2015

Lowering the Number of False Positive Responses to Electric Pulp Tests by Qualifying Patient Response

Katherine JS Lee
Virginia Commonwealth University

Lowering the Number of False Positive Responses to Electric Pulp Tests by Qualifying Patient Response

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

by

Katherine Jane Southwell Lee
Doctor of Dental Surgery Virginia Commonwealth University 2009
Bachelor of Science College of William and Mary 2004

Director: Karan J. Replogle, DDS, MS
Director of Advanced Specialty Education Program in Endodontics,
Virginia Commonwealth University Department of Endodontics

Virginia Commonwealth University
Richmond, Virginia
May 2015

Dedication

For my husband, Jimmy. Thank you for your all of your help and encouragement. I could not have done this without your support. I love you.

Table of Contents

Table of Tables

Table of Figures

Abstract

LOWERING THE NUMBER OF FALSE POSITIVE RESPONSES TO ELECTRIC PULP TESTS BY QUALIFYING PATIENT RESPONSE

By Katherine Jane Southwell Lee, BS, DDS

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

Virginia Commonwealth University, 2015

Karan Replogle, DDS, MS
Director of Advanced Specialty Education Program in Endodontics, Department of Endodontics

The electric pulp test (EPT) has been shown to be a valuable tool in assessing pulp vitality. One of its drawbacks, however, is its high number of false positives. The purpose of this study was to determine if qualifying the type of sensation elicited by the test could lower the percentage of false positive responses. A retrospective chart review of an eleven-month period was conducted, examining all patients with necrotic teeth tested with the EPT. Of 189 teeth, when the patient responded to EPT at first sensation 23.3% of teeth were incorrectly identified as vital. When the patient was asked to respond only if they felt an uncomfortable sensation, the false positive rate was lowered to 8.5%, a statistically significant difference. No association was found between the teeth reclassified as necrotic and age, gender, type of tooth, or number of canals.

Introduction

In order to ensure that the correct treatment is provided, establishing an accurate diagnosis is a critical component of an endodontic evaluation. An important part of making that diagnosis is determining whether the pulpal tissue of the tooth in question is vital or necrotic. One of the most well established tools for the evaluation of pulp vitality is the electric pulp test, or EPT(1).

The EPT measures the vitality of the dental pulp indirectly, by sending a gradually increasing electrical current through the tooth to stimulate a sensory response. Every tooth is innervated by sensory fibers arising from the trigeminal nucleus. These afferent fibers enter into the tooth at the apical foramen in large nerve bundles. As they approach the coronal region of the dental pulp, in the center of the tooth, they diverge into smaller bundles. These bundles continue to fan out into increasingly smaller groups of nerves, eventually forming the plexus of Raschkow, a mesh of single neurons at the periphery of the pulp. The terminal axons of these neurons shed the Schwann cells responsible for their myelination, and pass between the odontoblasts ending before, at, or slightly in the dentinal tubules (2,3).

Two types of sensory nerve fibers exist in the dental pulp: myelinated (A fibers) and unmyelinated (C fibers). Both A fibers and C fibers are nociceptors, neurons that respond to potentially damaging stimuli be sending signals to the central nervous system that will be interpreted as pain. C fibers are generally located in the center of the tooth, and innervate the body of the pulp, while A fibers extend to the periphery of the pulp, and are responsible for innervation of the dentinal tubules. Over 90% of the A fibers are A-delta fibers, and the

remaining ones are A-beta fibers. The A-beta fibers may be slightly more sensitive than A-delta fibers, but functionally these fibers are grouped together (2,3).

A fibers at the dentin-pulp border are generally stimulated by movement of fluid in dentinal tubules, caused by drilling, air-drying, or the sudden application of cold or heat. The rapid movement of fluid across the cell membrane of the axon terminal stimulates the axon's mechanoreceptors. If the stimulation is sufficiently large, it will trigger voltage gated sodium channels to depolarize, sending a nerve impulse up the A fiber and towards the brain. This is felt as an acute, sharp pain (3). In contrast, the smaller, unmyelinated C fibers mediate a dull, burning, poorly localized pain. A stimulant must reach the pulp proper to activate the C fibers, which have a much higher threshold than A fibers (2). The sensory fibers stimulated by an EPT are generally the A fibers located at the border of dentin and pulp. The EPT current overcomes the resistance of the enamel and dentin to reach these fibers and provoke a measurable response. C fibers do not usually respond to EPT, as they require significantly more current for stimulation than an EPT provides (4).

Electrical tests have been used in dental diagnosis for many years. The earliest use of electrical current in dentistry is attributed to Magitot. He applied electricity to teeth in an attempt to localize caries, and described his methods in his book *Treatise on Dental Caries*, published in France in 1867. The first use of electricity to test for vitality is believed to have been by Marshall in 1891, predating radiographs in dentistry by more than 70 years (5). For many years, dentists attempted to correlate not just the vitality, but also the pulpal health of the tooth with the results of electrical pulp tests (2). In 1963, Seltzer and Bender showed that clinical signs and symptoms (including results of the EPT) could not be directly correlated to the histologic status of the pulp

(6,7). Mumford also demonstrated no direct correlation between pulpal histology and response to EPT (8). Lundy and Stanley corroborated these findings in their 1969 study, but also emphasized that a negative reading for the EPT does occur when the pulp is necrotic (9).

Electric pulp tests used prior to the mid 1950's were generally bipolar (10). Electrodes were placed on both the buccal and lingual surfaces of the tooth to be tested, and the current was run through the crown of the tooth, from one electrode to the other. Most EPT's used today are monopolar, so only one electrode is placed on the tooth. To run current through the tooth, an electrical circuit is completed by means of a metal clip attached to the patient's lip, or by having the patient hold the metallic handle of the EPT (5). Both alternating current and direct current EPT's are available, but little difference has been found between them in performance (11). The relative amount of current applied is shown on various scales depending on the exact model of EPT, but is most commonly 1-80. If a patient feels sensation before the current scale reaches the maximum level of 80, the practitioner records their response to the electric pulp test as positive. This positive response is associated with pulp vitality. If the patient feels no sensation, and the scale reaches 80/80, the response to the EPT is considered negative. This negative response is associated with pulp necrosis (12).

Because electric pulp testers can be very technique sensitive, many studies have been done on proper technique during EPT use. It is very important to dry and isolate the tooth prior to testing, to reduce the chance of the current flowing along the wet tooth surface down to the gingival tissue and creating a false positive response (13). After drying the tooth, to ensure adequate current flow between the electrode and the tooth surface, it is essential to place a conducting medium on the electrode tip (13). Any medium can be used, as there is no

appreciable difference in efficacy between different conducting mediums, as long as they are water or petroleum based (14). It has also been found that setting the EPT to a slowly increasing current (less than 5 microAmps/second) is preferable both for accurate reading and patient comfort (15).

Several studies have also been done on the optimal placement of the EPT tip. It is generally agreed that for anterior and premolar teeth, placing the EPT tip on the incisal edge results in the fastest and strongest response with the least amount of current (16, 17). While there is not as much consensus for electrode placement on posterior teeth, a study by Lin et al. found that the mesiobuccal cusp tip is the optimum site for pulp testing first molars (18). If a tooth is crowned, but there is a small amount of tooth structure visible between the margin of the crown and the gingival tissue, the EPT electrode can be bridged to that tooth structure via any conductive instrument such as a file an explorer or a reamer (19).

Although often referred to as a pulp vitality test, the EPT is, strictly speaking, a pulp sensibility test, since it measures the ability of the dental pulp to respond to a stimulus. When a patient responds to the current from an EPT, no definitive information is gleaned concerning the integrity of the tooth's vascular tissue. A response simply indicates that there are intact A-delta fibers in the tooth capable of responding to a stimulus (20). The absence of any response, therefore, suggests that there are not any functioning sensory fibers in the tooth, and is associated with pulpal necrosis of the tooth being tested (12).

A true pulp vitality test measures the blood supply of the dental pulp directly. Two true pulp vitality tests do currently exist, laser Doppler flowmetry and pulse oximetry. Laser Doppler flowmetry assesses the blood flow in a tooth by passing a laser light through the tooth, and

measuring the percentage of light reflected off of moving red blood cells in the tooth's pulp (21). Pulse oximetry uses a probe placed on the tooth to measure the oxygen concentration of blood within the tooth. While both true vitality tests do show great promise (pulse oximetry tests have been found to be more reliable in determining pulpal status than EPT and cold tests) they are not commonly used to assess pulp vitality due to expense, time and technique sensitivity (22-24). For example, both pulse oximetry and laser Doppler flowmetry require natural tooth structure, and cannot be used through restorations. Additionally, both tests require careful isolation of the tooth in question with a rubber dam or foil to avoid interference from the gingival tissue adjacent to the tooth (25).

As a result of the difficulties currently present with true vitality tests, practitioners today continue to rely on sensibility tests to determine the vitality of pulps. EPT's are routinely used in conjunction with cold tests, since if an untraumatized adult tooth does not respond to cold or EPT, there is a very high probability that the tooth is no longer vital (1). In fact, the use of cold test in combination with EPT to test for vitality provides more accurate results than using either of the tests individually (26). EPTs are also particularly helpful when assessing older teeth and calcified teeth that are vital but respond negatively to cold as a result of limited flow of fluid through dentinal tubules caused by increased secondary dentin deposition (10).

One of the biggest challenges with EPTs are false positives, which occur when a patient reports a positive response to EPT (a sensation is felt at less than 80/80), indicating vitality even though the tooth is necrotic. Weisleder found in 2009 that only 75% of necrotic teeth responded negatively to EPT, giving a false positive rate of 25% for EPT (26). In Petersson's 1999 evaluation of various pulp testing methods, only 72% of necrotic teeth were correctly identified

as necrotic by EPT, giving a false positive rate of 28% (27). In his 2013 study on the predictive values of dental pulp tests, Villa-Chavez found that 12 out of 50 necrotic teeth had sensitive results to EPT, a false positive rate of 24% (28). In all of these studies, the false positive rate of cold tests was significantly lower. Peters, Baumgartner and Lorton had similar results in their 1994 study. They agreed that false positive responses are more likely to occur with EPT than cold testing, and found that while most false positives to cold testing occur in multi-rooted teeth, the number of false positive responses to EPT was evenly spread throughout the dentition (1).

Several factors have been identified as possible causes of these false positives. The conduction of current to adjacent gingival or periodontal tissues may elicit a false response (21). In fact, Peters et al were able to lower the number of false positives significantly by defining a positive response to EPT as a response greater than the response elicited when the probe was placed directly against the gingival tissue (1). Young or anxious patients who are fearful of an uncomfortable sensation may also be responsible for false positives (29). Additionally, necrotic and disintegrating tissues could be capable of conducting current to pulp tissue located further apically in the tooth, where intact A-delta fibers still exist (29). It has also been suggested that current conducts to adjacent teeth through metallic restorations (30).

In many of the studies previously done on EPTs, the patient was instructed simply to notify the practitioner as soon as he or she experienced any sensation during testing (1, 12, 27, 28). The practitioner did not qualify the type of response he or she was trying to elicit from the patient with the EPT. The EPT has been reported to elicit a variety of sensations, described in one study as vibration, tingling, pulsating or cold (13). Some of these sensations are perceived as uncomfortable, and some are not (31).

Anecdotal findings from experienced practitioners suggest that during testing of potentially necrotic teeth, the EPT will elicit a response which the patient does not find uncomfortable. If the patient is then educated on the type of response the EPT should elicit, and asked to repeat the EPT, stopping as soon as an uncomfortable response is elicited, the test will run to 80/80 with no response from the patient. The tooth, when subsequently accessed, is invariably necrotic. If the EPT had been stopped at the initial response, the test would have provided a false positive response, confusing the diagnosis. No literature exists as to whether qualifying the type of response to EPT in this manner helps to reduce the number of false positive responses, and thus improve the EPT's specificity (or ability to correlate a negative response with a necrotic pulp).

When diagnosing pulpal disease, it is not uncommon to have patients present describing symptoms of necrosis. Upon evaluation, clinical symptoms of necrosis, such as a developing radiolucency, are found. Yet when a cold test is performed, the patient states that he or she feels cold in the tooth. The pre-op diagnosis then becomes problematic. According to AAE diagnoses, this would be irreversible pulpitis, and some practitioners would classify it as such. Others would diagnose it as pulpal necrosis, and indeed, when the tooth is opened it is often necrotic. This is further complicated if the patient responds to EPT (a false positive response if the tooth is in fact necrotic). The purpose of this study was to determine if it is possible to qualify patient response to EPT in such a way that the percentage of false positive responses to EPT is decreased. Doing so would increase the number of correct pre-op diagnoses, and help to reduce diagnostic confusion.

Materials and Methods

The protocol for this study was approved by the Institutional Review Board of Virginia Commonwealth University. Data was collected from Virginia Commonwealth University's electronic medical records (axiUm) for all patients 18 years old and above, seen in the Virginia Commonwealth University Department of Endodontics Graduate Practice between January 15, 2014 and November 15, 2014 who had a necrotic tooth that was tested with an Electric Pulp Tester (EPT).

According Virginia Commonwealth University Department of Endodontics Graduate Clinic protocol, the indications for EPT use were as follows:

1. If a tooth tests negative (non-responsive) to cold (Endo Ice placed with #2 cotton pellet on dry tooth).
2. If the response to cold is inconsistent with the periapical status (a positive response to cold when a sinus tract or PAP is present).

Two types of EPT's were used in the clinic during this timeframe: Elements Diagnostic Unit (Sybron Orange, Ca) and the SybronEndo Vitality Scanner (Sybron Orange, Ca). Testing using the EPT was completed by residents, and was standardized as follows:

If a tooth was questionable (required EPT testing as described above) that tooth, as well as two other asymptomatic untreated teeth within the quadrant were tested. If two other teeth were not available in that quadrant, opposing or contralateral teeth were substituted as controls.

Teeth to be tested were air dried and isolated with cotton rolls. The EPT was set so the current increased slowly (less than 5 microamps/second). The probe tip was covered with toothpaste and placed on the incisal third or cusp tip (mesiobuccal cusp if tooth was a first molar and not crowned) of each tooth. If one of the teeth to be tested was crowned, the EPT test was run by bridging the EPT to a small instrument that could be placed between the margin of the crown and the gingiva. The practitioner (graduate endodontic resident) asked the patient to raise his or her hand as soon as a response was felt. All responses were recorded with a number (1/80-80/80). If no response was felt, 80/80 was recorded.

Depending on the results of the initial testing of the questionable tooth, a second round of testing was completed by the resident. If the EPT response was negative (ran to 80/80 with no response from the patient), the results of the test were recorded, and upon access, the actual vitality of the pulp was recorded. However, if the EPT tested positive (a response was felt by the patient prior to 80/80) the results were recorded, and the patient was then asked to repeat the test, raising their hand as soon as any uncomfortable stimulation was felt. This repeat test was also performed on an adjacent control tooth that was not symptomatic and not previously treated.

The results of the second round of EPT testing were recorded in the notes along with the results of the first test. When root canal therapy was initiated, the pulp chamber was visually inspected and the actual vitality of the pulp was also recorded. Upon access, any tooth that appeared partially necrotic was recorded as necrotic.

The data retrospectively collected from each chart included: the initial EPT reading and the second EPT reading (if applicable) for the tooth in question as well as a control tooth, the

type of tooth tested (anterior, premolar or molar), the number of canals present upon access, the gender and age of the patient, and the vitality of the tooth upon access.

This data was then analyzed to find out if there was a significant difference between the number of false positives for any response compared to the number of false positives for the first uncomfortable response using McNemar's test. Specificity (TN/(TN+FP)) was defined as in Weisleder's study as the proportion of non-cases identified correctly by means of the diagnostic test (26) . These specificity percentages were estimated and score 95% confidence intervals estimated. Tests for associations were performed by chi-square test or logistic regression, as appropriate.

Results

The results are presented in four sections. The first describes the patients and teeth included in the study. The second reports the specificity of a single EPT test and the specificity of a second re-qualified EPT test. The third describes other factors and their association with the teeth that changed from the first test to the second. In the remaining section, analyses of the changes and of the control teeth are described.

Patients and Teeth

A total of 189 charts were extracted from the axiUm medical records system and included in the subsequent analysis. There were 181 patients in the study. The number of males and females was nearly identical (90 and 91, respectively). The average age was 48.2 years (SD=17.9, range = 18 to 95). Table 1 shows the characteristics of the teeth studied. More than half were molars or multi-rooted. Of the 188 teeth with percussion recorded, 68% (128) were positive.

Figure 1. Patient Flow

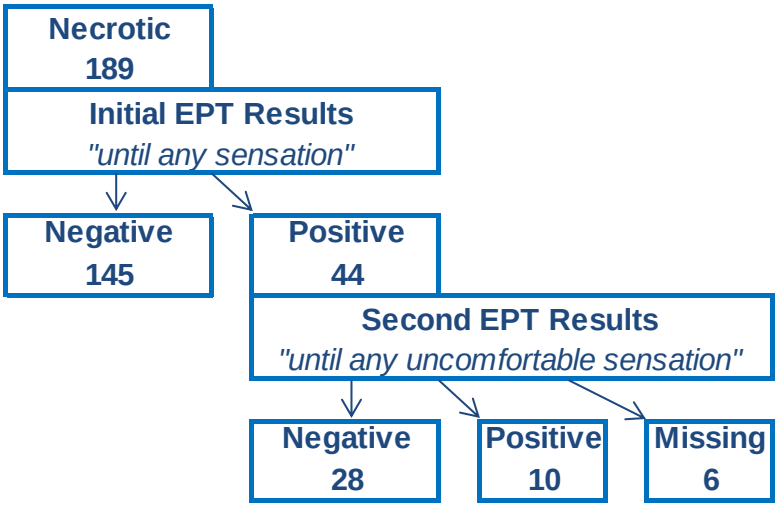


Table 1. Teeth Characteristics

Characteristic	N	Percent
type of tooth		
anterior	50	26.5
premolar	44	23.3
molar	95	50.3
# of canals		
M	119	63.0
S	70	37.0
Arch		
Mandibular	70	37.0
Maxillary	119	63.0
Left Right		
Left	81	42.9
Right	108	57.1
Tooth Groups		
Incisor	39	20.6
Canine	11	5.8
Premolar	44	23.3
Molar	95	50.3
Tooth Type		
I1	24	12.7
I2	15	7.9
C	11	5.8
P1	17	9.0
P2	27	14.3
M1	65	34.4
M2	30	15.9

Note: Percentages may not sum to 100% owing to rounding.

EPT findings

All 189 teeth were initially tested with the EPT—this was an eligibility requirement for the study. The tooth-by-tooth results are listed in the Appendix, Table 4. As Figure 2 shows, in 76.7% of the cases (145/189) there was no response to EPT, and thus 80/80 was recorded by the practitioner. As all 189 of these teeth were necrotic upon access, the specificity of an initial EPT is only 76.7% (95% CI = 70.2 to 82.2%). In other words, the EPT correctly identified the tooth as necrotic 76.7% of the time.

There was no statistically significant association between the 145 teeth that initially tested 80/80 and location, number of canals, tooth type, gender or age (Table 2).

Table 2. EPT Results are Unrelated to Tooth Characteristics, Gender or Age

	Initial 80/80		Subsequent 80/80		
Characteristic	N	Percent	N	Percent	P-value
Location					0.4739
Anterior	36	24.8	10	35.7	
Premolar	35	24.1	5	17.9	
Molar	74	51.0	13	46.4	
Number of canals					0.4861
Multiple	93	64.1	16	57.1	
Single	52	35.9	12	42.9	
Tooth Type					0.8328
I1	15	10.3	5	17.9	
I2	12	8.3	3	10.7	
C	9	6.2	2	7.1	
P1	15	10.3	1	3.6	
P2	20	13.8	4	14.3	
M1	49	33.8	9	32.1	
M2	25	17.2	4	14.3	
Gender					0.5092
Female	73	50.3	16	57.1	
Male	72	49.7	12	42.9	
Age					0.4307
mean		49.3		46.4	
SD		17.7		20.3	

Note: Percentages may not sum to 100% owing to rounding.

For the teeth that were positive for the first EPT test (values below 80), the protocol was for them to be tested again with different instructions (notifying the practitioner only if they experienced an *uncomfortable* sensation). The results are shown in Figure 3. Of these 44 cases, 6 did not have a second testing recorded in the notes. In the remaining cases, 28 had no response to EPT when tested again, and thus were correctly identified as necrotic. 10 were positive to the second EPT test, still testing incorrectly as vital. This second test increased specificity to 91.5%

(173/189, 95% CI = 86.7% to 94.7%). Or, if the 6 missing second measurements are not counted, the specificity was even higher, at 94.5% (173/183, 95% CI = 90.2 to 97.0%).

Figure 2. Distribution of Initial EPT Findings

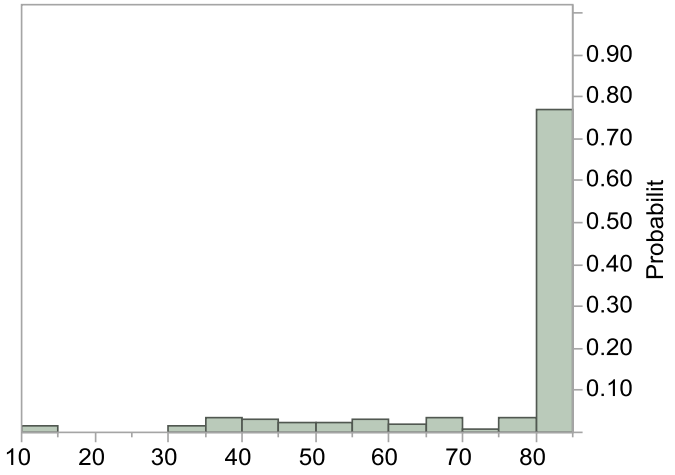
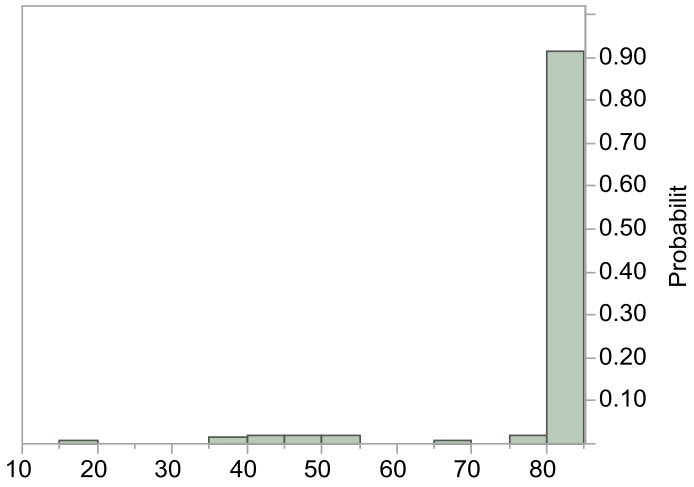


Figure 3. Distribution After Second EPT Findings



The second test's specificity was a statistically significant improvement (McNemar's chi-square $P < .0001$).

Analysis of change

There were 28 of 189 cases whose EPT results changed from vital on the first measurement to necrotic on the second. There was no statistically significant association between change and tooth type (P>0.4), multi-rootedness (P>0.5), sex (P>0.5), age (P>0.4), or percussion (P>0.5).

Change in EPT in test and control teeth

There were 38 control teeth for which an EPT result was recorded. The control teeth's initial EPT results averaged 27.1 (SD = 14.9, range = 7 to 62) and the 25 control teeth that were tested a second time had an average of 29.0 (SD = 16.7, range = 8 to 64). The second control teeth EPT results were significantly higher (paired t-test P = 0.0076).

For the vital control teeth, 0/25 tested necrotic (80/80) when the test was repeated and the patient asked to respond only if the sensation was uncomfortable. This is a statistically significant difference compared to the 28/38 necrotic teeth that tested necrotic (80/80) when the test was repeated. (P<.0001)

Discussion

An initial false positive rate of 23.3% for EPT was found in this study. This is in agreement with previous studies by Petersson, Weisleder, and Villa-Chavez, who reported false positive rates for EPT of 28%, 25% and 24%, respectively (26-28). By educating the patient to respond only if an uncomfortable sensation was felt, the false positive rate was lowered to 8.5%, significantly changing the number of necrotic teeth incorrectly classified as vital. If the six initial false positives for which there was no repeat testing recorded due to resident compliance are excluded, the false positive rate drops even further, to 5.5%.

By redefining for the patient what type of response the EPT should elicit, the percentage of teeth correctly identified as necrotic was raised from 76.7% to 91.5%. It is important to note that when the response was redefined and the test repeated on 25 vital control teeth, none of them were taken to 80/80 and incorrectly identified as necrotic. From this, it can be concluded that changing the EPT response from the first sensation to the first uncomfortable sensation decreases the number of false positive responses to EPT without increasing the number of false negatives.

The results also showed that there was statistically significant association between the teeth that were changed from false positives to true negatives and the gender of the patient. This is in agreement with findings by Fuss et al., who showed that the EPT is equally reliable in male and female patients (12). There was also no statistically significant association with age. This

may have been different if the study had included pulp testing for patients under age 18, since it has been shown that EPT is less reliable for patients age 9 to 13 years old (12).

It was theorized by the authors of this study that the necrotic teeth that could be changed from false positives to true negatives would be more likely to be teeth with multiple canals and/or roots. Teeth with multiple canals could have vital tissue in one canal, capable of responding to EPT, and necrotic tissue in another canal. The results showed no statistically significant association, however, between the teeth 28 teeth reclassified as false negatives and the number of canals or type of tooth (anterior, premolar, or molar). This agrees with previous research that found false positive responses to EPT were spread evenly throughout the dentition (1).

Additionally, there was no correlation between the teeth that changed from false positives to true negatives and percussion sensitivity. Because no statistically significant association was found between the 28 teeth reclassified as necrotic and age, gender, multi-rootedness, type of tooth or percussion sensitivity, the authors of this study found no reliable way to predict the cases in which qualifying patient response could change a false positive response to EPT to a true negative.

There are other studies that have tweaked the definition of a "positive" response to EPT in an attempt to lower the number of false positives. Peters et al tested the EPT on the gingiva prior to testing the tooth, and only EPT responses lower than the gingival response were considered positive (1). Fuss et al mentions that the patient was taught to distinguish between pressure and pulp sensitivity prior to initiating testing (12). Villa Chavez et al defines positive

responses as those below 70, and Petersson et al considered only responses below 50 as positive (27, 28).

At least one study of EPT's does exist in which "any pain was recorded as a positive response" (22). The author does not elaborate on why the EPT was used in this manner, when most EPT studies ask patients to simply respond at the first sensation (1, 12, 27, 28). The study herein is the first study to definitively show that by qualifying the type of response to EPT as uncomfortable, the number of false positives can be significantly lowered.

There is, however, potential bias to consider in this study. Not all necrotic teeth that came into the VCU Graduate Endodontic Practice between January 15, 2014 and November 15, 2014 were tested with the EPT. The EPT was not used on full coverage restorations that extended below the level of the gingiva. It was also not used on some necrotic teeth, even when the Graduate Endodontic Practice protocol dictated that it should, due to poor resident compliance. Additionally, because the practice protocol dictates that the EPT does not need to be used if the patient has a positive response to cold, there were potentially necrotic teeth with a false positive response to cold that were never tested with EPT.

Another potential source of bias was the manner in which the EPT was used. Over the eleven months in which our data was collected, twelve different graduate endodontic residents treated patients. These twelve residents were all instructed to use the EPT per VCU Graduate Endodontic Practice protocol. However, due to time constraints, residents may not have always strictly adhered to the instructions for increasing the current at less than five microamps/second, isolating the tooth properly, and explaining to the patient when to respond. There were six instances when the resident likely suspected a tooth to be necrotic due to a negative response to

cold and/or a periapical radiolucency, yet when the EPT tested positive, the test was not repeated per practice protocol.

The practitioners (residents) were not blinded when conducting the tests and assessing the vitality of the teeth upon access. This is a third source of potential bias. Prior to clinical testing the resident had already received a history of symptoms from the patient and often seen a radiograph. This knowledge might have affected how he or she chose to record their findings, since he or she may have already been expecting a certain result. As Mejare et al point out, determining whether or not a pulp is necrotic, partially necrotic or vital based on visualization alone is a subjective exercise, and may be even more so if the practitioner already expects a certain pulpal status (32).

Because this was a retrospective study that examined charts, some assumptions were made if data was missing or unclear, which may have provided an additional potential source of bias. If a resident found a tooth to be partially necrotic upon access, it was recorded as necrotic. Additionally, if a resident diagnosed a tooth as necrotic, but failed to record the tooth's pulpal status upon access, it was assumed to be necrotic, since no mention was made otherwise in the resident's note.

The only teeth included in this study were either necrotic teeth that presented to the VCU Graduate Endodontic Practice for treatment, or what was assumed to be healthy, vital control teeth in those same patients. There were no questionable teeth included—asymptomatic teeth with deep carious lesions, for example. In other words, a very narrow spectrum of diseased pulps were used. This is important because a recent study by Mejare et al examined Petersson's previous study on specificity and sensitivity of pulp testing, and found that the spectrum of

diseased pulps included in a diagnostic EPT study can influence the specificity and sensitivity results (32).

For the purposes of this study, a false positive for EPT was defined as a positive response in a non-vital tooth. A thorough review of the endodontic literature that examines pulp sensibility tests revealed inconsistencies in the profession's definition of a false positive. While several studies also chose to define a positive response to EPT in a non-vital tooth as a false positive, there were multiple landmark studies that chose to define this same response as a false negative (1, 12, 13, 26-28, 32). This discrepancy in the definition of a false positive resulted in inconsistent definitions of sensitivity and specificity as well.

Table 3. Differing Definitions of Sensitivity and Specificity

			Condition of Pulp	
	Endo	Conventional	Necrotic Pulp	Vital Pulp
EPT Test Results	Negative (80/80)	=Disease	True Positive (TP)	False Positive (FP)
	Positive (<80/80)	=Vital	False Negative (FN)	True Negative (TN)
			↓ Sensitivity [TP/(TP+FN)]	↓ Specificity [TN/(TN+FP)]

			Condition of Pulp	
	Endo	Conventional	Necrotic Pulp	Vital Pulp
EPT Test Results	Negative (80/80)	=Disease	True Negative (TN)	False Negative (FN)
	Positive (<80/80)	=Vital	False Positive (FP)	True Positive (TP)
			↓ Specificity [TN/(TN+FP)]	↓ Sensitivity [TP/(TP+FN)]

Petersson et al, for example, defined a sensitive result to EPT in a necrotic tooth as a false negative rather than a false positive. Petersson's study reasoned that because the objective of a test is to find disease, a positive EPT result is 80/80, since this connotes disease. Therefore a tooth that tests vital (<80/80 and thus negative for disease) but is in fact necrotic is a false negative. Since specificity is universally defined as the proportion of true negatives, or TN/(TN+FP), specificity in their paper measured the ability of a test to identify teeth without disease (vital pulps). So specificity is the percentage of vital teeth correctly identified as such. This was also how Villa-Chavez et al and Mejare et al chose to define their results (28, 32) .

Several other studies, however, chose to define a sensitive result to EPT in a necrotic tooth as a false positive (1, 12, 13, 26). This is inherently less confusing because, as a profession, when a tooth responds to cold or EPT, dentists tend to consider that a positive response, even though the result indicates that the tooth is testing negative for disease. In Weisleder et al's study, for example, a necrotic tooth that responded to EPT was considered a false positive. Specificity, or TN/(TN+FP), was defined as "the proportion of non-cases identified correctly by means of a diagnostic test" (26). So specificity is the percentage of necrotic teeth correctly identified as such. This was also how Fuss et al, Peters et al, and Cooley et al chose to define their results (1, 12, 16).

This study found a specificity of 76.7% initially. In other words, upon initial testing, 76.7% of necrotic teeth were correctly identified as necrotic. Petersson et al, Villa-Chavez et al, and Mejare et al would all have defined 76.6% as the sensitivity of the EPT, while Fuss et al, Peters et al, and Cooley et al would all define 76.7% as the specificity of the EPT. When reviewing endodontic literature regarding pulp vitality testing, the reader should pay close

attention to the author's definitions of false positive, false negative, sensitivity and specificity, since it is not consistent throughout all papers.

The findings of this study are relevant in multiple situations. In an academic setting, when cold and EPT tests produce conflicting results or do not agree with radiographic or clinical findings, it can be confusing for the dental student who is new to sensibility testing and unsure how to proceed. By lowering the number of false positive responses to EPT, confusion during diagnostic testing is reduced. Because lowering the false positives was accomplished in this study via patient education, it illustrates for dental students the importance of good communication with the patient during clinical testing.

The ability to lower the percentage of false positive responses EPT is also helpful for the seasoned practitioner. A more accurate EPT reading will be of use in perplexing diagnostic situations, such as when subjective and objective data are in conflict, when odontogenic versus non-odontogenic etiology is in question, or when the use of an anti-inflammatory medication masks symptoms.

The argument could be made that the specificity of EPT is unimportant because the clinician could just rely on cold to test for pulp vitality. However, it has been shown that the use of cold test in combination with EPT to test for vitality provides more accurate results than using either of the tests alone (26). By lowering the number of false positive responses to EPT, perhaps accuracy could be increased even more. Additionally, the EPT is particularly helpful in older patients who do not respond reliably to cold testing as a result of increased secondary dentin deposition and occlusion of dentinal tubules (10).

The argument could also be made that specificity of EPT is unimportant, since the EPT is of limited value because it does not distinguish between health and disease. A tooth with irreversible pulpitis responds positively to EPT, while a necrotic tooth responds negatively to EPT. So even though they have different responses to EPT, both teeth are diseased, and both teeth would benefit from non-surgical root canal therapy. If the recommended treatment is the same, the question could be asked why does it matter what the EPT findings are? As the endodontic profession explores and moves forward towards regeneration of pulp tissue, a diagnosis of vitality versus necrosis is more important than ever, and may change the recommended treatment.

In conclusion, this study demonstrated that the percentage of necrotic teeth incorrectly classified by EPT as vital could be reduced from 23.3% to 8.5% if patients were asked to respond to EPT only if the sensation they felt was uncomfortable. The majority of false positives were reclassified as true negatives when the response was qualified in this manner. No statistically significant association was found between these teeth and gender, age, multi-rootedness, type of tooth or percussion sensitivity. Qualifying patient response as uncomfortable did not change the number of vital teeth correctly identified as vital by the EPT.

References

1. Peters DD, Baumgartner JC, Lorton L. Adult pulpal diagnosis. I. evaluation of the positive and negative responses to cold and electrical pulp tests. J Endod. 1994 Oct;2010:506-11.

2. Lin J, Chandler NP. Electric pulp testing: A review. Int Endod J. 2008 May;41(5):365-74.

3. Trowbridge HO. Review of dental pain--histology and physiology. J Endod. 1986 Oct;12(10):445-52.

4. Narhi M, Virtanen A, Kuhta J, Huopaniemi T. Electrical stimulation of teeth with a pulp tester in the cat. Scand J Dent Res. 1979 Feb;87(1):32-8.

5. Jafarzadeh H, Abbott PV. Review of pulp sensibility tests. part II: Electric pulp tests and test cavities. Int Endod J. 2010 Nov;43(11):945-58.

6. Seltzer S, Bender IB, Ziontz M. The dynamics of pulp inflammation: Correlations between diagnostic data and actual histologic findings in the pulp. Oral Surg Oral Med Oral Pathol. 1963 Aug;16:969-77.

7. Seltzer S, Bender IB, Turkenkopf S. Factors affecting successful repair after root canal therapy. J Am Dent Assoc. 1963 Nov;67:651-62.

8. Mumford JM. Pain perception threshold on stimulating human teeth and the histological condition of the pulp. Br Dent J. 1967 Nov 7;123(9):427-33.

9. Lundy T, Stanley HR. Correlation of pulpal histopathology and clinical symptoms in human teeth subjected to experimental irritation. Oral Surg Oral Med Oral Pathol. 1969 Feb;27(2):187-201.

10. Ehrmann EH. Pulp testers and pulp testing with particular reference to the use of dry ice. Aust Dent J. 1977 Aug;22(4):272-9.

11. Carrotte P. Endodontics: Part 2 diagnosis and treatment planning. Br Dent J. 2004 Sep 11;197(5):231-8.

12. Fuss Z, Trowbridge H, Bender IB, Rickoff B, Sorin S. Assessment of reliability of electrical and thermal pulp testing agents. J Endod. 1986 Jul;12(7):301-5.

13. Cooley RL, Stilley J, Lubow RM. Evaluation of a digital pulp tester. Oral Surg Oral Med Oral Pathol. 1984 Oct;58(4):437-42.

14. Michaelson RE, Seidberg BH, Guttuso J. An in vivo evaluation of interface media used with the electric pulp tester. J Am Dent Assoc. 1975 Jul;91(1):118-21.

15. Abdel Wahab MH, Kennedy JG. The effect of rate of increase of electrical current on the sensation thresholds of teeth. J Dent Res. 1987 Mar;66(3):799-801.

16. Cooley RL, Robison SF. Variables associated with electric pulp testing. Oral Surg Oral Med Oral Pathol. 1980 Jul;50(1):66-73.

17. Bender IB, Landau MA, Fonsecca S, Trowbridge HO. The optimum placement-site of the electrode in electric pulp testing of the 12 anterior teeth. J Am Dent Assoc. 1989 Mar;118(3):305-10.

18. Lin J, Chandler N, Purton D, Monteith B. Appropriate electrode placement site for electric pulp testing first molar teeth. J Endod. 2007;33(11):1296-8.

19. Pantera EA,Jr, Anderson RW, Pantera CT. Use of dental instruments for bridging during electric pulp testing. J Endod. 1992 Jan;18(1):37-8.

20. Bhaskar SN, Rappaport HM. Dental vitality tests and pulp status. J Am Dent Assoc. 1973 Feb;86(2):409-11.

21. Rowe AH, Pitt Ford TR. The assessment of pulpal vitality. Int Endod J. 1990 Mar;23(2):77-83.

22. Dastmalchi N, Jafarzadeh H, Moradi S. Comparison of the efficacy of a custom-made pulse oximeter probe with digital electric pulp tester, cold spray, and rubber cup for assessing pulp vitality. J Endod. 2012 Sep;38(9):1182-6.

23. Gopikrishna V, Tinagupta K, Kandaswamy D. Comparison of electrical, thermal, and pulse oximetry methods for assessing pulp vitality in recently traumatized teeth. J Endod. 2007;33(5):531-5.

24. Jafarzadeh H, Abbott PV. Review of pulp sensibility tests. part I: General information and thermal tests. Int Endod J. 2010 Sep;43(9):738-62.

25. Newton CW, Hoen MM, Goodis HE, Johnson BR, McClanahan SB. Identify and determine the metrics, hierarchy, and predictive value of all the parameters and/or methods used during endodontic diagnosis. J Endod. 2009 Dec;35(12):1635-44.

26. Weisleder R, Yamauchi S, Caplan DJ, Trope M, Teixeira FB. The validity of pulp testing: A clinical study. J Am Dent Assoc. 2009 Aug;140(8):1013-7.

27. Petersson K, Soderstrom C, Kiani-Anaraki M, Levy G. Evaluation of the ability of thermal and electrical tests to register pulp vitality. Endod Dent Traumatol. 1999 Jun;15(3):127-31.

28. Villa-Chávez CE, Patiño-Marín N, Loyola-Rodríguez JP, Zavala-Alonso N, Martínez-Castañón GA, Medina-Solís CE. Predictive values of thermal and electrical dental pulp tests: A clinical study. J Endod. 2013;39(8):965-9.

29. Dummer PM, Hicks R, Huws D. Clinical signs and symptoms in pulp disease. Int Endod J. 1980 Jan;13(1):27-35.

30. Myers JW. Demonstration of a possible source of error with an electric pulp tester. J Endod. 1998;24(3):199-201.

31. Chambers IG. The role and methods of pulp testing in oral diagnosis: A review. Int Endod J. 1982 Jan;15(1):1-15.

32. Mejare IA, Bergenholtz G, Petersson K, Tranaeus S. Estimates of sensitivity and specificity of electric pulp testing depend on pulp disease spectrum: A modelling study. Int Endod J. 2015 Jan;48(1):74-8.

Appendices

Table 4. Frequency Count, Tooth number by EPT Result

		Initial EPT result		Second EPT result		
Tooth #	Total	Necrotic	Vital	Necrotic	Vital	missing
2	8	8	0	8	0	0
3	10	7	3	8	0	2
4	3	3	0	3	0	0
5	5	5	0	5	0	0
6	2	2	0	2	0	0
7	2	2	0	2	0	0
8	10	3	7	6	1	3
9	10	8	2	10	0	0
10	7	6	1	7	0	0
11	5	4	1	5	0	0
12	8	7	1	8	0	0
13	13	7	6	10	2	1
14	29	24	5	27	1	1
15	7	4	3	6	0	1
18	9	8	1	9	0	0
19	8	4	4	6	0	2
20	7	7	0	7	0	0
21	1	0	1	0	0	1
23	2	1	1	2	0	0
24	2	2	0	2	0	0
25	2	2	0	2	0	0
26	4	3	1	4	0	0
27	4	3	1	4	0	0
28	3	3	0	3	0	0
29	4	3	1	4	0	0
30	18	14	4	17	0	1
31	6	5	1	6	0	0

Notes: Necrotic=EPT 80 (negative), Vital=EPT <80 (positive), missing=not done. If the initial EPT was necrotic then the second EPT was not done and the results are shown here as though the second EPT was also necrotic.