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Identification of Resected Root-End Dentinal Cracks: A Comparative Study of Transillumination and Dyes

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The dilemma of diagnosing and possibly treating dentinal cracks continues to present a challenge in endodontics. The purpose of this in vitro study was to compare the effectiveness of transillumination and dyes in identifying root-end dentinal cracks. Fifty maxillary central incisors were decoronated, and the canals were instrumented to an ISO size 50 at the working length. The apical 3 mm of the roots was resected, and cracks were artificially created in the apical dentin. Four independent examiners evaluated the root ends at ×8 magnification with a surgical operating microscope using transillumination (group 1), sodium fluorescein dye (group 2), caries detect dye (group 3), methylene blue dye (group 4), and methylene blue plus transillumination (group 5). The examiners' ability to identify root ends correctly with and without cracks was analyzed by comparing the data with the predetermined standard (cracked and noncracked) using logistic regression analysis. All techniques used were shown to be more effective than random chance at diagnosing cracks. The areas under the curve of the different techniques were as follows: transillumination, 0.81 (95% confidence interval [CI], 0.69–0.93); sodium fluorescein, 0.72 (95% CI, 0.58–0.86); caries detector, 0.76 (95% CI, 0.63–0.89); methylene blue, 0.70 (95% CI, 0.55–0.84); and methylene blue plus transillumination, 0.82 (95% CI, 0.70–0.94). Thus, the crack assessment techniques that gave the best discrimination between cracked and noncracked specimens, regardless of rater, was methylene blue plus transillumination. This study emphasizes the usefulness of transillumination along with magnification in detecting dentinal cracks.

Root-end resection and ultrasonic preparation are commonly performed during apical surgery and could reveal or potentially create cracks in the root dentin. The dilemma of diagnosing dentinal cracks continues to present a challenge in endodontics. Many authors have evaluated resected root ends before and after root-end preparations, producing varying results. Layton et al. (1) described three types of cracks: canal cracks, intradentin cracks, and cemental cracks. They defined canal cracks as originating within the canal. These cracks are described as complete or incomplete, depending on whether they reach the external surface of the root. Intradentin cracks were described as being confined to dentin only, and cemental cracks as radiating from the cemental surface to the dentinal-cemental junction. They found that 18% of the roots were cracked after resection, and that 43% were cracked after root-end preparation with ultrasonic tips. Saunders et al. (2) discovered that 21% of the roots were cracked after root-end preparation with high-speed burs and ultrasonic tips. In a study by Abedi et al. (3), 28% of the roots revealed cracks after resection, and 62% showed cracks after root-end preparation with high-speed burs or stainless steel ultrasonic tips. Rainwater et al. (4) found that 8% of the root ends showed microcracks after resection, and 68% showed cracks after root-end preparation with stainless steel ultrasonic tips, diamond-coated ultrasonic tips, and high-speed burs. Frank et al. (5) discovered that the retropreparation of a root end creates a risk of generating cracks varying from 14% to 40%, depending on the method of preparation and the morphology and thickness of the root. Beling et al. (6) found that 15% of the roots showed cracks after resection, and that 20% were cracked after root-end preparation with ultrasonic tips.

Unaided vision seems inadequate, in most instances, to evaluate resected root ends properly during periapical surgery. Bellizzi and Loushine (7) encouraged the use of enhanced illumination and magnification as adjuncts for posterior surgery, as did Rubinstein (8) and Carr (9). Improved lighting and magnification has been provided by multiple sources: fiber optic headlamps and loupes, the surgical operating microscope, and the fiberoptic endoscope (10). Several authors have also suggested the use of methylene blue dye (1, 11) and transillumination (1, 11) as aids in detecting cracks in teeth. The definitive diagnosis of a failing nonsurgical endodontic case, in many situations, may be determined only during surgical exposure through direct inspection of the resected root surface. Because it can be speculated that the presence of dentinal cracks could negatively affect the successful treatment outcome, accurate diagnosis of these cracks would provide the clinician with important information to advise the patient better on

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the long-term prognosis of the endodontic treatment. The purpose of this in vitro study was to compare the effectiveness of transillumination and dyes in identifying root-end dentinal cracks.

MATERIALS AND METHODS

Fifty extracted, fully formed, human permanent maxillary central incisors were used for this in vitro study, none of which had previous endodontic therapy. They were kept in 100% humidity until used. After the removal of the clinical crown, an ISO size 10 Flexofile (DENTSPLY/Maillefer, Tulsa, OK) was inserted into the root canal and instrumented to the apical foramen to ensure patency. The working length was defined as 0.5 mm short of the foramen. Gates Glidden drills (DENTSPLY/Maillefer) were used to enlarge the root canal to a length approximately 5 mm short of the working length. The remaining 5 mm of the root canal was instrumented with 0.04 taper Profiles (DENTSPLY/Tulsa, Tulsa, OK) and Flexofiles with a step-back method to ISO size 50 at the working length. The apical 3 mm of each root was then resected perpendicular to the long axis using a multipurpose bur (DENTSPLY/Maillefer) in a high-speed handpiece with water spray. To ensure that no cracks were present after the resection, the root ends were evaluated at ×50 magnification with a video microscope (Micro Enterprises, Norcross, GA).

Dentinal cracks were then created in 25 experimental teeth by the following method. A cylindrical wedge with a 1.12-mm maximum diameter was placed in a miniature drill press on a top-loading balance and was inserted into the apical canal space of the tooth. The video microscope at ×50 magnification was focused on the tooth apex, and a 3-kg load was slowly applied to the tooth until dentinal cracks were observed, after which the load was immediately removed. Of the 25 cracked teeth, two teeth were eliminated from the study because of excessive separation that was visible to the naked eye. Twenty-three of the remaining 25 specimens that received the same 3-kg load but did not develop cracks were also used in this study, resulting in a total of 46 experimental teeth (23 cracked and 23 noncracked teeth).

The specimens were prepared for viewing by stretching a rubber dam with a hole punched in the center over the top of an empty film canister, secured with an elastic ligature. The root was then positioned in the rubber dam such that 2 mm of the resected apex was exposed. Five plastic trays were used as a viewing platform, each designed with 10 numbered wells, to accommodate the 46 specimens and film canisters. The trays containing the canisters and specimens were placed in a humidor before and after each viewing session.

For each of the five techniques evaluated, the teeth were randomized before each viewing session and arranged in the numbered wells within the trays. All 46 specimens were evaluated with a surgical operating microscope (Global, St. Louis, MO) at ×8 magnification by four independent examiners (three endodontists, one endodontic resident). In group 1, the teeth were viewed using a 2.0-mm–diameter fiber optic light source for transillumination (O'Ryan, Vancouver, WA). In group 2, the resected root surfaces were evaluated after staining with a 0.25% sodium fluorescein ophthalmic solution (Bausch and Lomb Pharmaceuticals, Tampa, FL) using a cobalt blue filter (Welch Allyn, Skaneateles, NY) on a transilluminator (Welch Allyn) to enhance the detection of the fluorescent stain. In group 3, the root ends were evaluated after staining with Snoop caries detecting dye (Pulpdent Corp., Watertown, MA), and with 2% methylene blue dye (Ocean Medical, Victoria, TX) in group 4. All dyes were allowed to remain on the resected root surface for 30 seconds, were rinsed with tap water for 5 seconds, and were dried with a brief air blast. The methylene blue dye group was rerandomized and examined with the addition of transillumination in group 5. For groups 1, 2, and 5, the surgical operating microscope light was turned off to enhance the effect of the transillumination or the fluorescent dye. After the sodium fluorescein and caries detect experiments, the teeth were soaked overnight in small plastic vials containing tap water to remove the previous dye.

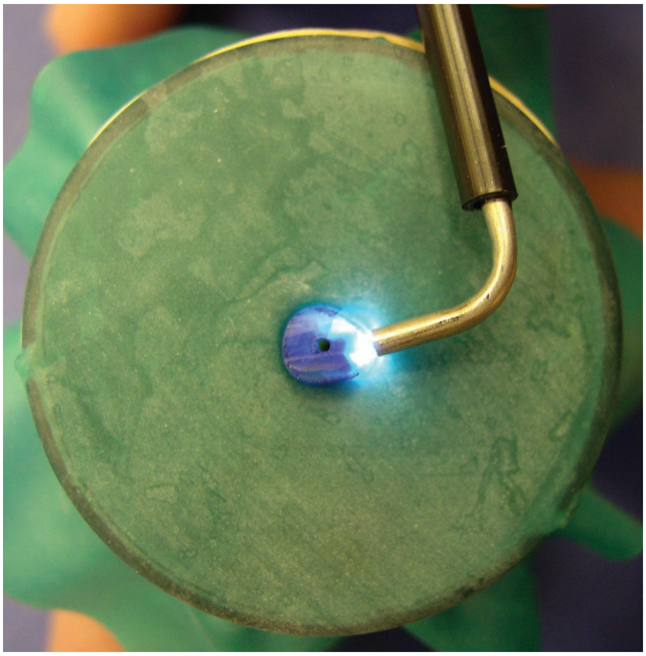

FIG 1. The model system used for viewing consisted of a rubber dam stretched over a film canister and secured with an elastic ligature. The root end was positioned in a punched hole such that 2 mm of the resected apex was exposed for transillumination.

The trays containing the specimens were placed on a bench top and viewed from a seated position. The examiner was not permitted to pick up the tray or change its orientation. The examiner was also permitted to orient the fiber optic light source on the root end only from the 4 o'clock to the 8 o'clock position (Fig. 1). For each specimen, a diagnosis of either cracked or not cracked was made and recorded. These responses were then compared to the known data on cracked and not cracked teeth.

Statistical Analysis

The data were analyzed by logistic regression. The logistic function is equivalent to fitting a linear regression mode, but the continuous outcome has been replaced by the logarithm of the probability of crack identification. Here, we used it to evaluate the efficacy of dyes and transillumination to identify cracks correctly in resected apical root dentin. The outcome variables calculated included sensitivity, defined as the probability of a diagnostic procedure indicating that the root is cracked, given that root is truly cracked; and specificity, defined as the probability of a diagnostic procedure indicating that the root is not cracked, given that the root is truly not cracked. Also calculated was the positive predictive value of each procedure, calculated as the probability that the root

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TABLE 1. Sensitivity (Se), specificity (Sp), positive predictive value (PPV), negative predictive-value (NPV), and AROC for each rater with each assessment method

Method/rater	Se	Sp	PPV	NPV	AROC	95% CI for AROC
Transillumination						
W	0.85	0.74	0.79	0.81	0.80	0.67–0.92
L	1.00	0.44	0.68	1.00	0.72	0.58–0.86
K	0.67	0.96	0.95	0.71	0.81	0.69–0.93
M	0.93	0.48	0.68	0.85	0.70	0.56–0.85
Sodium fluorescein						
W	0.74	0.74	0.77	0.71	0.74	0.60–0.88
L	0.89	0.39	0.63	0.75	0.64	0.49–0.79
K	0.19	0.87	0.63	0.48	0.53	0.37–0.69
M	0.89	0.70	0.77	0.84	0.79	0.67–0.92
Caries detector						
W	0.52	0.87	0.82	0.61	0.69	0.55–0.84
L	0.93	0.65	0.76	0.88	0.79	0.66–0.91
K	0.33	0.91	0.82	0.54	0.62	0.47–0.78
M	0.59	0.91	0.89	0.66	0.75	0.62–0.89
Methylene blue						
W	0.63	0.78	0.77	0.64	0.71	0.56–0.85
L	0.74	0.43	0.61	0.59	0.59	0.43–0.75
K	0.30	1.00	1.00	0.55	0.65	0.50–0.80
M	0.59	0.83	0.80	0.63	0.71	0.57–0.85
Methylene blue plus transillumination						
W	0.74	0.91	0.91	0.75	0.83	0.71–0.94
L	0.96	0.52	0.70	0.92	0.74	0.61–0.88
K	0.78	0.83	0.84	0.76	0.80	0.68–0.92
M	0.89	0.61	0.73	0.82	0.75	0.61–0.88

is truly cracked given that the diagnostic procedure indicated it is cracked. This is the most important outcome clinically. The opposite of this is the negative predictive value, which was also calculated. It is the probability that the root is truly not cracked, given that the diagnostic procedure indicates it is not cracked. When sensitivity is plotted against (1-specificity), the resulting curve is called a *receiver operating characteristic* curve that has a slope of 1. That is, the probability that the root is truly cracked (i.e. the true-positive rate) is plotted against (1-specificity), the probability that the root is not cracked when in fact it is cracked (i.e. the false-negative rate). When probability data are distributed above the slope of 1, it indicates that the diagnostic test is better than random chance. The degree to which the diagnostic data are distributed above the random chance is quantitated by calculating the area under the curve (AROC). Random chance yields areas between 0 and 0.5. To be useful as predictors, the AROC for diagnostic procedures should be between 0.6 and 1.0. The AROC values for each rater, with the dependent variable the true cracked status of the specimen and the independent variable the rater's assessment, were calculated along with their 95% confidence intervals (CIs) (12). Finally, to determine whether one rater had significantly better ability to discriminate between cracked and noncracked roots within diagnostic procedures, pair-wise multiple comparisons of AROCs between raters within procedures were made (13). Because of the number of tests performed within a particular procedure, a Bonferroni adjustment was made to the overall α level of 0.05 so that each pair-wise test was assessed using an α level of $0.5/6 = 0.0083$.

RESULTS

Table 1 summarizes the sensitivity, specificity, and positive and negative predictive value for each crack detection technique for each rater, the AROC of a graph of sensitivity versus 1 minus the specificity (that is, the true-positive diagnoses versus the false-negative diagnoses), and the 95% CIs for the AROC. The AROC values (Table 1) were very good for transillumination and methylene blue plus transillumination. Within any detection technique, there were no significant differences among raters (p values for tests not shown, but all were >0.0083). The overall AROC values were as follows: transillumination, 0.81 (95% CI, 0.69–0.93); sodium fluorescein, 0.72 (95% CI, 0.58–0.86); caries detector, 0.76 (95% CI, 0.63–0.89); methylene blue, 0.70 (95% CI, 0.55–0.84); and methylene blue plus transillumination, 0.82 (95% CI, 0.70–0.94). Thus, the technique that provided the best AROC, or the best discrimination between cracked and noncracked resected roots, regardless of rater, was methylene blue plus transillumination.

DISCUSSION

Saunders et al. (2) suggested that dentinal cracks could lead to failure of the treatment because of microleakage. Frank (5) stated, "one cannot equate infractions with subsequent root fractures, but the potential for later fractures must be considered." According to Saunders et al. (2), there is justified speculation as to whether these dentinal cracks would affect success over time. The clinical significance of these cracks is speculative, but they may be of concern if there are residual bacteria present or if coronal leakage occurs; bacteria may colonize in these cracks. Over time, these cracks could also expand and contribute to leakage of the root-end filling and subsequent clinical failure. Abedi et al. (3) found that the formation of dentinal cracks was a function of the ultrasonic unit power setting, time of ultrasonic application, and thickness of the remaining dentin. It would seem prudent that if pretreatment microcracks are detected or if thin dentinal walls are present, then the

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power setting of the ultrasonic and time of application should be adjusted to minimize the chance for crack creation or further crack propagation.

In an effort to make this study as clinically relevant as possible, the teeth were examined with only 2 mm of the root exposed above the rubber dam so that only the apical portion could be transilluminated. The examiner was also limited to moving the fiberoptic light source from the 4 o'clock to 8 o'clock position around the root end. During apical surgery, the root end is often level with the bone after resection, and to transilluminate, the operator may need to remove a small amount of buccal bone or transilluminate through the bone.

There were several factors in this study that made the diagnosis of fractures challenging. The first was the presence of grooves or irregularities caused by the bur on the resected root end. These irregularities can cause a change in the reflection of light, creating the illusion of a crack. They can also cause dyes to pool in these areas, creating a similar effect. Another factor was the difficulty of determining what actually defines a crack. As Pitts and Natkin (14) wrote, "a major problem with hairline fractures is their differentiation from craze lines, which do not extend into the canal and are of no clinical significance." In this study, a crack was defined as any dark line within the resected dentinal surface that appears to disrupt the integrity of the dentin, not to include artifacts produced by the resection of the root end. The operator's interpretation of what disrupts the integrity of the dentin is certainly subjective (15–17), which may account for some of the false-positive and false-negative results seen in the present study.

In looking at the types of dyes and transillumination, methylene blue and caries detect dyes both produced higher scores in specificity than sensitivity, which implies that they were better at disclosing which root ends did not have cracks and which did. On the other hand, the sensitivity scores were much higher for the transillumination technique than were the specificity scores, which implies that transillumination was better at determining which roots were cracked and which were not. It seems logical, therefore, that the combination of methylene blue and transillumination would have the highest accuracy of all the techniques evaluated. However, there was no statistically significant difference between transillumination alone and methylene blue plus transillumination. Initially, it was thought that the fluorescein sodium dye would be taken up by the cracks and fluoresce more dramatically than it did. This dye is often used in emergency rooms and by ophthalmologists to detect corneal abrasions of the eye. Even though there was no statistically significant difference between the dyes used in this study, the caries detect dye surprisingly had a higher sensitivity, specificity, and accuracy than did the methylene blue. Within the parameters of this study, transilluminating the root end, whether alone or in combination with a dye, appears to be the most accurate way of diagnosing root-end dentinal cracks.

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