Can laser Doppler flowmetry evaluate pulpal vitality in traumatized teeth?

THESIS

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By

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Abstract

Background/Aim: Vascular supply is the most accurate measure of tooth vitality but current sensibility tests use indirect measures of subjective neural response. This study aimed to evaluate Laser Doppler Flowmetry for the assessment of pulp vitality in traumatized permanent teeth in a pediatric population. Materials and Methods: A Laser Doppler Flowmeter was used to measure blood flow in a total of 194 teeth from 51 subjects (mean age 10.1; range 6 to 16 years). Teeth were categorized into groups including revascularized (n=8), traumatized (n=85) and control (n=101). Blood flow was measured with the PeriFlux System 5000 Laser Doppler Perfusion Monitor using probe (PH 407-6) and affixed to each tooth. Tests were repeated for each erupted permanent incisor in the same arch as control. Subjects were followed to evaluate traumatized teeth for pulpal status and necrotic teeth were confirmed clinically with endodontic therapy. Results and Conclusions: Among traumatized teeth, there was no difference in pulpal blood flow based on pulp diagnosis ($P=0.08$). Identification of pulpal vitality in traumatized teeth is challenging. Laser Doppler flowmetry could not distinguish necrotic from healthy pulp tissue. The technique necessitates good patient co-operation with carefully controlled conditions that preclude its use on a pediatric population.
Dedication

For Pat. Thanks for your support throughout the past 2 years.
Acknowledgments

I would like to acknowledge Melissa Moore-Clingenpeel for her assistance with the statistical analysis of the data. I would also like to thank Carlee Ridgway, Rohit Joshi, and the pediatric dental residents and dental assistants from Nationwide Children’s Hospital for their assistance with data collection. This study was supported by CTSA grant #UL1TR001070.
Vita

2003 .........................................................Grosse Ile High School, Michigan

2007 ..........................................................B.S., Biology and Economics,
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2011 ..........................................................D.D.S., The University of Michigan

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Fields of Study

Major Field: Dentistry
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Introduction

Dental injuries are extremely common, ranging from 20% to 30% of the population (1-8). They are most frequent during the first 10 years of life with up to 92% occurring before the age of 19 and peaking between the ages of 9-15 (1-5). The majority of traumatic dental injuries (TDI) affect the maxillary anterior teeth in both the primary and permanent dentitions (3, 4). Most dental injuries occur when growth and development are taking place and often lead to treatment that continues throughout a patient’s life. Complications include discoloration, root resorption, pulp canal obliteration, pain and infection (4), with immature teeth more likely to be lost than completely developed teeth (9).

The burden of TDIs for both the pediatric patient and their family cannot be understated. Cost of treatment can be extensive and includes direct and indirect financial expenses as well as emotional costs including a lower oral health-related quality of life (10). The time commitment for treatment of dental trauma sequelae is significant for both the patient and their family with direct and indirect treatment times averaging 9 appointments for more extensive injuries (11, 12).

Careful monitoring of traumatized teeth contributes to the time consuming nature in the treatment of dental injuries. The clinician faces a dilemma between initiating endodontic therapy to limit poor outcomes and maintaining pulp vitality to encourage continued
maturation (13-15). This is because immature teeth that have been treated endodontically are more prone to root fracture due to thin, weak root walls (13, 16, 17). Newer regenerative techniques attempt to minimize these complications by using stem cells present at the apex of an immature tooth to induce continued root formation (18).

However, the ideal outcome of trauma, pulpal healing, is rare, occurring in approximately 8% of traumatized teeth, with pulp canal obliteration or pulpal regeneration occurring most frequently in immature teeth (9, 14, 19-21). The need to preserve pulp tissue must be balanced with reducing risk of pain and infection and other complications through early endodontic intervention.

It is commonly accepted that at least two signs or symptoms of irreversible pulp damage or necrosis are necessary to make a diagnosis due to the challenges with current measures of vitality (14). There is poor correlation between the histological status of the pulp and clinical signs and symptoms (22). Careful history-taking from the patient is an important tool, but children often have limited recall of painful episodes or are unable to adequately describe them (23). Clinical examination can reveal signs of irreversible pulpitis or necrosis and includes coronal discoloration, tenderness to percussion, changes in mobility and radiographic changes (22, 24). Radiographically, it can take several weeks to distinguish inflammatory processes as destructive reactions or part of normal healing.

Continued root maturation also takes considerable time to verify on a radiograph.

Vitality tests provide important information about the status of the pulp and are routinely used to assess the condition of a tooth. Commonly employed sensibility tests include
thermal testing with heat or cold, and electric pulp stimulation, which assess the pulpal vitality indirectly through the neural response (15, 22). However, true pulpal vitality is conferred by the vasculature. These subjective tests rely on a patient’s reaction and ability to accurately respond to a stimulus, which can be challenging in a child (25). The sensations are often described as unpleasant and may cause children to react negatively. Sensibility tests are unreliable when there is known damage to the neural tissues (22). It is well documented that immature teeth do not respond reliably to electric pulp tests (EPT) because the nerves are not fully developed and have a higher threshold for response (26, 27). In mature teeth, a lower threshold may indicate pulpal inflammation while a higher threshold may indicate pulp tissue undergoing necrosis (22). Cold tests appear to be more reliable across all stages of root development (26). However, with a history of recent trauma, both mature and immature teeth often have unreliable responses to vitality tests (14, 15, 27-30). The time until teeth respond normally to sensibility tests ranges from weeks to several years and relates to the severity of luxation injury, with an average of six months to establish sensibility (27-30). In addition, children are often unable to cooperate with vitality tests and have difficulty indicating accurate responses (31). This results in a situation where false positive and false negative vitality tests are common in recently traumatized teeth. Especially in a pediatric population, establishing an accurate diagnosis of pulp vitality is difficult using current methods.

A direct measure of the vasculature would provide a more accurate assessment of pulpal vitality. Laser Doppler flowmetry (LDF) was first described in 1975 for non-invasive detection of microcirculation in humans (32) and in 1986 for use on teeth (33). In LDF,
light is emitted by a sensor and is scattered by non-moving and moving blood cells, the majority of which are red blood cells. The laser light changes frequency according to principles of Brownian motion and some of the scattered light is returned to a photodetector. It is then processed, converting the signal into a perfusion value for pulpal blood flow (PBF) (34). This perfusion value, or flux, is dependent on both the number of moving cells in the tissue and their average velocity. The flux is defined in arbitrary “perfusion units” (PU) along a relative scale defined by a carefully controlled motility standard (35). LDF gives an objective value of PBF that does not rely on patient response and is non-invasive.

The ability to accurately diagnose pulp status in a recently traumatized tooth by directly assessing pulpal blood flow would allow more timely treatment. This would reduce the risk of pain, infection and complications including loss of the tooth, while allowing healthy teeth to continue root maturation. The goal of this study was to determine the feasibility of using laser Doppler flowmetry in a pediatric population. We examined PBF in healthy permanent teeth in these children. We also investigated the ability of LDF to distinguish necrotic pulp tissue from healthy permanent traumatized teeth, and evaluated the capability of LDF to monitor progression of a revascularization procedure. Finally, we compared LDF to other established sensibility tests for evaluation of pulpal vitality.
Methods

The study design was independently reviewed and approved by the Institutional Review Board (IRB) at Nationwide Children’s Hospital, Columbus, Ohio.

Subject selection. Subjects consisted of patients who presented to the Nationwide Children’s Hospital dental trauma clinic (Columbus, Ohio) between July and December 2014. Patients were recruited to the ‘Revascularization Group’ if they had any permanent anterior or posterior tooth that had pulpal regeneration procedures completed in the past. Patients were considered for the ‘Trauma Group’ if they had history of trauma to a permanent anterior tooth and had not yet received definitive pulpal treatment. A ‘Control Group’ consisted of all erupted incisors in the same arch as the study teeth.

Study design. All treatment was performed by pediatric dental residents at Nationwide Children’s Hospital dental trauma clinic as part of the routine treatment protocol for traumatized teeth based on the International Association for Dental Traumatology Guidelines. The sequence of treatment or management approach for traumatized teeth did not change if the patient enrolled in the study. Legal guardians provided informed consent for all participating subjects. Patients received radiographs based on risk assessment and length of time since previous imaging. Demographic data on patient age, ethnicity and sex were obtained. Date of initial trauma, initial fracture injury and initial periodontal injury were recorded for each tooth. Additionally, presence of a splint and
presence of a permanent or temporary restoration were recorded for each tooth. Vitality tests including percussion, palpation, thermal test (Endo-Ice, Coltene, Switzerland), and electric pulp test (Kerr Vitality Scanner, SybronEndo, California) were completed for all traumatized teeth. Mobility was assessed according to the Miller Scale (36). Presence or absence of a sinus tract and coronal discoloration were recorded. Patient behavior was rated for each subject according to the Frankl scale (37). The same tests were repeated for all teeth within the Trauma, Revascularization and Control Groups.

Apical development of all study and control teeth was determined according to the Moorees Scale, a common measure of tooth maturity (Figure 1) (38). Radiographs from the day of PBF measurement were shown to three standardized raters and a consensus of maturation status was reached. Teeth with stage 1 through 4 were considered “open” and stage 5 and 6 were considered “closed.” For some control teeth, radiographs were not available when the image was centered on the study teeth.

Apparatus. Pulpal blood flow (PBF) measurements were collected using a laser Doppler flowmeter (Periflux System 5000, Perimed, Stokholm, Sweden). Light with a wavelength 780 nm was produced by a diode laser within the flowmeter and transmitted to a probe (Probe 407, Perimed, Stokholm, Sweden) with a cross-sectional diameter of 1 mm containing 3 optical fibers of 125 µm and fiber-to-fiber distance of 250 µm. Time constant was set at 0.2. The flowmeter processed the amount of afferent Doppler-shifted light and produced an output signal converted into perfusion units. Data was sent to an IBM Lenovo Thinkpad (Lenovo, Morrisville, North Carolina) where it was stored and
analyzed using the manufacturer provided software (Perisoft for Windows, Perimed, Stockholm Sweden). The apparatus was calibrated prior to each data collection session with a colloidal suspension motility standard (PF1001, Perimed, Stockholm Sweden).

*Blood flow measurement.* Following all routine diagnostic treatment, study patients were transferred to a designated chair with the same researcher (MC) in order to standardize study tests. Blood pressure and pulse were obtained for all subjects.

All study teeth and controls were isolated with cotton rolls and dried with gauze. Probe holders *(PH)* (PH 407-6) (Perimed, Stockholm, Sweden) were fixed to the teeth using light-cured Kerr Premise Flowable Composite (Kerr, Orange, CA) in shade A1 without acid etching or applying bonding agent to the tooth and ensuring that no excess material came between the probe tip and the tooth. The Probe-407 was then inserted into the PH and was approximately 1-2mm from the gingival margin based on previous studies *(Figure 2)* (39). PHs could not be placed on teeth that had splints, some lower incisors or teeth that were not fully erupted, so the probe was held by hand. The patient was asked to remain still and blood flow from each tooth was recorded for a total of 30 seconds.

*Pulpal diagnosis.* Diagnosis of pulpal vitality status was established with routine vitality tests and radiographs, and was based on the last recorded vitality measurement in the patient’s record. Clinical records of each patient were monitored until December 31, 2014 to determine status at that time. If no pulpal treatment had been initiated prior to that date the pulp tissue was assumed to be vital (normal). Teeth that were categorized as
necrotic were verified by clinical observation of the pulp tissue during endodontic treatment.

Data analysis. The mean PU for each tooth was calculated during each session by averaging the individual PU collected over 30 seconds. Subjects were asked to remain still during the recording sessions to minimize movement artifact. Raw data was statistically analyzed using SAS version 9.3 (SAS Institute, Cary, North Carolina) and PBF values were found to be normally distributed. To compare PBF values between groups of teeth, mixed model analyses were done to account for repeated measures within patients. In order to determine whether any of the above factors would become significant after controlling for other important covariates, a series of stepwise mixed models was performed. ROC curve analysis was completed to determine which parameters could best identify necrotic teeth compared to healthy traumatized teeth. Statistical significance was set at $P<0.05$. 

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Results

A total of 51 patients (Table 1) were enrolled in the study and 194 teeth (Table 2) were investigated. Of these, 52% were control teeth, 44% were traumatized teeth and 4% were revascularized teeth with the majority being either permanent maxillary central or lateral incisors. By the end of the study period, 16% of the traumatized teeth were confirmed to be necrotic.

Among control teeth, PBF was analyzed based on age \((P=0.12)\), gender \((P=0.60)\), and race \((P=0.94)\) with no significant difference based on these patient-related factors (Table 3). PBF was then evaluated looking at tooth-level variables (Table 4). While there were not enough of all tooth morphotypes to analyze, among maxillary central and lateral incisors there was no significant difference in PBF \((P=0.99)\). Nor was there a difference based on arch (maxillary or mandibular) \((P=0.28)\) or stage of root development \((P=0.42)\). However, when controlling for apical developmental stage, age became a significant predictor of PBF, with each year increase in age correlated to a 3.31 unit decrease in PBF \((P=0.016)\).

There was no statistically significant difference in PBF between revascularized teeth and the control teeth \((P=0.12)\) (Table 4). Among traumatized teeth, PBF levels were not significantly different between necrotic and normal pulps \((P=0.08)\) (Table 4).
To evaluate reliability of the LDF readings, only control teeth of the same type within the same patient were analyzed for intra-correlation coefficient. Twenty-two patients had 2 control lateral incisors that could be investigated. Of the total variability, 11% can be attributed to the patient.

Alternative vitality measures including EPT, cold and the presence of coronal discoloration were compared to LDF using an ROC analysis to determine which parameters could best distinguish necrotic from normal pulps among the traumatized teeth (Table 5). Maximum sensitivity and specificity were determined using the Youden index. A combination of EPT and cold provided the best predictive ability, with a specificity of 93.1 but a low sensitivity of 35.7. Among individual measures, LDF had the highest sensitivity at 76.47, while the presence of a discolored crown had the highest specificity at 98.8.
Discussion

Traumatized teeth pose a challenge to the dentist, especially in a pediatric patient, where history taking can be difficult and the reliability of currently utilized vitality tests is less reliable due to presence of immature teeth and need for patient cooperation. Timely diagnosis of pulpal health is important to balance eliminating sources of bacteria for prevention of pain and infection with maintaining vitality for promotion of continued root maturation. In our present study, we evaluated the ability of LDF to assess PBF in the permanent teeth of children.

Among control teeth, our findings were consistent with other studies, which found increased age to be correlated with decreased PBF (40, 41). Other studies have had mixed findings related to whether tooth morphotype may play a role in the recorded pulpal blood flow (42-46) and, while our study could only compare two similar tooth types, we found no difference. There do not appear to be any studies that specifically evaluate the effect of tooth maturity in terms of apical closure on pulpal blood flow.

Under our experimental conditions, LDF did not show statistically different values in PBF between necrotic and healthy traumatized teeth. There was also no significant difference in PBF between revascularized and control teeth. Theoretically, necrotic teeth should have relatively lower perfusion than healthy teeth, which is the opposite of what
we found. This is likely due to the large variability in terms of standard deviation in our data.

Other authors have shown LDF to provide a valuable measure of vitality in traumatized teeth compared to EPT, pulse oximetry and CO₂ (47-49). However, these studies have been done under carefully controlled experimental conditions, and LDF has been noted to be very technique sensitive and time-consuming (45, 50-53). Conditions suggested to maximize consistency of LDF readings include use of temperature-controlled environments; allowing patients to rest prior to measurement; use of rigid splints to minimize movement artifact and ensure consistent probe placement on the crown; and use of a rubber dam to minimize contamination from gingival blood flow with as much as 80% of the value not attributed to pulpal tissues (34, 39, 40, 42, 45, 54, 55). In our study, we chose to use a PH directly fixed to the teeth with cotton roll isolation for ease of use. In 28% of control teeth, however the probe was held by hand due to presence of splint or partially erupted teeth making holder fixation impossible. Standard error was much higher in these teeth without PHs, representing 59% of total PBF, while variability was 19% of total PBF for teeth with PH used, confirming that even small movements can affect signal. Our chosen methodology is likely the reason for the large variability in recorded PBF values. However, analyzing teeth with only PH used did not change the results significantly. One other study attempted to determine the feasibility of LDF in a private practice setting where the temperature was not controlled and no splints were used (51). They also were not able to reliably determine a difference in PBF between vital and necrotic teeth and found that the values were not reproducible.
Other sources of variability include various optical properties of the tooth that affect the penetration of laser light (45). Traumatized teeth are more likely to be discolored and have restorations or splints present, which have been related to lower reliability of LDF readings (45, 56). This is especially true in revascularized teeth, where placement of MTA in the coronal third of the root and a restoration is necessitated by the technique. In our study, revascularized teeth had the largest variability in PBF. In addition, case reports using LDF to monitor changes in pulpal blood flow over time often show an initial period of ischemia followed by renewed blood supply for up to 6 months in teeth that retain vitality (16, 57, 58). Our study did not control for time since injury and evaluated many different types of traumatic injuries.

LDF may be better used to measure changes over time to predict long-term vitality (52, 59-62). Several studies have attempted to establish specific diagnostic cut-off criteria for LDF that will predict vitality or necrosis in injured teeth (50, 63-69). It is important to note that flux values of PBF are not comparable between different devices and it may be difficult to compare temporally within devices because of the need for careful calibration and consistent placement of the probe (45).

In a comparison of LDF with other established measures of pulpal vitality, it is interesting to note that LDF had the highest sensitivity but was slightly lower than what has been reported previously (64). This is likely due to the high variability and the technique used for probe fixation in our study. However, the combination of EPT and cold provided the highest overall accuracy in detection of healthy and necrotic teeth. In
our study, the specificity of these tests was similar to other reported values. However, the sensitivity in our population was much lower, 35.7, compared to established values of up to 90 (47, 70, 71). Sensitivity is a measure of true positive, or the ability of a test to accurately detect disease. For EPT and cold tests, this implies the absence of a response. However, in a tooth that is becoming devital, the neural tissues are the last to necrose and thus a tooth can still have limited response to stimulation (22). Additionally, children often learn avoidance techniques for objectionable situations (72). By indicating a response even in the absence of one, they are able to decrease the unpleasantness of the stimuli. Thus, even if a tooth is indeed necrotic, a child is more likely to respond to sensibility tests, which further decreases overall sensitivity. We were unable to find another study that reported sensitivity and specificity of EPT or cold tests in a pediatric population and this is something that warrants further investigation.

Other limitations of LDF include the time consuming nature of measurements. Our protocol measured each tooth for 30 seconds, a shorter time compared to most other studies, yet took an average of 10 to 15 minutes for each patient. In addition, devices are currently prohibitively expensive, with average cost of $20,000 USD.

There is a need to find techniques that can directly assess pulpal blood flow for assessment of true pulpal health. At this time, LDF with our clinical protocol does not provide a reliable method to distinguish healthy from diseased pulps. Alternative devices include pulse oximetry and ultrasound Doppler flowmetry. Pulse oximetry assesses percentage of oxygen saturation in arterial hemoglobin by measuring light absorbance
and is similar to the pulse oximetry used in other medical fields (73). However, the presence of mostly arterioles rather than arteries in the pulp tissue and the hard tissue insulation make pulse detection more difficult and a lack of tooth-specific probes on the market limits the ability of the photodetectors to function properly (74). Ultrasound Doppler flowmetry uses a probe that emits ultrasonic waves, which reflect off moving red blood cells. Ultrasound Doppler flowmetry can show real-time wave patterns and gives blood flow rates in absolute velocity of moving cells (75, 76). However, this is still a relatively new use of ultrasound technology.
**Conclusion**

In this study, LDF was tolerated well by pediatric patients. However, there was large variability in the PBF values using this technique. LDF could not distinguish between healthy and necrotic pulp tissue among traumatized teeth. It was also not able to reliably discriminate revascularized teeth from control teeth and had the largest variability within this group. We found LDF to be very technique-sensitive and due to these limitations did not find it feasible for use in routine clinical practice.
Appendix A. Figures

Stage 1: ¼ anticipated root length formed
Stage 2: ½ anticipated root length formed
Stage 3: ¾ anticipated root length formed
Stage 4: Full anticipated root length, no apical closure
Stage 5: Full anticipated root length, apical foramen ½ closed
Stage 6: Full anticipated root length, apical foramen constricted

Figure 1. Moorrees scale of dental development.
Figure 2. An example of the LDF probe holder in place. Teeth were isolated with cotton rolls and the probe holder was placed 1-2mm from the gingival margin. The Probe 407 was inserted into the probe holder.
## Appendix B. Tables

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age in years</strong></td>
<td>10.1</td>
<td>6 – 16</td>
</tr>
<tr>
<td><strong>Gender</strong></td>
<td>N</td>
<td>%</td>
</tr>
<tr>
<td>Female</td>
<td>16</td>
<td>31</td>
</tr>
<tr>
<td>Male</td>
<td>35</td>
<td>69</td>
</tr>
<tr>
<td><strong>Ethnicity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Caucasian</td>
<td>25</td>
<td>49</td>
</tr>
<tr>
<td>African American</td>
<td>16</td>
<td>31</td>
</tr>
<tr>
<td>Other</td>
<td>10</td>
<td>20</td>
</tr>
</tbody>
</table>

*Table 1.* Demographic data by subject, N=51.

<table>
<thead>
<tr>
<th>Teeth Type</th>
<th>Total (N=194)</th>
<th>Control (N=101)</th>
<th>Trauma (N=85)</th>
<th>Revascularized (N=8)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maxillary Central</strong></td>
<td>N (%)</td>
<td>N (%)</td>
<td>N (%)</td>
<td>N (%)</td>
</tr>
<tr>
<td></td>
<td>94 (48)</td>
<td>27 (27)</td>
<td>60 (71)</td>
<td>7 (87)</td>
</tr>
<tr>
<td><strong>Maxillary Lateral</strong></td>
<td>82 (42)</td>
<td>65 (65)</td>
<td>16 (19)</td>
<td>0 (0)</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td>18 (10)</td>
<td>8 (8)</td>
<td>9 (10)</td>
<td>1 (13)</td>
</tr>
<tr>
<td><strong>Apical Status</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Closed</td>
<td>134 (69)</td>
<td>67 (66)</td>
<td>62 (73)</td>
<td>5 (62.5)</td>
</tr>
<tr>
<td>Open</td>
<td>51 (26)</td>
<td>25 (25)</td>
<td>23 (27)</td>
<td>3 (37.5)</td>
</tr>
<tr>
<td>Undetermined</td>
<td>9 (5)</td>
<td>9 (9)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
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</table>

*Table 2.* Demographic data by tooth.
### Table 3. PBF based on patient-level variables, control teeth only.

<table>
<thead>
<tr>
<th>Age</th>
<th>N (%)</th>
<th>PBF (PU)</th>
<th>SE</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>101 (100)</td>
<td>-1.7355</td>
<td>1.0826</td>
<td>0.1149</td>
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<table>
<thead>
<tr>
<th>Gender</th>
<th>N (%)</th>
<th>PBF (PU)</th>
<th>SE</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>28 (28)</td>
<td>12.7072</td>
<td>5.254</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>73 (72)</td>
<td>16.0229</td>
<td>3.3389</td>
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<table>
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<tr>
<th>Race</th>
<th>N (%)</th>
<th>PBF (PU)</th>
<th>SE</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caucasian</td>
<td>48 (47)</td>
<td>17.1115</td>
<td>4.326</td>
<td></td>
</tr>
<tr>
<td>African American</td>
<td>32 (32)</td>
<td>13.8263</td>
<td>5.0892</td>
<td></td>
</tr>
<tr>
<td>African</td>
<td>12 (12)</td>
<td>12.2725</td>
<td>7.8871</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>9 (9)</td>
<td>13.9607</td>
<td>9.577</td>
<td></td>
</tr>
</tbody>
</table>

### Table 4. PBF based on tooth-level variables, control teeth only.

<table>
<thead>
<tr>
<th>Tooth Type</th>
<th>N (%)</th>
<th>PBF (PU)</th>
<th>SE/SD (SD)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxillary Central</td>
<td>27 (27)</td>
<td>11.535</td>
<td>11.87</td>
<td>0.9928</td>
</tr>
<tr>
<td>Maxillary Lateral</td>
<td>66 (65)</td>
<td>14.8346</td>
<td>12.55</td>
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</table>

<table>
<thead>
<tr>
<th>Apical Development</th>
<th>N (%)</th>
<th>PBF (PU)</th>
<th>SE/SD (SE)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open</td>
<td>25 (25)</td>
<td>10.7458</td>
<td>5.4142</td>
<td>0.4172</td>
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<tr>
<td>Closed</td>
<td>67 (66)</td>
<td>15.9024</td>
<td>3.4219</td>
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</table>

<table>
<thead>
<tr>
<th>Arch</th>
<th>N (%)</th>
<th>PBF (PU)</th>
<th>SE/SD</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxillary</td>
<td>93 (92)</td>
<td>14.1515</td>
<td>2.9355</td>
<td>0.2836</td>
</tr>
<tr>
<td>Mandibular</td>
<td>8 (8)</td>
<td>25.1327</td>
<td>9.7027</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Traumatized Pulp Status</th>
<th>N (%)</th>
<th>PBF (PU)</th>
<th>SE/SD</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Necrotic</td>
<td>14 (16)</td>
<td>22.9431</td>
<td>6.0507</td>
<td>0.0819</td>
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<tr>
<td>Normal</td>
<td>70 (82)</td>
<td>15.0074</td>
<td>2.6331</td>
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</tbody>
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<table>
<thead>
<tr>
<th>Revascularized Status</th>
<th>N (%)</th>
<th>PBF (PU)</th>
<th>SE/SD</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>101 (52)</td>
<td>14.3425</td>
<td>2.9814</td>
<td>0.1209</td>
</tr>
<tr>
<td>Revascularized</td>
<td>8 (4)</td>
<td>0.3326</td>
<td>7.6648</td>
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</table>
Table 5. Analysis of sensitivity, specificity and predictive ability of various vitality tests for pulpal necrosis in traumatized teeth, N=85.

<table>
<thead>
<tr>
<th>Predictors</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Area Under ROC Curve</th>
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</thead>
<tbody>
<tr>
<td>LDF</td>
<td>76.47</td>
<td>47.58</td>
<td>0.5584</td>
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<tr>
<td>Cold</td>
<td>35.7</td>
<td>91.6</td>
<td>0.6973</td>
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<tr>
<td>EPT</td>
<td>21.4</td>
<td>92.5</td>
<td>0.6045</td>
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<tr>
<td>Discoloration</td>
<td>7.1</td>
<td>98.8</td>
<td>0.5297</td>
</tr>
<tr>
<td>Cold + EPT</td>
<td>35.7</td>
<td>93.1</td>
<td>0.7014</td>
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</table>
Bibliography


