An in vitro comparison of quantitative percussion diagnostics with a standard technique for determining the presence of cracks in natural teeth

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Statement of problem. The detection of cracks and fractures in natural teeth is a diagnostic challenge. Cracks are often not visible clinically nor detectable in radiographs.

Purpose. The purpose of this study was to evaluate the diagnostic parity of quantitative percussion diagnostics, transillumination, clinical microscopy, and dye penetration.

Material and methods. Three independent examiners provided blind testing for the study. Examiner 1 transilluminated 30 extracted teeth and 23 three-dimensional copy replica control teeth and documented any visible cracks. Each tooth was then mounted in acrylic resin with a periodontal ligament substitute. Examiner 2 examined each specimen aided by the clinical microscope and transillumination and documented visible tooth cracks and fractures. Examiners 1 and 3 then independently tested all specimens with a device developed for quantitative percussion diagnostics. All visible cracks/fractures were removed with a water-cooled fine diamond rotary instrument. Crack visibility was enhanced by the use of a clinical microscope, dye penetrant, and accessory transillumination. This disassembly process was video documented/photographed for each specimen. One more quantitative percussion diagnostics testing was administered when the disassembly was complete.

Results. Quantitative percussion diagnostics crack detection agreed with the gold standard microscope and transillumination method in 52 of 53 comparisons (98% agreement). Moreover, the method achieved 96% specificity and 100% sensitivity for detecting cracks and fractures in natural teeth. When all tooth cracks were removed, quantitative percussion diagnostics indicated no further structural instability.

Conclusions. Quantitative percussion diagnostics can nondestructively detect cracks and fractures in natural teeth with accuracy similar to that of the clinical microscope, transillumination, and dye penetrant. In addition, the method was able to reveal the presence of many cracks that were not detected by conventional transillumination. (J Prosthet Dent 2014;■:■-■)

Clinical Implications

Nonvisible cracks and fractures, even those that are not detected with conventional transillumination, can be identified by quantitative percussion diagnostics (QPD). This new diagnostic approach provides a risk assessment tool that can locate structural instabilities in natural teeth and is not dependent on direct visualization. QPD represents a paradigm shift from nonquantitative traditional methods to data from quantitative dynamic buccal loading.

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People are living longer, many keeping some or all of their teeth for a lifetime.[1] An unexpected consequence of this positive trend is that dental clinicians are seeing an increasing frequency of cracks and fractures associated with wear, age, trauma, and parafunctional habits.[2-4] As with any mechanical structure, teeth are susceptible to fatigue failure from repeated dynamic loading, especially in a patient with parafunctional habits, highly restored teeth, or both.[5] During the clinical evaluation, the presence of a crack may be detected by an explorer or a change in the color or shadow in the area of fracture, and if there is a subgingival fracture, a localized periodontal defect will be evident. Other methods of detecting cracks include transillumination, magnification, dye penetrants, radiographs, occluding tests, ultrasonography, and quantitative percussion diagnostics (QPD).

Transillumination is considered a standard method of locating cracks or fractures in teeth.[6-9] According to the manufacturer's instructions, the blockage of light transmission indicates a significant structural crack or fracture in a tooth (Ti2200 Transillumination cable; Orascoptic). Unfortunately, transillumination is limited to the visible regions of a tooth. Defects that are located interproximally or beneath the gingival/bone complex are generally not detectable by transillumination, which limits the diagnostic capabilities of the instrument.[10,11] Superficial enamel craze lines can be mistaken for a structural crack and lead to false positives. The addition of magnification during transillumination can improve the visualization of a crack.[12,13]

Illumination and magnification as provided by a clinical microscope have been used to locate cracks that are difficult or impossible to see with unaided vision.[14] The addition of the clinical microscope to a diagnostic protocol for crack and fracture detection allows expanded visible data, whether a tooth is being examined initially or during a disassembly process.[15] Magnification levels from ×14 to ×18 have been suggested to evaluate early fractures when teeth are asymptomatic but have structural defects. Early diagnosis and intervention can limit the propagation of the fracture and possibly prevent pulpal involvement, periodontal bone loss, or catastrophic failure. Additional sources of improved illumination and magnification include the use of endoscopy with a scanning electron microscope (SEM), but these methods can be expensive and complicated in the clinical setting.[16]

Dye penetrants, including methylene blue, gentian violet, sodium fluorescein, and caries detection dye, have been used in dentistry and industry for decades to identify cracks and fractures and are recognized to be initial visible indicators of significant cracks. Initially, cracks may not have sufficient room between the layers to allow the dye to penetrate with capillary action and disclose the defect. Subjective assessment of the penetration of the dye into grooves and irregularities can create false positives and negatives. Wright et al[6] reported that methylene blue with transillumination and magnification discriminated best between cracked and uncracked resected roots. Ghorbanzadeh et al[17] found the combination of methylene blue and transillumination to be the most sensitive method of detecting apical root cracks.

Radiographs, including cone beam scans, are generally ineffective in diagnosing cracks and fractures in teeth unless the crack is displaced significantly in a plane parallel to the beam or if bone loss is associated with the crack/fracture.[7,11,18-20] Micro-computed tomography and SEM can enhance the visibility of a fracture but are not practical for routine clinical assessment.[21,22]

Each of these methods is dependent on visibility to diagnose the structural defect. Occlusal testing is not visually dependent and can be helpful during diagnosis but is typically only effective at the terminal stages of crack formation where the pulpal tissues respond to the flexing of the tooth at the crack interface.[23,24] The involved cusp will often elicit pathognomonic pain on the release of pressure after occluding on an instrument such as the Fracfinder (Denbur Inc) or the Tooth Slooth II (Professional Results Inc).

Vitality testing and apical percussion testing with an instrument handle are not specific.[23,24] A novel system using an ultrasound device and a transducer to distinguish areas with and without a simulated crack was able to detect defects at the cementoenamel junction (CEJ) but was unable to distinguish any defects beyond the CEJ or in bone/root areas.[25]

Quantitative percussion diagnostics (QPD) is a test based on the technologic refinement of a method used for decades in dentistry and medicine. In dentistry, using the handle of the dental mirror is the most common method of percussing teeth to detect sensitivity, mobility, and the auditory sound differential such as heard between a tooth and an osseointegrated dental implant. As currently practiced in dentistry, this is a crude detection technique that is not quantifiable.[7]

QPD has been developed as a medical device for dentistry that precisely measures the structural stability of teeth and dental implants (Periometer; Perimetrics LLC). This device consists of a computer interfaced to a handheld percussion probe system that provides data related to the structural stability of the object being tested. Specifically, it provides a damping capacity parameter known as the loss coefficient (LC), a plot of the mechanical energy returned to the handpiece as a function of time for 10 percussions, and a numerical defect indicator based on the shape of the data in this energy return graph. Studies have found that QPD can quantify the level of osseointegration around dental implants by precise monitoring of the overall micromovement of the dental implant when percussed from the buccal surface.[26] Buccal loading has been found to be a critical direction in working and nonworking occlusal forces that generate high stress within the tooth.[27]

The present QPD instrument is a Food and Drug Administration (FDA)

510(k) Class I medical device approved for measuring the damping characteristics of the periodontium and its associated fixed structures (teeth, implants, or both). Given the sensitivity of the device in measuring implant localized or internal mobility, it was hypothesized that the device might also be effective in measuring the localized instabilities in natural teeth such as produced by cracks and fractures. The overall movement of a tooth could relate to mobility induced by periodontal disease, recent orthodontic movement, or traumatic occlusion. Localized movement of a tooth could be internally generated by conditions such as cracks in the tooth structure or loose/fractured restorations.

The present study was designed to evaluate the effectiveness of QPD as an instrument for diagnosing cracks in teeth. QPD measures the damping characteristics of the periodontium and its associated fixed structures (teeth, implants, or both). The Ti2200 Transillumination cable is the only FDA-approved medical device specifically designed to detect cracks and fractures in teeth. However, this technique cannot detect cracks in nonvisible areas. Accordingly, microscopic disassembly aided by transillumination and dye penetrant was used as the standard to compare the efficacy of the 2 methods. The objective of the present study was to test the null hypothesis that QPD would be as effective as transillumination in detecting cracks in the visible portions of teeth and to determine whether QPD could potentially reveal the presence of those defects that are interproximal or beneath the gingival/bone complex where transillumination is not feasible.

MATERIAL AND METHODS

Tooth selection

A total of 30 extracted teeth with minimal restorations and mature apices were collected for the present study from an initial pool of over 100 teeth. Any debris or surface deposits were removed with a hand scaler. Three independent examiners were assigned different phases of the study to maintain the objectivity of all assessments. Examiner 1 used a surgical microscope at 10× magnification to document any visible fractures, cracks, or defects in the crown and root of each tooth. All specimens were initially transilluminated to document the presence of cracks in the crown and root of each tooth. Cracks were documented by using videography, still photography, and description in a secured written form. Each natural tooth specimen was assigned a number, tested in a random order by a different examiner, and continuously hydrated during the entire study.

One problem was the acquisition of a sufficient number of uncracked natural teeth for controls. By the time teeth are extracted as part of a dental treatment plan, most have been in the mouth for decades and could easily have developed cracks and fractures due to extensive use, parafunctional habits, trauma, or a combination of those, including defects induced by the extraction process. Even teeth extracted in young patients for orthodontic treatment, or unerupted third molars, consistently contain cracks and fractures associated with the trauma of extraction. Consequently, including a number of synthetic tooth models as undamaged controls in the present investigation was necessary.

Advancements in the area of 3-dimensionsal (3D) copy replicas have allowed the fabrication of synthetic teeth that are anatomically precise copies of natural teeth (TruTooth; DELendo). The ability to have consistency in the size and geometry of the tooth specimens allowed for more accuracy in the assessment of the QPD data. In addition, the material characteristics of these synthetic teeth are comparable with the material characteristics of natural teeth. The DELendo tooth replicas that were used in the present work are made from Objet VeroClear RGD810 rigid transparent polymer. The elastic modulus of this material (between 2 and 3 GPa) is somewhat lower than, but within an order of magnitude of, that for dentin.[26] Using these tooth replicas provided a sufficient number of defect-free controls, which was not feasible with extracted natural teeth.

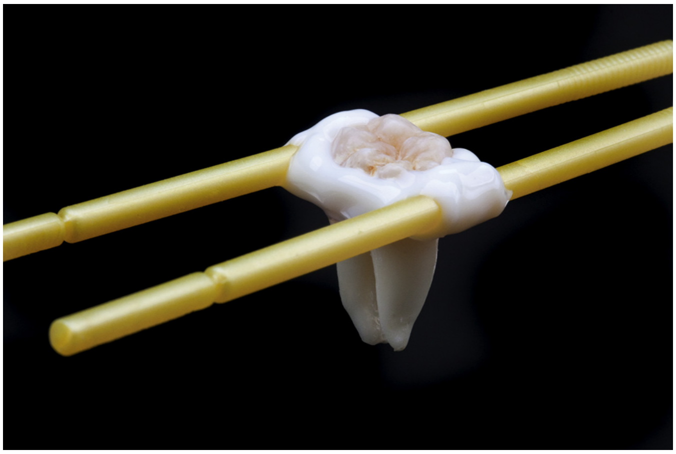
Twenty-three transparent 3D replica teeth of a mandibular right first molar were acquired and visually examined for any cracks or fractures. No cracks were observed under the microscope or with transillumination. The replicas were then mounted according to the study protocol and tested with QPD. The QPD data generated included normalized energy return as a function of time, the LC (an indicator of overall mobility),[28-30] and the normal fit error (NFE) (an indication of localized mobility due to a defect).[31,32] The replica teeth tested were virtually identical to the one uncracked natural mandibular right first molar that was in the study, for a total of 27 intact specimens. These were combined with the 26 cracked specimens for a total of 53 specimens.

Specimen preparation

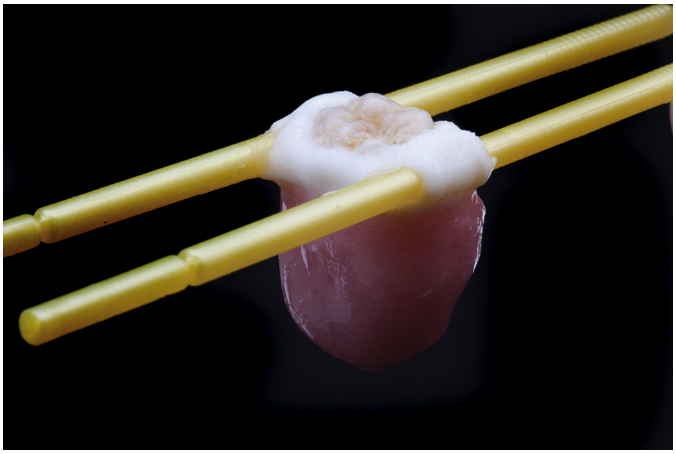
Each tooth or tooth replica was painted with a thin, uniform layer of die spacer (Kerr-Sybron Dental Lab Products) from 2 mm above the CEJ apical to the tip of the root and allowed to dry (Fig. 1). This process was repeated 2 times for each tooth to achieve a sufficient thickness to simulate the properties of the periodontal ligament. Next, a thin bead of liquid rubber dam (Liquidam; Philips Oral Healthcare) was applied circumferentially 0.5 mm below the CEJ to block the acrylic resin to achieve a normal simulated bone height as shown in Figure 2. When the bead had set, a microbrush applicator (Disposable Applicators; 3M ESPE) was secured with liquid rubber dam to the mesial and distal sides of the tooth so that it was parallel to the occlusal plane (Fig. 3). Additional liquid rubber dam was applied to all 4 sides of the tooth, covering approximately two-thirds of the apical portion of the coronal

1 Latex liquid applied to simulate periodontal ligament.

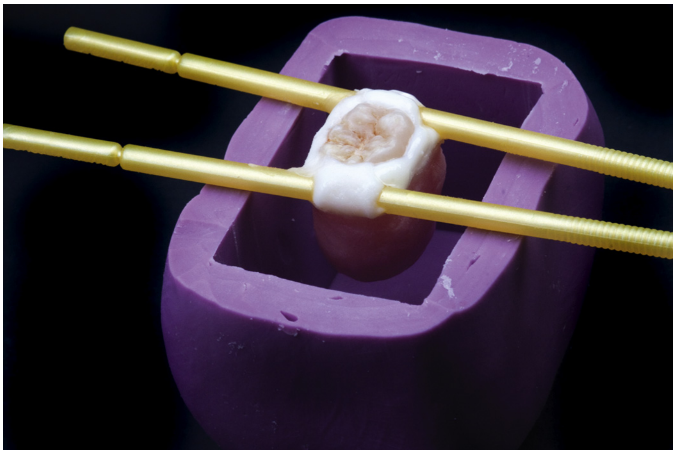
2 Rubber dam barrier applied to cementoenamel junction to establish ideal crestal bone level with acrylic resin.



3 Support rods mounted and secured to proximal tooth surfaces, parallel to occlusal plane.



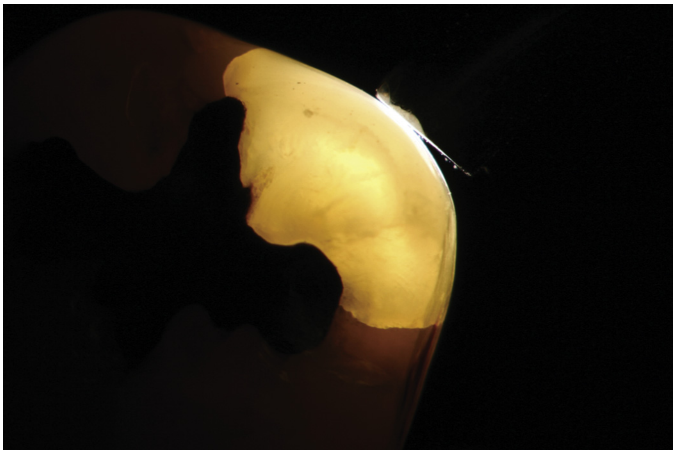
4 Polymer and monomer applied to root structure of tooth.



5 Proper position of tooth suspended in mold.

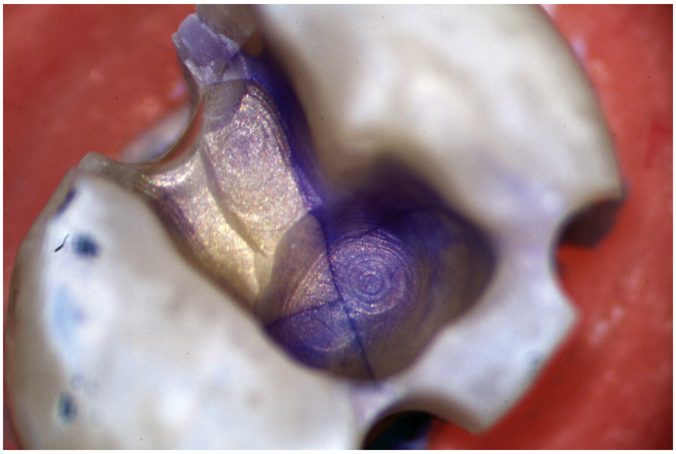
segment of the tooth to ensure that acrylic resin did not touch these surfaces. Autopolymerizing acrylic resin (Teets; Co-Oral-ite Dental) was applied to the root of each tooth with a brush powder/liquid application technique until a minimum of 3 mm of void-free acrylic resin had been created around the entire root structure (Fig. 4). Next, the mounted tooth was placed in the middle of a rectangular (27×42×25 mm) polyvinyl siloxane (Precision; DenMat Holdings LLC) mold with the buccal side of the tooth facing the long side of the mold (Fig. 5). Once the tooth was in place, additional autopolymerizing acrylic resin was mixed and poured into the mold. Each mold was then placed in a pressure pot at 138 kPa for 30 minutes. Once polymerized, each specimen was removed from the pressure pot, the mounting aids were separated from the tooth, and any excess acrylic resin was trimmed. The completed specimens were stored in water. Each mounted specimen was assigned a number and evaluated by computed tomography scan (i-CAT; Imaging Sciences Intl) to ensure that there were no voids in the acrylic resin adjacent to the tooth root.

Examiner 2 independently examined each mounted, numbered test specimen with the manufacturer's recommended



6 Transilluminated fractured cusp.

7 Quantitative percussion diagnostics testing on mesial buccal cusp of specimen tooth.



8 Specimen tooth demonstrating multiple fractures noted upon disassembly under magnification with use of dye penetrant.

transillumination protocol. The findings of examiner 2 were recorded in a written form to indicate whether the specimen demonstrated fractures when transilluminated (yes or no), and, if so, the location was recorded (coronal, root above the acrylic resin, or root potentially below the acrylic resin) (Fig. 6).

Examiner 3 tested each specimen with QPD, and all data were recorded in the computer record and transferred to a secure Excel worksheet (Microsoft Excel; Microsoft Corp). Examiner 1 also independently tested each specimen with QPD, and all data were recorded and transferred to a secure Excel worksheet. A photograph of the QPD testing is shown in Figure 7.

Once all the predisassembly data were collected, each specimen was disassembled with a high-speed handpiece with cool water spray and a clinical microscope (Global Surgical). This procedure was recorded with a video camera and still photography. The disassembly protocol began by cleaning the tooth with alcohol, and the specimen number was recorded with video and still photography for documentation purposes. Next, the tooth was etched with 35% phosphoric acid (Ultra-Etch; Ultradent Products Inc), washed, and dried. The specimen was then examined through the clinical microscope at 10× magnification, and video documentation was initiated. Toluidine blue indicator (Toluidine Blue O dye; Taylor), was painted on the entire tooth surface, allowed to set for 30 seconds, and then thoroughly rinsed off. Any visible signs of dye penetrant action or lack of action was recorded and documented by video and still photography and in the written record (Fig. 8). The tooth was then disassembled under 10× magnification with a high-speed handpiece under water coolant and fine grit diamond rotary instrument to follow and remove any visible cracks and fractures up to the dentinoenamel junction (DEJ) by using the transillumination device for light transmission and crack detection. Video documentation and photographs were made to document the location and extent of the tooth disassembly required to eliminate fractures up to the DEJ. The first step that removed cracks entirely contained within the enamel was critical to differentiate between superficial cracks that did not endanger the structural integrity of the tooth and the more damaging cracks that extended into the body of the tooth. The aforementioned steps were repeated for any fractures that extended into the dentin up to the pulpal roof. Lastly, the pulpal roof and all pulp tissue were removed with a barbed broach. The steps were then repeated, and the pulp chamber and canals were inspected for fractures.

Once completely disassembled, the tooth specimens were examined under a microscope at 10× magnification with both the light and transillumination to check for any remaining cracks. After examiner 1 confirmed that all cracks had been eliminated, examiner 3 tested all 53 specimens and controls again with QPD. All findings were documented and recorded in a secure Excel spreadsheet.

RESULTS

The results for the conventional transillumination determination and tooth disassembly examination are listed in the first 3 columns of Table I. An "X" in the second column of this table designates a crack as defined by the manufacturer's instructions for conventional macroscopic transillumination. An "X" in the next column for the disassembly examination indicates the observation of a major dentinal crack or more than 10 enamel cracks in the tooth specimen. Conventional macroscopic transillumination indicated cracks in 11 of the 30 natural teeth. The 2 transillumination examiners were in agreement for all specimens but one, specimen 10, which is designated as cracked (X) in Table I. By contrast, cracks were detected in all but 4 of the tooth specimens per the present disassembly protocol. A comparison of these results indicates that conventional transillumination does not indicate all cracks that are evident in a thorough microscopic disassembly aided by both transilluminating light and dye penetrant.

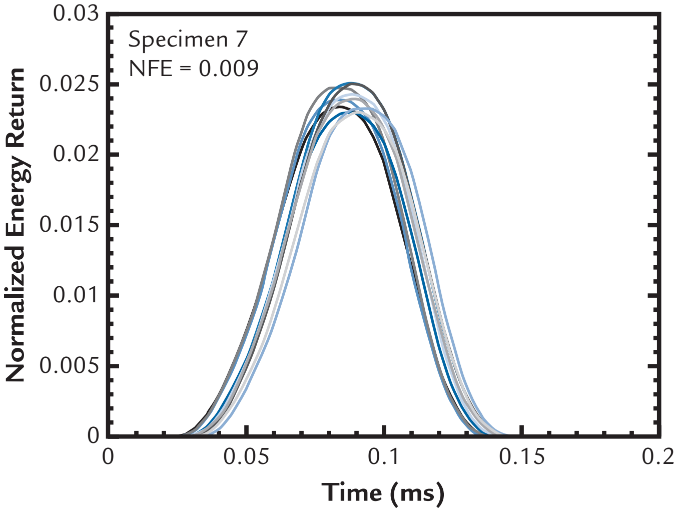
A representative plot of normalized energy return as a function of time for 1 of the uncracked natural teeth (specimen 7) is shown in Figure 9. Ten sets of data in this plot correspond to the 10 percussion responses that were measured over a 4-second duration when the probe was activated. The difference between an ideal energy return versus time response for an intact tooth (a symmetrical bell-shaped curve) and from the measured response from a specimen tooth is called the NFE. The higher the NFE, the more damaged the structure. The response peaks for this intact tooth were all relatively uniform and symmetric in shape. These characteristics gave rise to the relatively low value of the NFE (0.009).[31,32] The energy return data for a tooth that was determined to contain significant cracks that reached the DEJ (specimen 1) were plotted against time (Fig. 10). These data exhibited nonuniformity in the response peak from 0.06 to 0.09 ms, resulting in an NFE that was somewhat greater (0.026) than that for specimen 7. Representative energy return data for a tooth that contained larger cracks that compromised the margin of the tooth (specimen 2) were plotted versus time (Fig. 11). Nonuniformity was also observed in these data in the form of an additional peak between 0.09 and 0.13 ms. The more pronounced perturbation resulted in a still higher value of NFE (0.045). The specimen with larger cracks that propagated below the margin exhibits a nonuniformity relatively late in time compared with that for specimen 1.

The LC was plotted against NFE (Fig. 12) from the QPD for both replica and natural tooth specimens. A

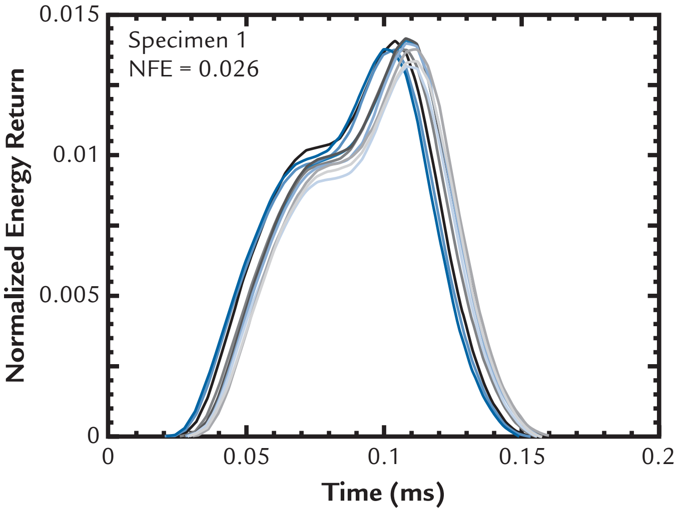
Table I. Crack occurrence within extracted tooth specimens determined by conventional transillumination, microscopic disassembly, and QPD

Specimen No.	Transillumination	Microscopic Disassembly	QPD Initial	QPD Final
1	0	X	X	0
2	X	X	X	0
3	0	X	X	X*
4	X	X	X	0
5	0	X	X	0
6	0	X	X	X*
7	0	0	0	0
8	X	X	X	X†
9	X	X	X	0
10	X	X	X	0
11	0	X	X	X*
12	0	X	X	0
13	X	X	X	0
14	X	X	X	0
15	0	X	X	0
16	0	X	X	0
17	0	X	X	0
18	0	X	X	0
19	0	0	X	0
20	0	X	X	0
21	0	X	X	0
22	0	X	X	0
23	X	X	X	0
24	X	X	X	0
25	X	X	X	0
26	X	X	X	0
27	0	0	0	0
28	0	0	0	0
29	0	X	X	0
30	0	X	X	0

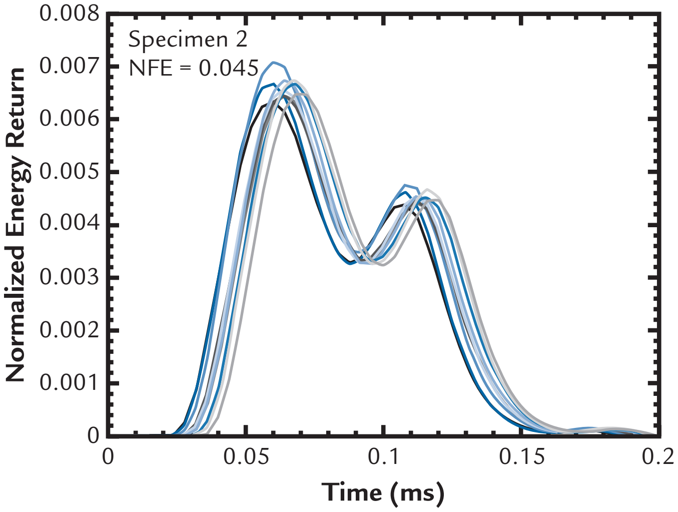
QPD, quantitative percussion diagnostics; NFE, normal fit error.
Microscopic disassembly: >10 enamel/dentin cracks revealed by using transillumination and dye penetrant.
QPD: NFE>0.02.
*Less damage indicated compared with initial test.
†Disassembly halted owing to undermined cusp.



9 Representative energy return results for an intact tooth (specimen 7 in Table I). Data corresponding to 10 percussion responses are shown.



10 Typical energy return data for tooth that contains significant cracks that reached enamel-dentin junction (specimen 1 in Table I). Responses for 10 percussions are shown.

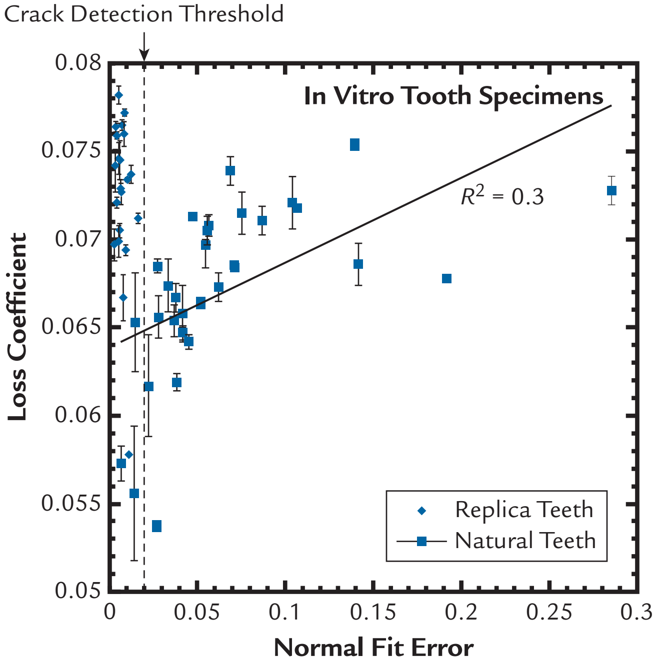


11 Representative data for a tooth that contains a deep crack in crown that compromises margin (specimen 2 in Table I).

least-squares linear fit to the natural tooth data is also shown in Figure 12 to demonstrate that overall the LC tended to be greater as the NFE increased. However, the correlation between these 2 parameters is poor (R^2=0.3). This outcome is reasonable, given that overall instability as represented by the LC can be influenced by factors other than local instabilities that are characterized by NFE. Such factors could include the geometry of the tooth, the thickness of the periodontal ligament, and the density of the bone surrounding the tooth. Although local instabilities can significantly increase the overall instability of a tooth, other factors may influence it more. Thus, being able to monitor both overall and local instabilities in teeth is important, because they are not necessarily linked.

The NFE data for all specimens were compared with the crack detection results from the microscopic disassembly examinations represented in the third column in Table I. Based on this comparison, a threshold NFE value of 0.02 for crack detection produced a 98% agreement between the QPD prediction of the presence of cracks and the microscopic disassembly (MD) verification of the presence of cracks. In addition, a vertical dashed line in Figure 12 indicates the threshold value of 0.02. All of the NFE values for the tooth replica controls (diamond symbols) fell below this threshold, along with the values for the few natural tooth specimens that were found to contain no significant cracks and fractures. Furthermore, the LC values for the intact extracted tooth specimens (NFE<0.02) and the replica tooth specimens fell within the same range of data.

The findings in Table I also demonstrate that QPD was able to detect more fractures in teeth than conventional transillumination, as recorded in the magnified and illuminated destructive disassembly with dye penetrant. Interestingly, percussion testing generally yielded a below-threshold NFE value for each previously cracked tooth once the damaged tissue was removed during the disassembly process. This overall result is demonstrated in the fifth column of Table I.



12 Loss coefficient plotted against normal fit error for natural tooth and replica specimens. A least-squares linear fit to natural tooth data is shown (R^2=0.3).

Table II. Comparison of cracked/intact tooth classification from QPD and from MD for combined set of 53 extracted and replica tooth specimens

QPD Predicted Frequency Row % Col %	MD Gold Standard Intact	 Cracked	 Total
Intact			
Frequency	26	0	26
Row %	100.00	0.00	
Col %	96.30	0.00	
Cracked			
Frequency	1	26	27
Row %	3.70	96.30	
Col %	3.70	100.00	
Total	27	26	53

QPD, quantitative percussion diagnostics; MD, microscopic disassembly.

The results of the statistical analysis, including the 23 controls with the set of 30 natural teeth, for a total of 53 specimens, are given in Tables II and III. The data in Table II show that 52 of 53 teeth (0.981) were classified into the same category by both QPD and MD, and Table III provides the 95% CI (0.901-0.997) for this proportion. In addition, this analysis indicates that a detection threshold NFE of 0.02 for the 53 natural and synthetic posterior teeth achieved 96% specificity (95% CI, 0.817-0.933) and 100% sensitivity (95% CI, 0.871-1.000) for detecting cracks based on a comparison with microscopic disassembly.

DISCUSSION

By yielding a 98% rate of agreement, the data from the present study support the null hypothesis that QPD is as effective as transillumination for detecting cracks and fractures in teeth. Further, QPD was able to detect fractures in 1 tooth that were not visible and could not be detected by transillumination.

The present study reconfirms the conclusions that cracks and fractures in natural teeth are commonplace.[1-2] As the study progressed, it became evident that even teeth identified as potentially uncracked controls developed cracks and fractures from the extraction process, making it difficult to collect undamaged natural control teeth. Fortunately, novel 3D copy technology has made it possible to create precise models of natural teeth that test consistently with uncracked natural tooth controls.

The magnification and illumination provided by a clinical microscope have been used in the present work as instruments to locate cracks that are difficult or impossible to see with unaided vision. The addition of the clinical microscope to a diagnostic protocol for crack and fracture detection allows expanded visible data, whether a tooth is being initially examined or during a disassembly process.[14] Unfortunately, these tools are all limited to visible areas. Cracks and fractures that develop deep into the body of the tooth or in visually inaccessible areas are not detected by these traditional techniques.

QPD is an objective, technologically refined method of detecting structural instability. This method is not based on visual input but rather on the response of the tooth to a low-magnitude tap on the buccal surface. The data represent how the structure responds mechanically to buccal loading. It is a dynamic test that is consistent with typical physiologic loading during eating, parafunction, and trauma. Thus, it is reasonable to suppose that it is sensitive in detecting damage caused by those loading modes. The data are precise, are repeatable, and can be compared over time with subsequent tests. Finally, QPD provides a new type of

TABLE III. Associated statistics from experimental data indicating 95% confidence level

Statistic	Proportion	95% CI
Proportion correctly classified	52/53=0.9811	(0.9006-0.9967)
Positive predictive value	26/27=0.9630	(0.8172-0.9934)
Negative predictive value	26/26=1.0000	(0.8713-1.0000)
Sensitivity	26/26=1.0000	(0.8713-1.0000)
Specificity	26/27=0.9630	(0.8172-0.9934)
False-positive rate	1/27=0.0370	(0.0066-0.1828)
False-negative rate	0/26=0.0000	(0.0000-0.1287)

diagnostic data not previously available with other methodologies used in clinical dentistry.

The present study clearly confirms that QPD is as effective as transillumination for detecting cracks and fractures in the visible portions of teeth. Interestingly, QPD also detected the presence of defects in 1 specimen where the cracks were interproximal or beneath the gingival/bone complex, whereas transillumination was not able to detect these nonvisible defects.

CONCLUSIONS

By exhibiting a 98% rate of agreement (95% CI, 0.901-0.997), the study data show that QPD was able to identify cracks and fractures in natural teeth as well as transillumination, even when transillumination was aided by the clinical microscope and dye penetrants. Additionally, the data demonstrated that QPD was able to identify cracks and fractures in a tooth that was not identified by transillumination alone. In addition, QPD exhibited 96% specificity (95% CI, 0.817-0.9934), and 100% sensitivity (95% CI, 0.871-1.000). Further research is indicated to test the limits of information provided by this new diagnostic paradigm for determining the structural integrity of natural teeth.

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