figure 1. Kaplan-Meier Survival Analysis by Procedure

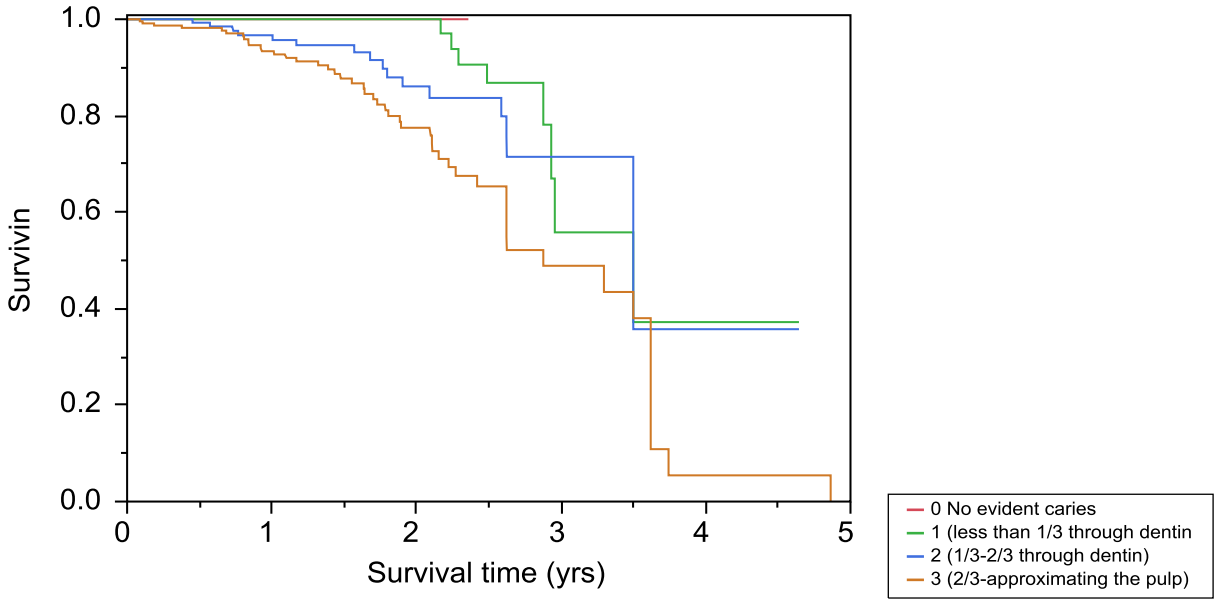


Figure 2. Kaplan-Meier Survival Analysis by Caries Depth

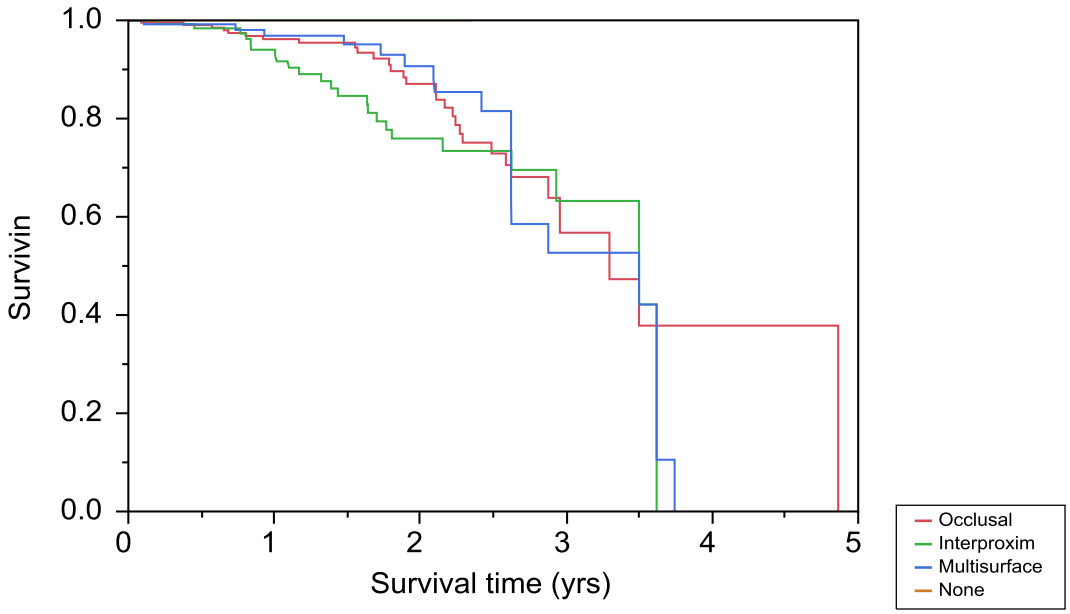


Figure 3. Kaplan-Meier Survival Analysis by Caries Location

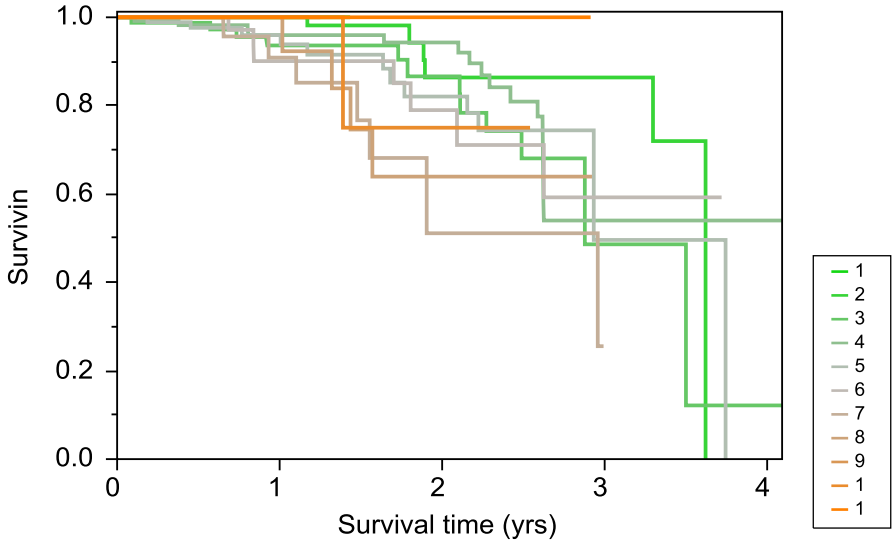
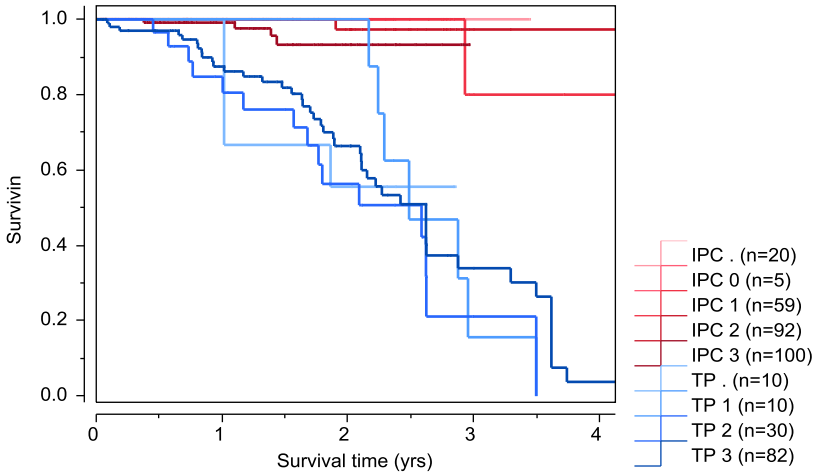


Figure 4. Kaplan-Meier Survival Analysis by Age (years)

Overall



Separately by each Caries Depth group

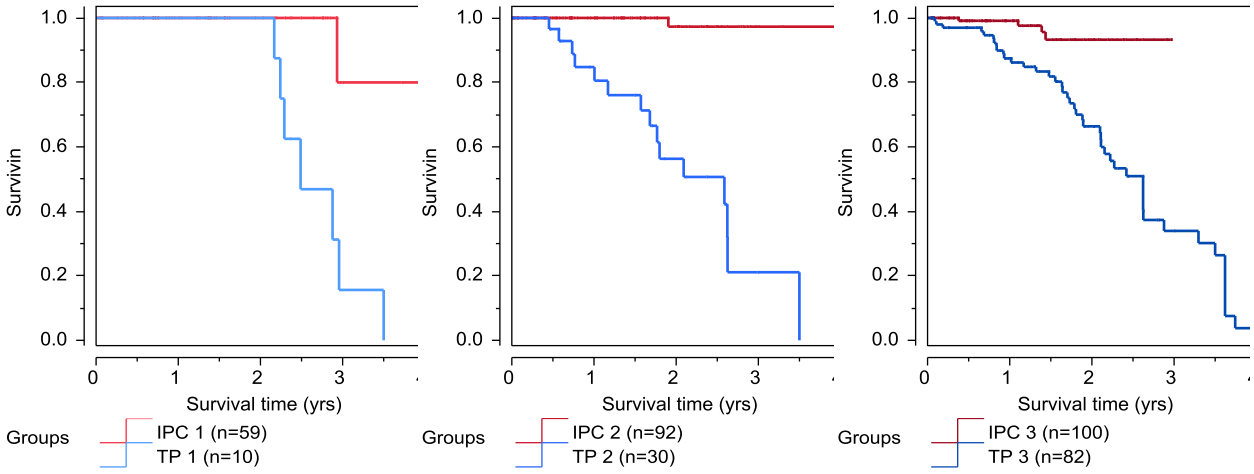


Figure 5. Procedure Differences Based on Caries Depth

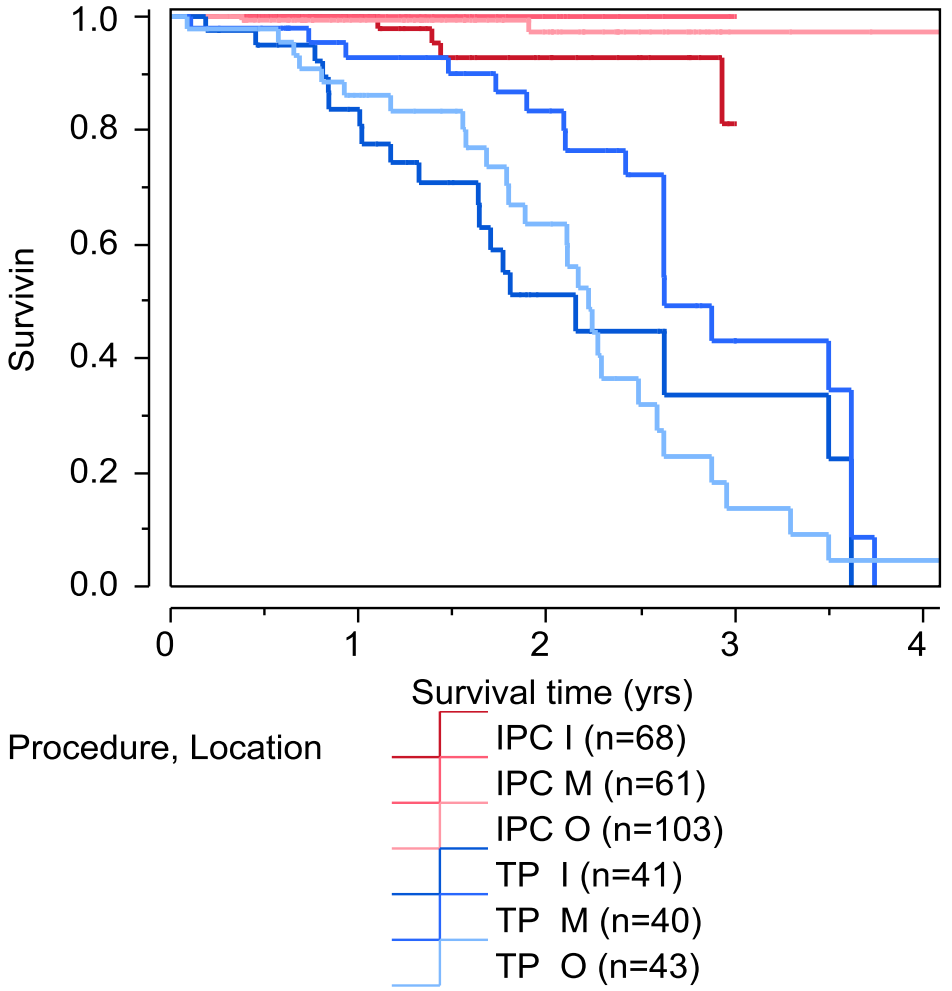


Figure 6. Procedure Differences Based on Caries Location

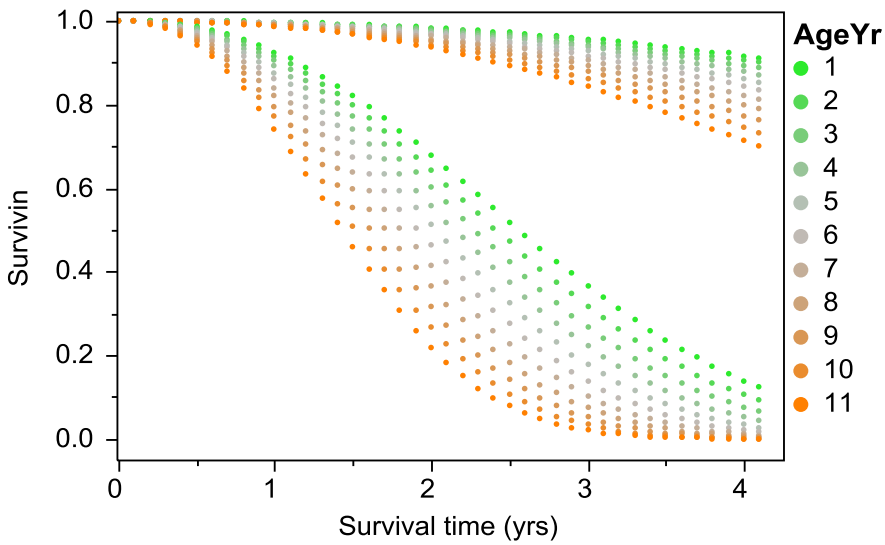


Figure 7. Average Survival Plot by Treatment and Age (Occlusal Caries)

Vita

Aaron Schmick was born on July 20, 1987. He was raised in Montoursville, Pennsylvania. He graduated magna cum laude with a Bachelor of Science in Biology from University of Pittsburgh in 2010. Aaron graduated dental school in 2014 from University of Pittsburgh School of Dental Medicine in Pittsburgh, PA. Immediately following graduation Aaron entered the Pediatric dental residency at Virginia Commonwealth University where he will complete his training in June 2016.