Comparison of photothermal radiometry and modulated luminescence, intraoral radiography, and cone beam computed tomography for detection of natural caries under restorations

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Objectives. The aim of this ex vivo study was to measure the sensitivity, specificity, and receiver operating characteristic (ROC) area under the curve (AUC) of a caries diagnostic system based on photothermal radiometry and modulated luminescence (PTR/LUM) and compare them with the values for digital intraoral radiography (IR) and cone beam computed tomography (CBCT) in detecting recurrent decay.

Study Design. Class 2 composite restorations were prepared on 70 proximal surfaces: 35 with caries and 35 without caries. The gingival floor of the restored surfaces was assessed for caries under the restorations using each of the 3 modalities. Statistical calculations and analysis were performed using the R statistical computing environment.

Results. The average scores for sensitivity among the 6 observers were 0.89 for PTR/LUM, 0.38 for IR, and 0.40 for CBCT. Sensitivity for PTR/LUM was significantly greater than sensitivity for IR and CBCT. Average scores for specificity were 0.83, 0.80, and 0.70 for PTR/LUM, IR, and CBCT, respectively. CBCT had significantly lower specificity. The AUC was 0.65 for IR and 0.59 for CBCT, which were significantly different. PTR/LUM had moderate intraobserver agreement.

Conclusions. PTR/LUM, which involves non-ionizing radiation, can serve as a sensitive adjunct in early caries detection and monitoring. (Oral Surg Oral Med Oral Pathol Oral Radiol 2020;129:539−548)

Dental caries continues to be a common chronic disease among various population groups.[1,2] It is a dynamic lesion with alternating periods of demineralization and remineralization of the dental hard tissue, necessitating techniques with a high sensitivity index for early detection and to prevent cavitation. Recurrent caries (caries around restorations) occurs at subsurface regions and usually between the marginal interface of an existing restoration and the tooth.[3,4] It is the principal cause of restoration failure and retreatment.[5,6] Patient care can be improved with detection at the earliest stage of the disease process.[2]

Intraoral radiography (IR) is a useful component in evaluation, diagnosis, and treatment planning for caries. However, the ALARA (as low as reasonably achievable) principle necessitates the justification of its use.[7] Though intraoral radiographs are commonly used to evaluate teeth for caries at the interproximal or contact areas, they do not reveal enamel white-spot lesions[2,3,7] or all recurrent caries around restorations. Approximately 30%-40% mineral loss is necessary before an early enamel caries lesion is visible radiographically,[7] and demineralization may not appear radiographically until at least 9 months or longer after initiation.[8]

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Received for publication Mar 1, 2019; returned for revision Aug 31, 2019; accepted for publication Sep 13, 2019.

2212-4403/$-see front matter
https://doi.org/10.1016/j.oooo.2019.09.006

Photothermal radiometry and modulated luminescence (PTR/LUM), commercially marketed as the Canary System (Quantum Dental Technologies, Toronto, ON, Canada), is a noninvasive energy conversion technology that measures 2 different signals: modulated thermal infrared radiation (PTR) and modulated luminescence (LUM).[3,9] PTR/LUM is based on the combination of 2 slightly different responses of the tooth tissues to a periodic irradiation with a pulsating laser beam; it measures heat and light responses. The first response signifies the conversion of absorbed optical energy into thermal energy that results in a modulation in the temperature of tooth structure (PTR). The second response signifies the conversion of absorbed optical energy to radiative energy (LUM).[3,9-11] A schematic illustration is shown in Figure 1. The PTR/LUM system measures the strength of the converted heat (PTR amplitude), the time delay of the converted heat to reach the surface conductively (PTR phase), the strength of the converted luminescent light (LUM amplitude), and the time delay of the converted luminescent light (LUM phase). Heat generated from the modulated light at the point of contact measures

Statement of Clinical Relevance

Radiographs, though valuable in the detection of advanced caries lesions, are less sensitive for early or recurrent lesions under restorations. The canary system, which involves non-ionizing radiation, can serve as a sensitive adjunct in early caries detection.

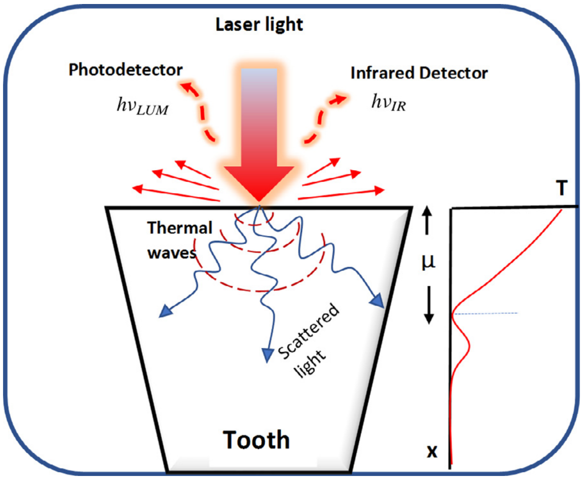

Fig. 1. Schematic representation of the photothermal radiometry and modulated luminescence (PTR/LUM) technology. Conversion of optical energy from a modulated excitation source into heat and light. In this diagram, a modulated red laser at 660 nm was shone on a tooth surface. Light (photon) interaction with the tooth surface generates (1) thermal energy radiation (heat response) and (2) luminescence energy radiation (light response). $E = h\nu$, where E is radiated energy, which can be related to the Plank constant h and emitted photon frequency ν. The plot illustrates the progress of temperature T as a function of depth (x) from the tooth surface. $h\nu_{IR}$, the energy of a thermal infrared photon; $h\nu_{LUM}$, the energy of a luminescence response; T, thermal-wave amplitude; μ, thermal diffusion length in the material at the given modulation frequency; x, depth coordinate.

maximum temperature (T), as shown in Figure 1, and it decays (red line in Figure 1) up to the diffusion length (μ) of the probing tooth thickness (x). The thermal response is collected by the infrared (IR) detector up to the diffusion length (μ) of the probing tooth crystal structure. Diffusion length (μ) depends on the material properties of the crystal structure of the tooth.

As a caries lesion progresses with increasing demineralization, there is a corresponding change in the amount of infrared radiation and luminescence collected.[3,10] Canary numbers (CN) are then generated on a scale of 0-100, allowing the differentiation of a sound surface from a carious surface.

Intraoral radiography is an important diagnostic tool for caries detection. It has been documented that about 25%-42% of caries lesions are underdiagnosed when clinical examination is performed without radiographic examination.[12,13] Intraoral projections include the use of conventional intraoral film, solid state detectors such as the charge-coupled device (CCD) or light sensitive complementary metal oxide semiconductor (CMOS) chip with a scintillator layer that coverts x-rays to light, and photostimulable phosphor (PSP) plates.[13] These systems produce 2-D information about the imaged tooth structure. With the advent of digital radiography, images can be processed faster and can be manipulated for contrast, magnification, and brightness to aid in diagnosis.

Caries is usually detected with the use of bitewing radiography or visual inspection. However, studies indicate low sensitivity of radiography in detection of initial, noncavitated lesions.[12,13]

Cone beam computed tomography (CBCT) has been used for a wide variety of dental diagnostic purposes such as dental implant treatment, craniofacial anomalies, endodontics, orthodontics, and periodontics.[12,13] Although intraoral radiographs are used in diagnosing caries, they are less reliable in the detection of early caries and recurrent caries around existing restorations, with sensitivity in the range of 0.30.[11] The use of CBCT in caries diagnosis is limited mainly by the higher radiation dose associated with it as well as lower spatial resolution and multiple artifacts.[12,13] PTR/LUM offers a potentially safer and more sensitive method[14-17] for detecting recurrent caries. However, there are no published studies that have compared its use in detection of recurrent caries under composite restorations relative to IR and CBCT.

The purpose of this study was to compare the sensitivity and specificity of PTR/LUM, IR, and CBCT and the area under the receiver operating characteristic (ROC) curve of IR and CBCT. The null hypothesis stated that there were no statistically significant differences among the modalities for any of the parameters.

MATERIALS AND METHODS

Teeth extracted from patients attending The University of Texas Health San Antonio Center for Oral Health Care and Research were collected, cleaned, immersed in 10% formalin for 2 weeks, and stored in 0.1% thymol solution to maintain tissue hydration and prevent bacterial growth. They were washed with and subsequently stored in distilled water before scans were made. The study was given an exemption as a nonhuman research activity by the University of Texas Health San Antonio Institutional Review Board (Protocol Number: HSC20180022N).

In selecting the teeth to be used in the project, extracted premolar or molar teeth without any deformity other than caries limited to the crown were included. Teeth with root caries, forceps marks, or any type of deformity such as abrasion, noncarious cervical lesions, endodontic treatment, gross tooth structure loss, fractures, cracks, and stains were excluded. In total, 54 teeth were used, with 35 carious surfaces and 35 noncarious surfaces.

Class 2 composite restorations were prepared on all 70 ($n = 70$) of the proximal surfaces to be examined. To simulate the proximal contact points, the teeth were mounted in sets of 4-5, in a $1 \times 1 \times 3$ cm^3 rectangular

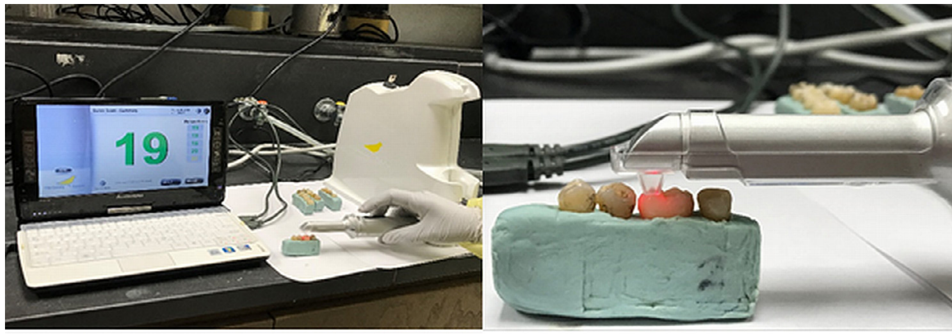

Fig. 2. Canary system with the probe positioned perpendicular to the tooth surface to be scanned.

block of Sil-Tech condensation silicone with a total of 13 blocks used for the study. Each rectangular block fit precisely in an optomechanical assembly that was positioned with micron accuracy.

Procedure

A class 2 restoration was prepared on each of the 35 sound proximal surfaces. Each cavity was etched with 35% phosphoric acid gel (Ultradent Products Inc., South Jordan, UT, USA) for 15 seconds, rinsed with water for 20 seconds, and air dried for 3 seconds. Each prepared cavity was lined with ESPE bonding agent (3M, St. Paul, MN, USA) and light cured for 10 seconds. Filtek Supreme Ultra Universal Restorative Master's Kit Capsule, shade C3 B (3M) was then applied in incremental layers. It was light cured for 20 seconds with each increment and subsequently finished and polished using the Dental Ultradent Jiffy composite adjusting and polishing kit.

A class 2 restoration was also prepared on each of the 35 carious proximal surfaces; however, caries was intentionally left on the gingival floor of each cavity preparation. Each cavity was filled with composite restorative material as described earlier. Only the gingival floor was assessed for the presence of caries under a restoration using PTR/LUM, intraoral radiography, and CBCT.

Before examination, an oral and maxillofacial radiology resident was trained and calibrated on the use of the PTR/LUM system for caries detection. With the PTR/LUM system set on quick scan mode, the gingival floors of the restored teeth were scanned by placing the tip of the PTR/LUM handpiece on the occlusal aspect of the marginal ridge of the restoration, perpendicular and as close as possible to the site to be examined, in accordance with the manufacturer's instruction (Figure 2). Canary numbers (CN) were automatically generated by the device. The system generates CN with values ranging between 1 and 100 representing the presence or absence, as well as the severity, of caries lesions. Each restored tooth surface was scanned 3 times and the average CN was recorded. The manufacturer states that a number between 1 and 20 indicates a healthy surface (absence of caries), 21-70 indicates decay, and 71-100 indicates advanced decay, as shown in Figure 3. For the present study, a score of 1-20 was interpreted as "no caries" and a score of 21-100 was interpreted as "caries." Eleven of the surfaces (5 sound and 6 carious) were also rated twice with an interval of 1 week to assess intraobserver agreement.

Intraoral radiographs of all restored teeth were exposed with the Sirona system (Schick CDR DICOM and Wireless, Schick Technologies, Long Island City, NY, USA) operating at 63 kVp and 8 mA for 0.16 seconds. The sample blocks were mounted on a fixed base made of Sil-Tech condensation silicone. Two fixed 2-cm-thick acrylic plates as seen in Figure 4A were used to stabilize the x-ray tube head and standardize the tooth position during x-ray exposure (Figure 4B). This provided a standardized projection geometry in the buccolingual direction, thereby acquiring bitewing radiographs without the opposing arch. The sample teeth were placed in blocks made of Sil-Tech condensation silicone to simulate soft tissue. Images were acquired using a number 2 CCD sensor (E2 V Technologies Inc., Elmsford, NY, USA) and XDR software (Cyber Medical Imaging Inc., Studio City, CA, USA). The CCD images were saved as bitmap files and

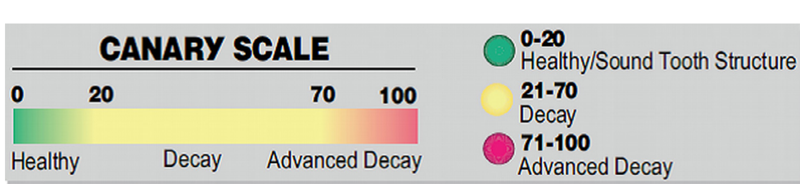

Fig. 3. Canary system scale of Canary numbers (CN).

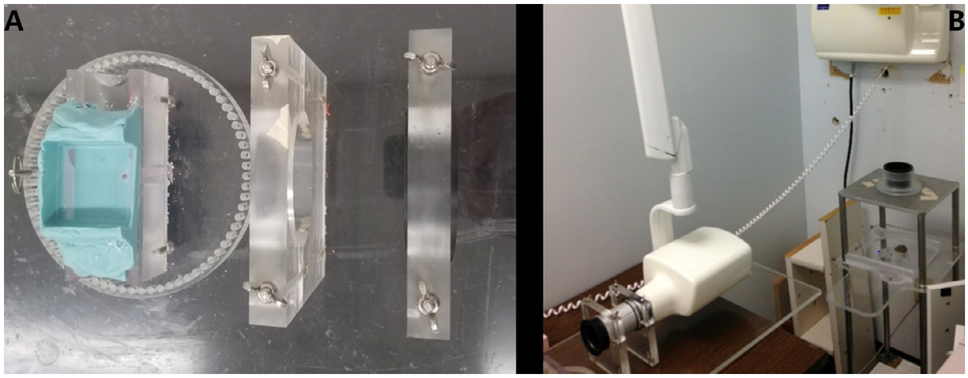

Fig. 4. **(A)** Fixed base made of Sil-Tech condensation silicone and 2 fixed 2-cm-thick acrylic plates used to stabilize the x-ray tube head and standardize the tooth position during x-ray exposure. **(B)** Intraoral radiograph acquisition using the Planmeca intraoral dental x-ray machine with the tube head positioned in the experimental setup ready for exposure.

subsequently viewed as DICOM images on the ImageJ viewing software with accommodation for adjusting contrast resolution and brightness, as seen in Figure 5.

CBCT images were exposed with the 3 DX Accuitomo H unit (J Morita Mfg Corp., Kyoto, Japan). Each sample was placed in a bowl that was halfway filled with water to simulate the soft tissues, as shown in Figure 6. The scanner was operated at 90 kVp and 7 mA for 17.5 seconds with 360-degree rotation. The field of view was 4 cm × 4 cm and acquisition voxel size was 0.08 mm. The acquired data were reconstructed with a 0.250 mm slice interval and thickness. Observers used the Anatomage Invivo6 advanced 3-D imaging software (Anatomage 6.0, San Jose, CA, USA) to evaluate the resulting images in 3 orthogonal planes and 3-D rendering as seen in Figure 7. IR and CBCT images of the same set of teeth, depicting teeth with and without caries under the composite restoration, are shown in Figure 8.

Each of the intraoral radiographs and CBCT images was shown in random order to 6 second and third year oral and maxillofacial radiology residents who were trained to interpret the IR and CBCT images. They assessed the gingival floor of each restored tooth surface with no time limitation, with one session for intraoral radiographs and one session for CBCT images. The observers were asked to rate each proximal surface as to the likelihood of the presence of a recurrent caries lesion, on the following scale: 1 = definitely absent; 2 = probably absent; 3 = don't know; 4 = probably present; and 5 = definitely present. A rating of 3 was classified as negative (no caries). After 7 days, 11 of the surfaces (5 sound, 6 carious) were reevaluated by the observers to assess intraobserver agreement. The observers were blinded to the study design.

Fig. 5. Example of an intraoral radiograph as acquired in a bitewing orientation.

Statistical analysis was performed using the R statistical computing environment. Program code developed by Nambiar[18] was modified slightly to calculate sensitivity and specificity for each observer and image combination, as well as to prepare ROC curves, calculate the area under each curve (AUC), and determine confidence intervals for AUC. Observer ratings were compared with the ground truth of visual inspection.

Sensitivity and specificity were calculated for the PTR/LUM system based on the CN data and for the IR and CBCT systems based on the 5-point scale data for each observer. Ratings of 1, 2, or 3 were considered to agree with an actual status of no carious lesion, and ratings of 4 or 5 were considered to agree with an actual status of presence of a carious lesion.

The area under the ROC curve was calculated by use of the trapezoid rule. The AUC is a measure of the probability that given 2 surfaces, one with a lesion and the other a sound surface, an experienced dentist will correctly identify the lesional surface. An imaging system that enabled an observer to correctly identify lesion status with high confidence on all surfaces would have an AUC value of 1.0. A system that resulted in the observer guessing at each site would yield an AUC value of 0.5. An ROC curve was not prepared for the PTR/LUM system because the observer responses were dichotomous.

The 95% confidence intervals for sensitivity and specificity for each technique were calculated based on

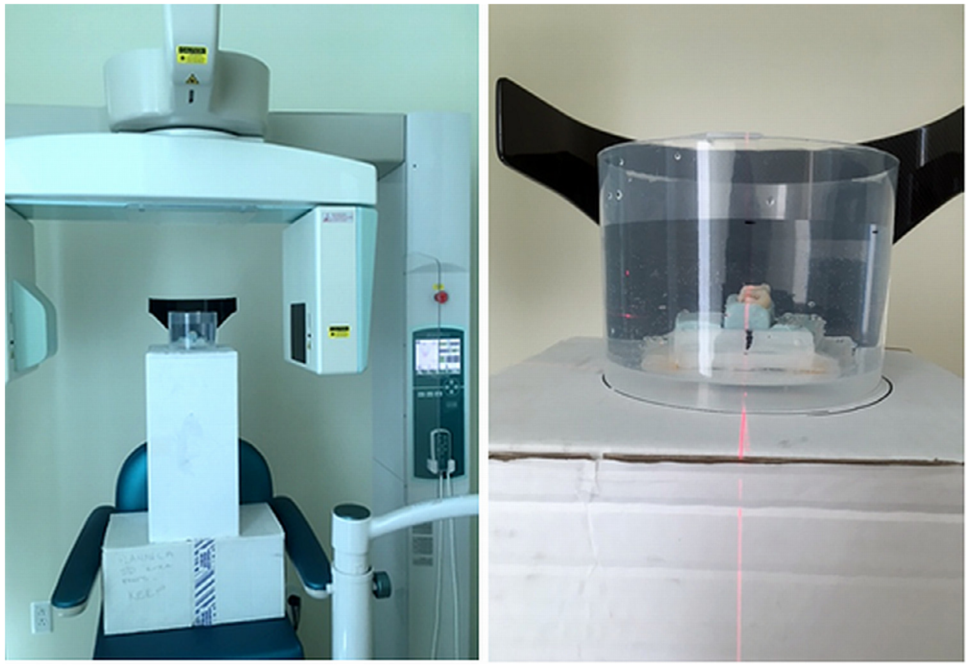

Fig. 6. Cone beam computed tomography (CBCT) acquisition using the 3 DX Accuitomo H CBCT unit with teeth placed in a water-filled bowl to simulate soft tissue.

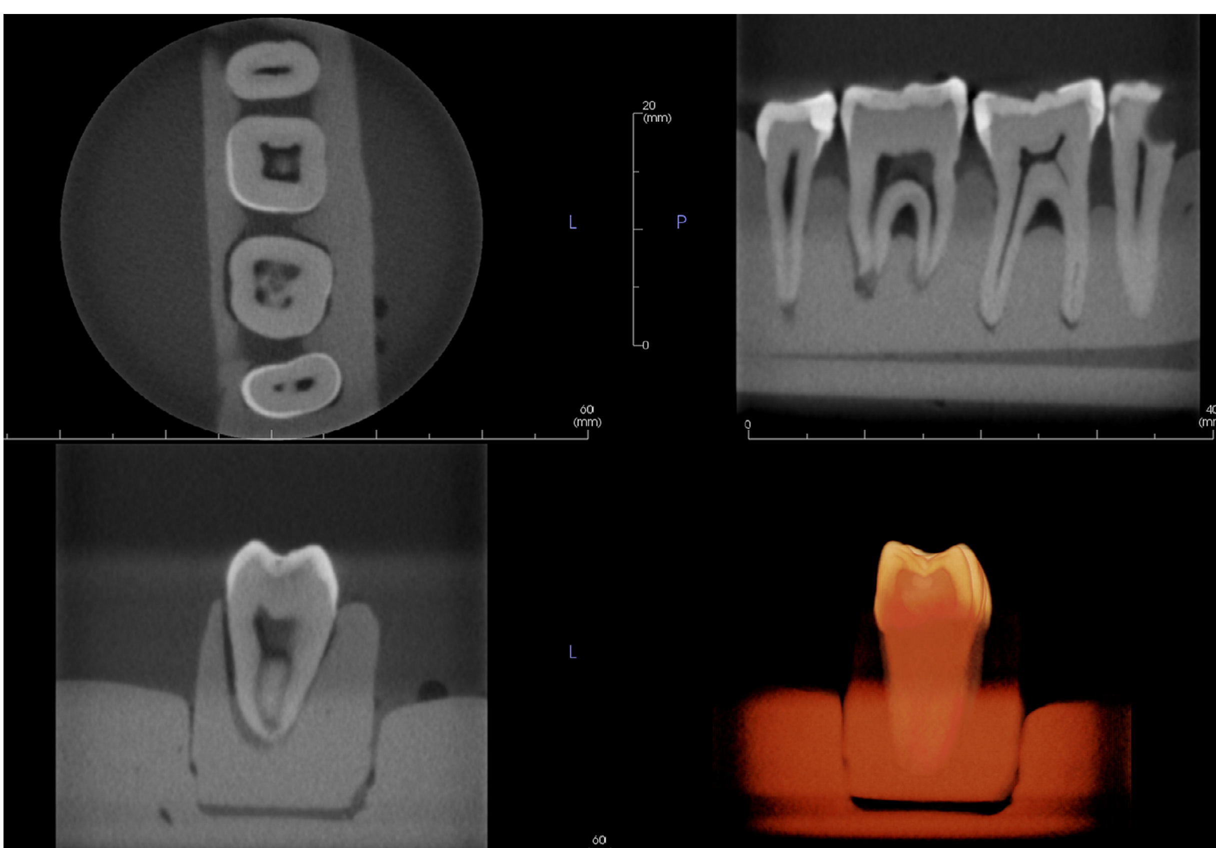

Fig. 7. Multiplanar presentation of the cone beam computed tomography images in axial, coronal, sagittal, and 3-D rendering.

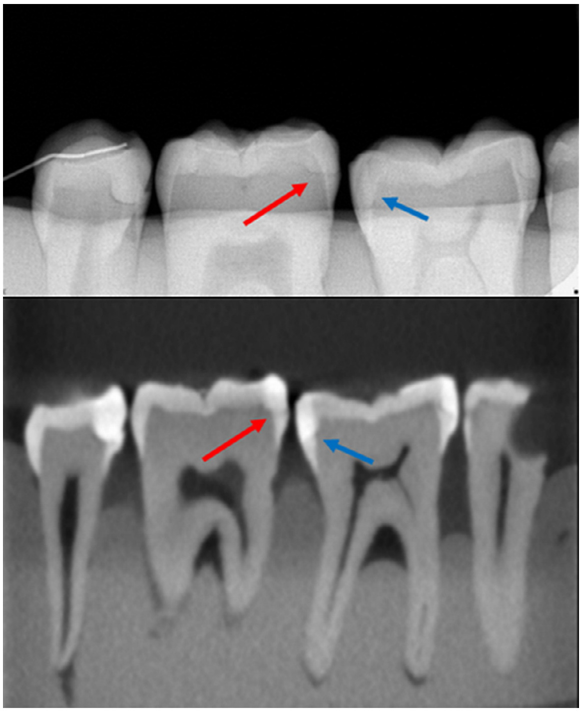

Fig. 8. Example of images obtained from an intraoral radiograph (top) and sagittally reformatted cone beam computed tomography (bottom) of the same set of teeth. Caries is indicated by the red arrows. A noncarious surface is indicated by the blue arrows.

the standard error of the binomial test of one proportion, with the value of n for sensitivity being the number of true carious teeth rated and for specificity being the number of true noncarious teeth rated. The confidence intervals for the IR and CBCT techniques were calculated for the aggregate of the 6 observers. For the AUC of the ROC plots, the confidence intervals were calculated from the standard error for an ROC curve, as derived by Hanley and McNeil.[19]

Cohen's κ statistic was calculated to determine the interobserver agreement and intraobserver agreement for each imaging method, using the dichotomous classification system. Landis and Koch suggest that a κ score less than 0.2 indicates poor to slight agreement, between 0.21 and 0.40 shows fair agreement, between 0.41 and 0.60 indicates moderate agreement, between 0.61 and 0.80 shows substantial agreement, and 0.81 or greater indicates almost perfect agreement.[20]

RESULTS

Sensitivity and specificity for all 3 modalities are shown in Table I along with the area under the ROC curve for IR and CBCT. The sensitivity with 95% confidence intervals (CIs) for PTR/LUM was 0.89 (0.78-0.99), whereas the average sensitivity among the 6 observers with 95% CIs were 0.38 (0.31-0.44) for IR and 0.40 (0.33-0.46) for CBCT. The sensitivity for PTR/LUM was clearly greater than and outside the CIs for sensitivity for IR and CBCT. Specificity for the three modalities was 0.83 (0.71-0.95), 0.80 (0.75-0.86), and 0.70 (0.64-0.76) for PTR/LUM, IR, and CBCT, respectively. The specificity for CBCT was outside the CIs of the other 2 modalities and thus was significantly inferior, but there was no significant difference between PTR/LUM and IR.

The ROC plot for the IR and CBCT techniques, averaged across all 6 observers, is shown in Figure 9, along with the 95% confidence intervals. The mean value of AUC for intraoral radiography was greater than the upper 95% CI for CBCT, so IR was significantly different from CBCT for this diagnostic purpose.

κ Statistics for Interobserver Agreement

Out of the 15 pairings among the 6 observers using the IR technique, 6 pairs exhibited poor agreement ($\leq$0.2 for the κ statistic), 7 pairs had fair agreement (between 0.21 and 0.40), and 2 pairs of observers (2 and 3 and 2 and 4) had moderate agreement. For the CBCT technique the agreement among observers was slightly worse, with 8 observers showing poor agreement, 6 exhibiting fair agreement, and 1 pair (3 and 4) with moderate agreement.

κ Statistics for Intraobserver Agreement

Table II shows the observed agreement and the κ statistic. PTR/LUM had moderate intraobserver agreement ($\kappa = 0.56$). For observers 1 and 4, the κ statistic suggested that there was little difference between the IR and CBCT modalities regarding how well the method enabled them to be consistent in their reading of the images; they were rated moderate with both methods. For observers 2, 3, and 5, the CBCT method appeared to have the advantage, enabling them to have almost perfect agreement when reading the same image

Table I. Comparison of modalities: sensitivity, specificity, and area under the ROC curve with 95% CI

Modality	*PTR/LUM*	*IR*	*CBCT*
Sensitivity (95% CI)	0.89 (0.78-0.99)	0.38 (0.31-0.44)	0.40 (0.33-0.46)
Specificity (95% CI)	0.83 (0.71-0.95)	0.80 (0.75-0.86)	0.70 (0.64-0.76)
AUC	—	0.65 (0.59-0.70)	0.59 (0.53-0.64)

ROC, receiver operating characteristic; *CI,* confidence interval; *PTR,* photothermal radiometry; *LUM,* luminescence; *CBCT,* cone beam computed tomography; *IR,* intraoral radiography; *AUC,* area under the curve.

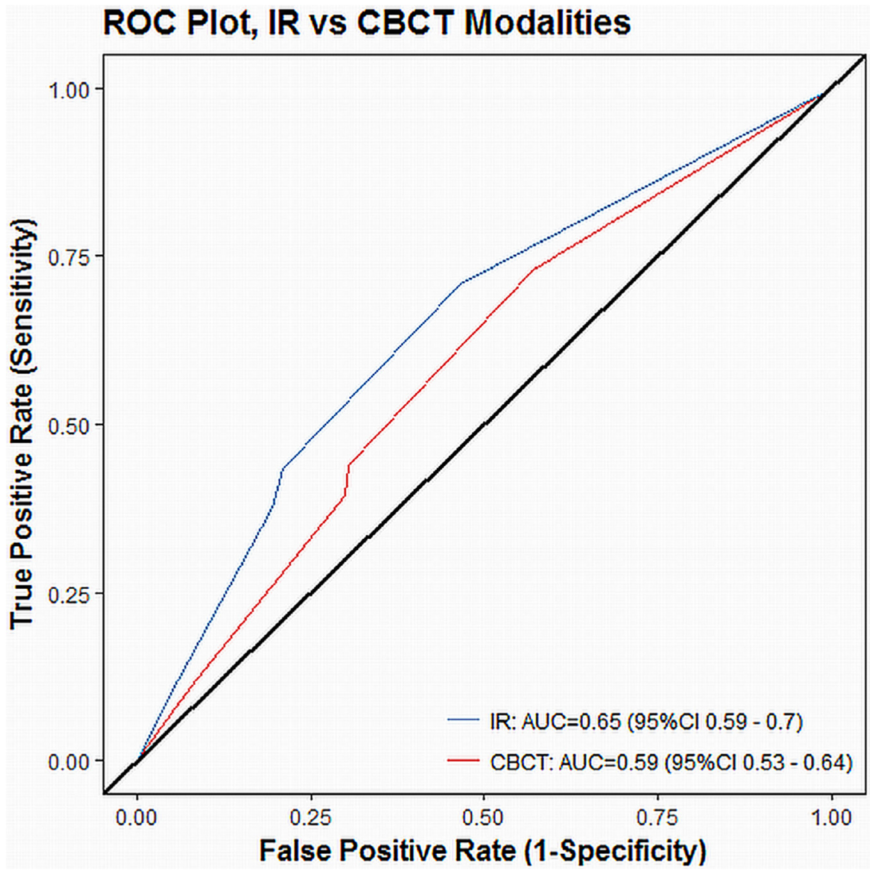

Fig. 9. Receiver operating characteristics (ROC) plot from combined observer performance using intraoral radiography (IR) and cone beam computed tomography (CBCT). *AUC,* area under the curve; *CI,* confidence interval.

compared with the IR method, which indicated moderate to substantial agreement. Observer 6 had a poor intraobserver agreement for both methods.

Table II. Comparison of modalities: intraobserver agreement

Imaging method/observer	*Observed agreement*	*κ*
IR		
Observer 1	0.73	0.48
Observer 2	0.82	0.61
Observer 3	0.91	0.62
Observer 4	0.73	0.48
Observer 5	0.73	0.46
Observer 6	0.55	-0.28
CBCT		
Observer 1	0.82	0.42
Observer 2	0.91	0.81
Observer 3	0.91	0.81
Observer 4	0.82	0.54
Observer 5	1.00	1.00
Observer 6	0.91	0.00
PTR/LUM	0.82	0.56

IR, intraoral radiography; *CBCT,* cone beam computed tomography; *PTR,* photothermal radiometry; *LUM,* luminescence.

DISCUSSION

The principle of ALARA necessitates justification for the use of ionizing radiation in the diagnosis of dental diseases.[7] Its use must be restricted to situations in which radiographic examination is necessary in reaching a diagnosis or planning for the best treatment outcomes. The trend for proximal caries lesions to increase with age has been documented.[21] The use of intraoral radiographs in caries detection has been well researched in various studies.[22,23] Its sensitivity for detecting early caries or recurrent caries has been shown to be poor.[11,13,24] This indicates the need for the development of more sensitive imaging modalities[5,9,14,25] aimed at early detection and ultimately improved treatment outcomes.

The Canary System, based on the PTR-LUM technique, is a noninvasive energy conversion technology that provides combined optical and thermal ("photothermal") information about the condition of tooth microstructure.[14] The PTR/LUM measures the strength of the converted heat and light from the intensity modulated laser beam and time delay it takes for the heat to reach the surface conductively. The PTR-LUM system has an effective probing depth of up to

5 mm below the tooth surface and a probing area of 1.5 mm in diameter. A Canary number ≤20 indicates healthy tooth structure, whereas a CN >70 indicates a large lesion. Canary numbers between 20 and 70 indicate the presence of early caries lesions or cracks that may need to be treated.[15,16]

In this investigation, the PTR/LUM system had high sensitivity (0.89), and this is in agreement with the results of other reported studies.[26,27] Abogazalah and Ando,[26] in their review article on alternative methods to visual and radiographic examinations for proximal caries detection, implied that the PTR/LUM system can objectively quantify caries lesions and differentiate between caries and developmental defects.[26] They suggested that the PTR/LUM system has the potential for early detection of recurrent caries. A study by Abrams et al.[10] on the correlation of various diagnostic systems with caries lesion depth reported a high correlation of the PTR/LUM system with depth of decay, indicating that this modality may provide the clinician with information about the size and position of caries and aid in monitoring treatment. In the present investigation, however, both intraoral radiography and CBCT modalities were less than ideal, with average sensitivities 0.38 for IR and 0.40 for CBCT.

For specificity, the ability to correctly identify an intact restoration with no recurrent caries, the PTR/LUM system and IR performed well, with specificities of 0.83 for PTL/LUM and 0.80 for IR, whereas the CBCT method was inferior to both on average (0.70). Although studies have documented the specificity of the PTR/LUM system to be about 0.8, which is comparable to the results of this investigation, Jallad et al.[28] reported a low specificity of 0.43 for the PTR/LUM system in their ex vivo study using visual, light-induced fluorescence and PTR/LUM techniques to detect occlusal caries on permanent teeth. They suggested that the sensitivity and AUC can be affected by the distribution of the extent of the lesions in the sample. Increasing numbers of deeper (large) lesions, which are easier to detect, will lead to an overestimate of sensitivity, whereas underestimation will occur if there is a relative overabundance of small white spot lesions.[28] However, Abrams et al.,[5] in their ex vivo study using 4 different modalities for the detection of caries around amalgam restorations at 3 different distances from the margin of the restoration, documented sensitivity/specificity values for the PTR/LUM system at sites 2.0, 1.5, 0.5, and 0 mm from the margin ranging from 0.95 to 1.0 and 0.85 to 1.0, respectively, which are higher than the results of the present study.

In a systematic review and meta-analysis of 117 papers (13,375 teeth, 19,108 surfaces) comparing radiographic modalities for early approximal caries detection, Schwendicke et al.[22] found low sensitivity but high specificity. The pooled sensitivities and specificities and 95% CIs were calculated. For dentinal lesions, sensitivities ranged from 0.36 (0.24/0.49) for proximal to 0.56 (0.53/0.59) for occlusal lesions, and specificities ranged between 0.87 (0.85/0.89) for proximal and 0.95 (0.94/0.96) for occlusal lesions. They reported that dental practitioners generally used a combination of visual and radiographic methods to make a diagnosis. These results were similar in terms of sensitivity and slightly higher in terms of specificity compared with those obtained in the present study, in which intraoral radiography and CBCT techniques produced sensitivity and specificity of 0.38/0.80 and 0.40/0.70, respectively.

Another systematic review and meta-analysis of 103 papers on visual inspection for caries detection also found a trend toward lower sensitivities and higher specificities when the studies were performed in the clinical setting compared with the laboratory.[29] This indicated the disparity between a well-designed experimental environment and the real-life situation. Other research has found that visual inspection and the use of radiography for caries detection in general have about the same sensitivity and specificity.[13]

Valizadeh et al.,[24] in their evaluation of CBCT and comparison with intraoral periapical radiography in proximal caries detection, concluded that CBCT images did not enhance detection of proximal caries in comparison with periapical images. The usefulness of CBCT in different aspects of dental practice, such as 3-D image analysis, implant planning, and endodontic evaluation, is well known. However, various studies have reported that CBCT does not improve the accuracy of caries detection compared with conventional film or digital intraoral radiography.[12,13,30,31] Though it has been documented that CBCT has a higher sensitivity than intraoral radiography for cavitated approximal caries, the aim of the present study was to evaluate recurring caries under restorations and its early detection.

In the present investigation, the confidence intervals reported are based on the calculation of standard error for an ROC curve, as derived by Hanley and McNeil.[19] The confidence intervals of each observer overlapped for each imaging technique, indicating that there was no statistically significant difference among observers for AUC for either of the radiographic techniques. The overall confidence intervals for the AUC for all observers were >0.5 for each system, so both systems are better than guessing.

There are varying reports on the interobserver agreement in studies on detection of caries using intraoral radiography and CBCT.[12,13,24] Senel et al.[13] reported interobserver agreement ranging from 0.631 to 0.811 for CBCT and intraoral radiography with no statistically significant difference. Poor to fair interobserver and intraobserver agreement among pairs of observers using the IR and CBCT techniques was found in the present investigation, with each observer having a large but unique set of false negatives. The differences in inter- and intraobserver agreement κ values among the different studies may be related to the study design, study material, viewing conditions, radiographic quality, and experience of the observer, all of which are important factors in determining observer agreement.

For the PTR/LUM system, it has been documented that there can be a large range in CN among Canary scans taken per study tooth[25] because the PTR/LUM system is sensitive to angulation.[5,28] Training and calibration before starting our study ensured the examiners adhered strictly to the manufacturer's protocol of placing the probe perpendicular to the surface being examined.

Some of the factors that make CBCT less of an appropriate method for detection of recurrent caries under a restoration are beam hardening artifact caused by metallic restorations, which has a profound effect on the quality of CBCT images; and the higher cost, poorer accessibility, and greater radiation dose of CBCT compared with intraoral radiography. These factors limit its use as a primary radiographic modality for dental caries detection.[26,32] In present times, evidence-based dentistry is used in patient management. The purpose of research is to document reports that ultimately can be implemented as the best evidence into clinical practice. The purpose of the diagnostic tools in our study was to accurately diagnose early stages of a caries lesion and ultimately initiate treatment to halt the progression of and subsequent damage created by the disease. Though clinical trials have reported that the PTR/LUM system is a well-tolerated and sensitive method and has little to no difference in signal when the tooth surface is wet or has plaque formation,[25] methods presenting higher sensitivity may increase false positive diagnoses, which may increase the potential for unnecessary overtreatment.[26,28,32] Therefore, these alternative diagnostic methods should not be used alone but as adjunct methods to support conventional techniques until the diagnostic accuracies are well documented in clinical trials.

The present study was limited by its ex vivo design and by the fact that the PTR/LUM system is very sensitive to positioning and angulation, both of which can give false positive and false negative results. Future research on PTR/LUM would benefit from calculation of the Youden index,[33] which could be useful in validating the threshold CN of 20 reported by the PTR/LUM manufacturer. Also, the sample used in this study may not represent the distribution of recurrent caries in clinical situations.

CONCLUSIONS

The PTR/LUM system, which involves nonionizing radiation, can serve as a sensitive adjunct in early caries detection and monitoring, especially among patients at high risk for caries. Radiographs, although valuable in the detection of advanced caries, are less sensitive for early lesions or recurrent lesions under restorations. PTL/LUM can have value when used in conjunction with visual examination and IR. However, this needs to be validated by further clinical research. The higher radiation dose and the low sensitivity and specificity associated with CBCT prohibit its routine use for caries detection.

ACKNOWLEDGMENTS

The authors would like to acknowledge their statistician, Mr. Michael Mader, for the statistical analysis.

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