Clin Oral Invest (2010) 14:319–325
DOI 10.1007/s00784-009-0307-z

ORIGINAL ARTICLE

Effect of computer assistance on observer performance of approximal caries diagnosis using intraoral digital radiography

Kazuyuki Araki · Yukiko Matsuda · Kenji Seki · Tomohiro Okano

Received: 5 February 2009 / Accepted: 12 June 2009 / Published online: 26 June 2009

Abstract Logicon Caries Detector™ (LDDC) is the only commercially available computer-assisted diagnostic system for caries diagnosis. The object of this study is to elucidate the efficacy of LDDC when used by inexperienced dentists. Fifty extracted teeth were imaged using an RVG6000. Seven dentists who had just passed the Japanese National Dental Board Examination observed those images without LDDC (woLDDC) and assessed the probability that caries lesions were present, then re-assessed the same teeth using LDDC (wLDDC). The areas under the receiver operating characteristic curves (Az) were compared. No statistically significant difference was found between woLDDC Az values and wLDDC Az values when caries lesions of all depths were considered. When positive cases were restricted to caries lesions in the inner half of the enamel or to dentine caries lesions, however, wLDDC Az values were significantly larger than woLDDC (p=0.043 and 0.018, respectively).

Keywords Diagnosis · Caries · CAD/CAM · Computer-assisted diagnosis · Radiography · Radiation

Introduction

Caries diagnosis and treatment constitute a significant portion and an important aspect of dentists' work. Many methods of diagnosing caries have been introduced, including radiography, ultrasound, fiber optics, and tomography; there is an especially wide range of techniques for diagnosing caries on approximal surfaces [1-3]. Intraoral radiography has, however, remained the most widely used method in conjunction with clinical examination for diagnosis of caries lesions [4, 5].

Caries lesions can also be diagnosed through the use of various computer-aided assessment tools, including image-enhancement methods [6-12], image subtraction [13], and computer-aided diagnosis [14-19]. Yet, computer-aided diagnosis programs have not been widely used thus far, for a simple reason: only one of them is commercially available. This is the Logicon Caries Detector™ (LDDC, Eastman Kodak Company, Rochester, NY, USA). The effectiveness of LDDC is disputed: Gakenheimer et al. [16] reported its effectiveness in diagnosis, but it should be noted that Gakenheimer was one of the developers of the program and an employee of the manufacturer. He may, therefore, have had conflicting interests in the outcome of his evaluation of the program [20]. In contrast, Wenzel et al. did not find LDDC effective [21]. Navarro et al. recently reported the effectiveness of LDDC [22], but their experiment involved only one observer, who may have been an experienced dentist. Thus, the effectiveness of LDDC in the diagnosis of caries lesions is still uncertain. Furthermore, LDDC may be more effective for inexperienced dentists, but this is also unclear.

In the present study, we set out to answer these questions by observing the effect of LDDC use on the accuracy of approximal caries diagnosis, specifically, its effect on the accuracy of diagnoses made by inexperienced dentists.

Materials and methods

Sample preparation and image acquisition

One hundred approximal surfaces of 50 extracted human upper first and second premolar teeth were used as

K. Araki (✉) · Y. Matsuda · K. Seki · T. Okano
Department of Radiology, Showa University School of Dentistry, Kitasenzoku 2-1-1, Ohta-ku, Tokyo 145-8515, Japan
e-mail: araki@dent.showa-u.ac.jp

specimens. None of the specimens had a visible cavity on the surface, and none had fillings in their crowns. Two other teeth (one upper first premolar and one first molar) were positioned on either side of each experimental specimen to represent the adjacent teeth. The three teeth were arranged in a row with approximal surfaces in contact and roots embedded in a 40×20×10-mm-sized utility-wax block, so that both the mesial and the distal approximal surfaces of each experimental tooth could be evaluated. An RVG6000 digital radiography system (KODAK) was used as the sensor system. The RVG6000 consists of a super CMOS solid-state sensor and an optical fiber. It offers three sensor sizes; in this experiment, the outer size and the size of the active area of the sensor were 40×27 and 30×22 mm, respectively. Pixel size was 18.5 µm and shades of gray were 4,096.

The exposure conditions were 60 kV, 7 mA, and 0.08 s, and the distance between focus and sensor was 40 cm. The presence of soft tissue was simulated by placing a 1-cm-thick piece of a soft-tissue equivalent material (Though Water Phantom, Kyotokagaku, Kyoto, Japan) in the appropriate place.

Observation and statistical analysis

Seven dentists who had just passed the Japanese National Dental Board Examination were instructed in the use of LDDC by being given a written manual and shown sample images. The dentists observed radiographic images of experimental specimens without using LDDC (woLDDC) and assessed the likelihood that caries lesions were present according to the continuous rating scale (CRS), which corresponds to the observer's confidence level of lesion presence: (100=definitely positive, 50=unable to determine, 0=definitely negative). They then re-examined the same teeth using LDDC ver. 4.0 and re-assessed the likelihood of caries lesions [with LDDC (wLDDC)]. All images were displayed on a Sharp Mebius laptop computer model PC-WA70K (Sharp, Osaka, Japan). The liquid crystal display size was 1,280×800 dots. Before the experiment, the display setting was adjusted using a free monitor test tool (EIZO, Tokyo, Japan). All observations were performed in a quiet room with subdued ambient light.

Figures 1 and 2 show sample images and outputs generated using LDDC. Figure 1 was generated by observer 1 and Fig. 2 was generated by observer 2. When using LDDC, each observer first defined the region of interest for detection of caries lesions using the V-tool or wedge. This is visible on the crown of the tooth in Fig. 1a. Using special gradient filters, LDDC automatically finds the outer edge of the tooth and the boundary between the enamel and the dentin (DEJ). Then it divides the crown into 15 contour lines (ten in the enamel, five in the dentin). These lines run nearly parallel to the outer edge of the crown and the DEJ (Figs. 1b, c and 2b, c). The program then analyzes the X-ray density along the contour lines in the enamel and adjacent dentin, seeking local radiolucencies (dark regions in the image) using a high pass filter. It then extracts density and spatial information about the most obvious local radiolucencies for use in lesion classification. The extracted local radiolucencies are displayed on the image (Figs. 1b and 2b) and on the tooth density plots (Figs. 1c and 2c) as yellow or red lines. A red line indicates that the lesion probability is higher than the decision threshold, which is 15% or lower for a false positive outcome at the default setting. The program extracts data on each feature's magnitude (darkness), area, depth of penetration, alignment in the enamel and/or dentin (if the feature extends into the dentin), and the magnitude in the dentin (if the feature extends into the dentin). Then, using artificial neural

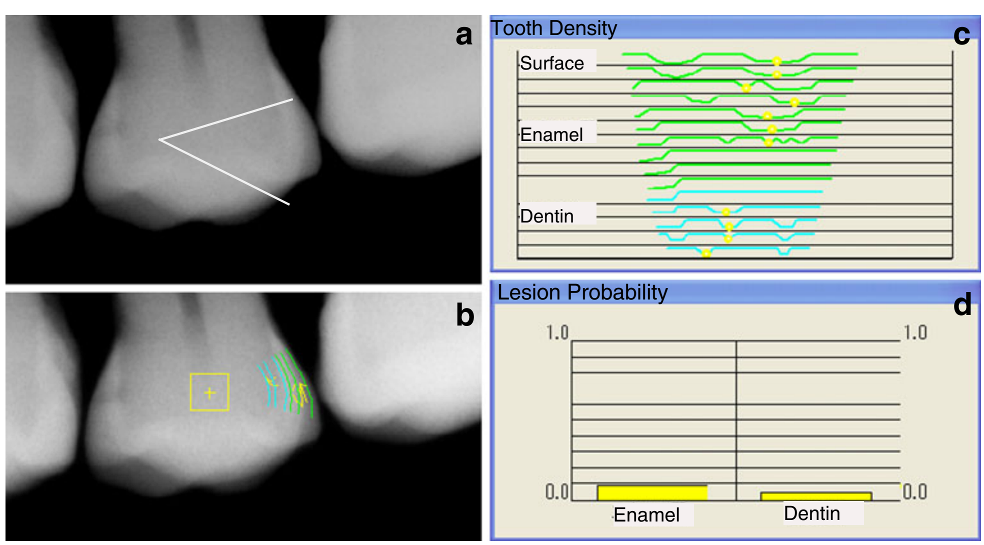

Fig. 1 Sample of LDDC output and the change in observer performance in the case of a sound surface. **a** The V-tool, which is used to indicate the tooth surface being analyzed, is visible on the original image (i.e., woLDDC). **b**–**d** LDDC output generated by observer 1. The distal surface of this experimental tooth was caries-free according to Micro CT. After viewing the image woLDDC, observer 1 assigned a CRS value of 100 to this surface. After viewing the image wLDDC, the same observer revised the CRS value to 0

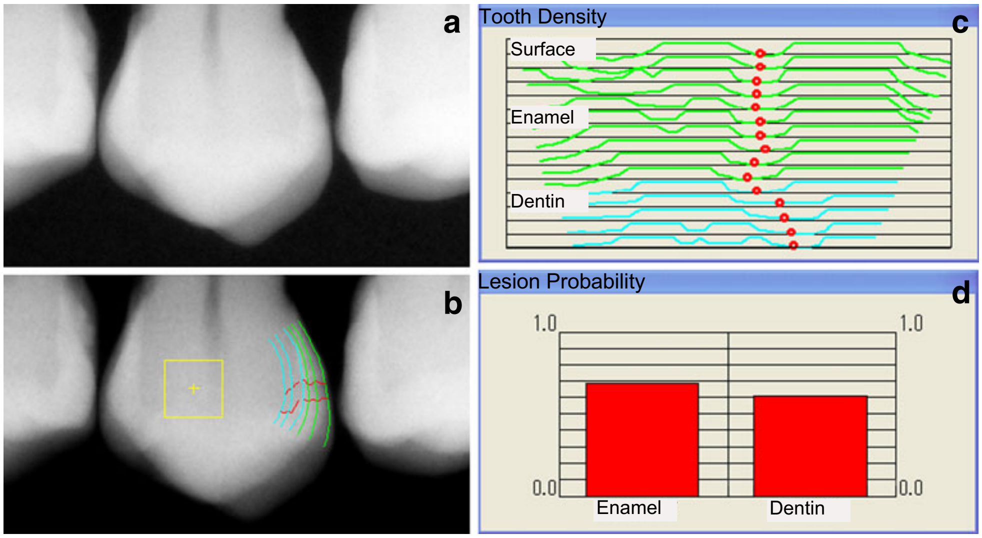

Fig. 2 Sample of LDDC output and the change of observer performance in the case of caries lesions in the external half of the dentin. **a** Original image (without LDDC). **b**–**d** LDDC output and its interpretation by observer 2. The distal surface of this experimental tooth contains a caries lesion in the external half of the dentin. After viewing the image woLDDC, observer 2 assigned a CRS value of 42 to this surface. After viewing the image wLDDC, the same observer revised the CRS value to 100

networking methods, the program compares the features in the current X-ray image with those in a database of 608 images of teeth with lesions present. Sample outputs of the program are shown as lesion probability plots, one for enamel and one dentin, in the form of bar graphs (Figs. 1d and 2d). These bar graphs are displayed in red when the lesion probability exceeds the decision threshold (Fig. 2d). More detailed features of LDDC are described elsewhere [20, 23].

The distal surface of the experimental tooth shown in Fig. 1 was caries lesion-free according to Micro CT. After viewing the image woLDDC, observer 1 assigned a CRS value of 100 to this surface. After viewing the image wLDDC, the same observer revised the CRS value to 0. The distal surface of the experimental tooth in Fig. 2 contains a caries lesion in the external half of the dentin. After viewing the image woLDDC, observer 2 assigned a CRS value of 42 to this surface. After viewing the image wLDDC, the same observer revised the CRS value to 100.

Receiver-operating characteristic (ROC) curves were generated from the ratings that the dentists assigned to the teeth. We also defined three categories of positive lesions according to the true caries lesion depth: one group consisted of all caries lesions on all surfaces (all caries), one consisted of caries lesions that had penetrated through at least half of the enamel (inner half enamel caries), and one consisted of caries lesions that had penetrated into the dentin (dentine caries). ROC curves were generated for woLDDC and wLDDC ratings for each lesion group.

The area under each ROC curve (Az) was then calculated, and Az values were statistically evaluated using the Wilcoxon signed-rank test. ROC curve generation and statistical analysis were performed using the Statistical Package for the Social Sciences (SPSS 14 J, SPSS Japan, Tokyo, Japan).

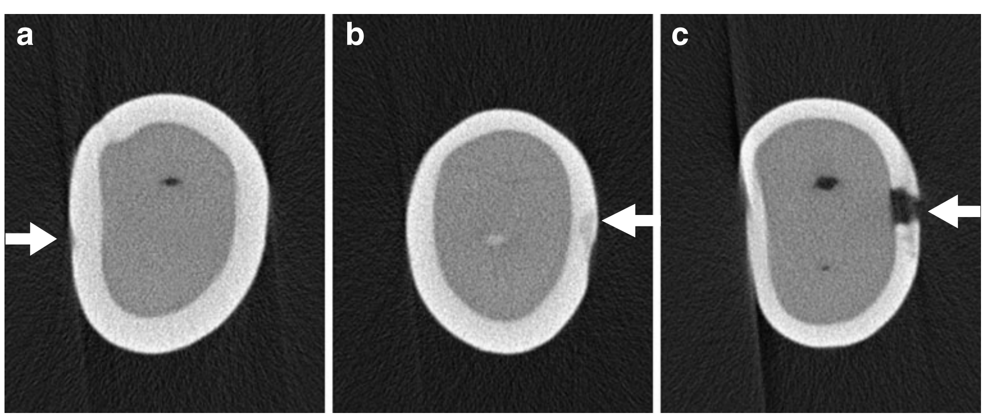

Fig. 3 Sample images acquired using Micro CT. **a** Caries lesion restricted to the outer half of the enamel (*arrow*). **b** Caries lesion extending into the inner half of the enamel but not extending into the dentin (*arrow*). **c** Caries lesion extending into the outer half of the dentin but not the inner half (*arrow*). Micro CT (XCT Research SA, Stratec) was operated at 50 kVp and 0.5 mA

Gold standard

Before this experiment began, all 50 teeth were scanned by Micro CT (XCT Research SA, Stratec, Birkenfeld, Germany) operating at 50 kVp, 0.5 mA, to determine the presence or absence of approximal caries lesions and the depths of all caries lesions present. Fifty axial slices were generated at the crown against the tooth major axis with a pixel size of 50× 50 µm and a slice interval of 50 µm. Figure 3 shows a few examples of these axial slice images. Each set of slice images was displayed on a CRT monitor in sequence using ImageJ Software (NIH, Bethesda, MD, USA) and evaluated as a gold standard by a Japanese board-certified oral and maxillofacial radiologist to determine whether approximal caries lesions were present in that tooth and how deep they were.

Results

Micro CT revealed that 29 of the 100 approximal surfaces had no caries lesions (29%), 17 surfaces had caries lesions restricted to the outer half of the enamel (17%), 30 surfaces had caries lesions extending into the inner half of the enamel but not into the dentin (30%), and 24 surfaces had dentine caries lesions that extended into the outer half but not the inner half of the dentin (24%) (Table 1). There were no surfaces with caries lesions extending into the inner half of the dentin. Figure 3 shows some examples of the micro CT images on which these measurements are based.

Figure 4 shows the ROC curves generated from the pooled data of our seven observers. When caries lesions of all depths were considered (Fig. 4a), the difference between the woLDDC curve and the wLDDC curve was small. The difference between these two curve types became more apparent as only progressively deeper caries lesions (first only the inner-half enamel caries, Fig. 4b, then only the dentin caries, Fig. 4c) were considered. In other words, the observers were more likely to revise their estimates of the likelihood of caries lesions after using LDDC when analyzing deeper caries lesions.

Table 2 shows the results of ROC analysis. For the diagnosis of all caries lesions regardless of depth, the mean

Table 1 Caries lesion distribution as diagnosed with Micro CT

Micro CT diagnosis	Number of surfaces
Sound	29
Caries lesion in external half of enamel	17
Caries lesion in internal half of enamel	30
Caries lesion in external half of dentin	24
Total	100

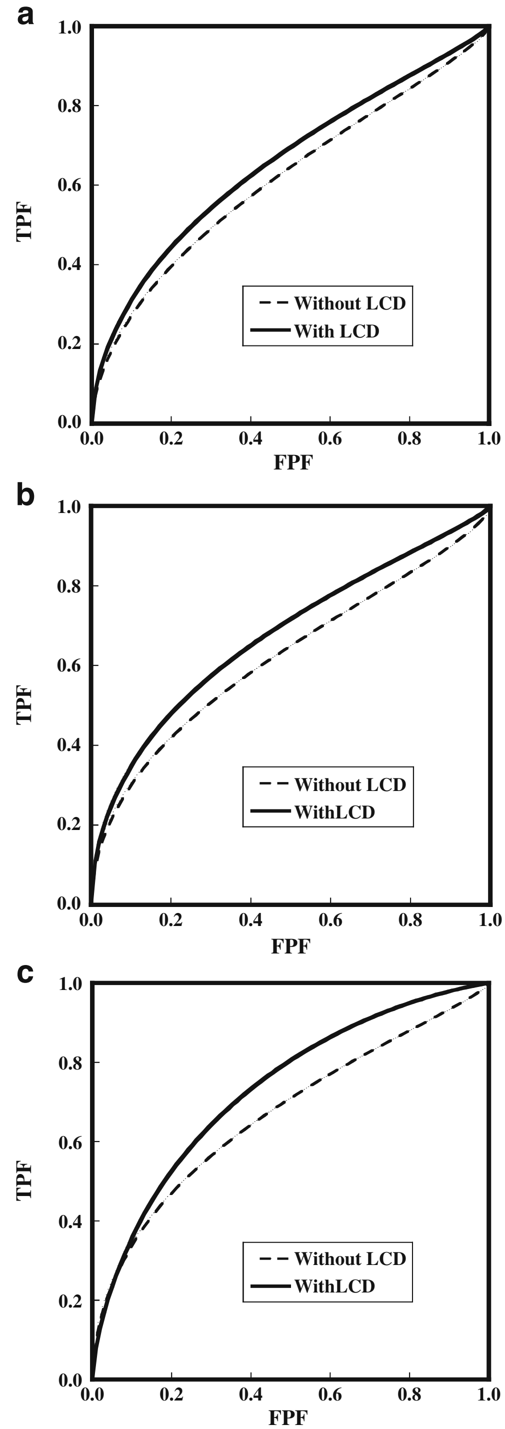

Fig. 4 ROC curves calculated from the pooled data from all seven observers. **a** ROC curve incorporating responses concerning all caries: all surfaces containing caries lesions are defined as positive. **b** ROC curve incorporating responses concerning only inner-half enamel caries: only surfaces containing caries lesions penetrating more than halfway through the enamel or into the dentin were defined as positive. **c** ROC curve incorporating responses concerning dentine caries: only surfaces containing caries lesions penetrating into the dentin were defined as positive

Table 2 Az values for observations with (wLDDC) vs without (woLDDC) LDDC in the three positive categories

Observer	Az value					
	All caries		Inner half enamel caries		Dentin caries	
	woLDDC	wLDDC	woLDDC	wLDDC	woLDDC	wLDDC
1	0.623	0.640	0.608	0.629	0.689	0.698
2	0.603	0.668	0.623	0.723	0.742	0.875
3	0.667	0.743	0.704	0.750	0.748	0.854
4	0.712	0.660	0.729	0.703	0.741	0.750
5	0.605	0.608	0.534	0.621	0.588	0.705
6	0.553	0.738	0.559	0.709	0.640	0.641
7	0.564	0.579	0.643	0.701	0.674	0.689
Mean ± SD	0.618±0.056	0.662±0.061	0.629±0.071	0.691±0.048	0.689±0.060	0.745±0.088
	p=0.090		p=0.043		p=0.018	

Az (the area under the ROC curve) was 0.618 for woLDDC vs 0.662 for wLDDC. In the case of caries lesions penetrating to the inner half of the enamel, the mean Az was 0.629 for woLDDC vs 0.691 for wLDDC. In the case of the dentine caries, the mean Az was 0.689 for woLDDC vs 0.745 for wLDDC. For both categories of deeper caries lesions considered together, the Az values of diagnoses made wLDDC were significantly larger than those of diagnoses made woLDDC (p=0.043 and 0.018).

Discussion

LDDC did not appear to improve caries diagnostic ability when all caries lesions were considered as a group. This result is consistent with those reported by Wenzel et al. [21, 24]. When only deeper caries lesions (inner half enamel and dentin caries) were considered, however, LDDC appeared to improve diagnostic ability by a significant amount. In other words, the improvement in Az value resulting from the use of LDDC is more evident when deeper caries lesions are considered. These results are consistent with those of Gakenheimer et al., who called LDDC “a software decision aid for the diagnosis of caries that have penetrated into the dentin” [16], and with those of Navarro et al. [22]. Thus, our results may show that each of these conflicting previous studies is partially correct in its conclusion.

As described in the “Materials and methods” section, above, LDDC analyzes the density changes in images of the tooth crown and extracts data on six parameters [20, 23]. These data transfer into an artificial network system for diagnosis. The neural network consists of three-layer feed-forward networks, which were trained to recognize caries lesions using stored images of 288 teeth, out of a database of images of 608 teeth with lesions present at a range of depths. The remaining images of 320 teeth were used to test the network. This training set includes incisors, canines, premolars, and molars. No information is available concerning how many of each type of tooth is included in this training set. In the present study, we used only premolars; the accuracy of LDDC's diagnoses may vary when other types of teeth are used. Furthermore, the neural network's internal process may vary each time and/or from image to image in a way that cannot be logically explained [20].

It is also possible that the difficulty of using LDDC affected the outcomes: our observers were trained on LDDC before the experiment, but they nevertheless stated that it was slightly difficult to use the v-tool accurately because the LDDC output was very sensitive with regard to the v-tool position and shape. This difficulty was also reported in Wenzel's study; the authors noted that moving the v-tool by only one or two pixels could result in a drastic change in the lesion probability estimate [24].

Another complication is the fact that we may have used a different version of LDDC software in our experiment, as the versions used by Gakenheimer et al. and Wenzel et al. are not known [16, 21, 24]. We used version 4.0, which is relatively new; because of the relatively long time interval between the other studies and ours, we suspect that they may have used different versions. The use of different versions may have affected the results; however, since no information on differences between the versions has yet been published, it is difficult to say exactly how.

Microscopy assessment is generally used as a gold standard method for the detection of caries lesions; we used Micro CT for that purpose here, as in our previous study [25, 26]. Clinical radiographic detection of caries lesions depends on the amount of demineralization caused by the caries, and is more accurate in cases of greater demineralization. Micro CT, on the other hand, is potentially capable of detecting even microscopic changes in mineral density [27, 28]. Furthermore, micro CT provides us with continuous slice images; in other words, there are no gaps between the slices. This offers an advantage over the practice of sectioning and examining histological tooth specimens, in which an average tooth section is about 200 to 700 μm thick, and in which some of the tooth thickness between each section is lost during preparation through cutting with the diamond saw. Micro CT images are sometimes distorted by the so-called metal artifacts caused by the presence of fillings, but in this experiment, we used only teeth without fillings in order to avoid that limitation. For these reasons, we consider Micro CT to be a useful alternative tool for caries diagnosis, as Lee et al. have suggested. [28].

Of the 100 proximal surfaces used in this study, only 29% were sound. We tried to collect equal numbers of caries lesions in each depth category, insofar as this was possible. This resulted in a relatively low proportion of sound surfaces. Although we knew that the elevated disease prevalence rate in the sample would influence the accuracy of our dentists' diagnoses, we chose to arrange our sample this way so that we could determine whether the accuracy of each diagnosis method (with LDDC and without) changed with caries lesion depth.

Digital intraoral radiographic systems provide similar images, and similar diagnostic ability, to those provided by conventional radiographic film, even when computer assistance is not used. The results of several experiments indicate that digital radiographic systems require lower doses of radiation exposure than film does [29-34]. In a preliminary experiment, we have observed that the exposure condition (exposure dose) required by RVG6000 was about one quarter of that required by Insight film (KODAK) in this experimental geometry. Its lower exposure requirement and its equivalent diagnostic ability indicate that the digital system is to be preferred for clinical use. Furthermore, our results suggest that computer assistance can actually provide more precise diagnoses.

Current understanding of caries and their treatment is quite different from the opinions common in former times. Nowadays, superficial and inactive lesions are not treated surgically, but are recommended for surveillance at an appropriate, individualized time interval [35-37]. These intervals vary from patient to patient and are determined by certain risk factors, such as social history, use of fluoride, and quality and quantity of saliva [38]. Patients who are classified as having a high caries risk according to these factors are recommended to receive a radiographic examination every 6 months. Moderate- and low-caries-risk patients are recommended to receive radiographic examinations annually and once every 2 years, respectively. It is thought best to use the same instrument for each surveillance examination so that the conditions for each intraoral radiograph are as similar as possible.

As these guidelines indicate, false positive diagnosis is now considered to be a more serious incorrect test outcome than false negative diagnosis. This is because, in populations with low disease prevalence and small lesions, the continued presence of caries resulting from false negative diagnosis is considered to be less harmful than unnecessary surgical treatment resulting from false positive diagnosis [39]. In a study by Mileman et al. [40], inexperienced observers (dental students) showed a higher rate of false positive diagnoses than experienced observers did. This was one reason why we wanted to test the effect of LDDC on the accuracy of caries diagnosis by inexperienced observers specifically.

In the present study, woLDDC and wLDDC Az values for all caries were similar to those in some previous studies [39, 41], yet slightly lower than that in the study by Mileman et al. [40]. The fact that our Az values were lower than theirs may be due to the depths of the caries in our sample. For example, about 45% of the samples used by Mileman et al. had dentine caries, whereas only 24% of ours did. The use of more samples with lesions restricted to the superficial layers of the teeth may have resulted in a high rate of false negatives and a low rate of true positives. In addition, we used only non-cavitated caries lesions, for which diagnosis is often more difficult.

Conclusions

In conclusion, LDDC resulted in improved diagnosis of approximal caries by inexperienced observers when the caries lesion extended into the inner half of the enamel or into the dentin.

Acknowledgment

Conflict of interests We declare that we have no conflicts of interest.

References

1. Schneiderman A, Elbaum M, Shultz T, Keem S, Greenebaum M, Driller J (1997) Assessment of dental caries with Digital Imaging Fiber-Optic TransIllumination (DIFOTI): in vitro study. Caries Res 31:103–110
2. Matalon S, Feuerstein O, Calderon S, Mittleman A, Kaffe I (2007) Detection of cavitated carious lesions in approximal tooth surfaces by ultrasonic caries detector. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 103:109–113
3. Peker I, Toraman Alkurt M, Altunkaynak B (2007) Film tomography compared with film and digital bitewing radiography for proximal caries detection. Dento-Maxillo-Facial Radiol 36:495–499
4. Kidd EA, Pitts NB (1990) A reappraisal of the value of the bitewing radiograph in the diagnosis of posterior approximal caries. Br Dent J 169:195–200

5. Pitts NB, Rimmer PA (1992) An in vivo comparison of radiographic and directly assessed clinical caries status of posterior approximal surfaces in primary and permanent teeth. Caries Res 26:146–152
6. Pitts NB, Renson CE (1985) Reproducibility of computer-aided image-analysis-derived estimates of the depth and area of radiolucencies in approximal enamel. J Dent Res 64:1221–1224
7. Pitts NB, Renson CE (1986) Image analysis of bitewing radiographs: a histologically validated comparison with visual assessments of radiolucency depth in enamel. Br Dent J 160:205–209
8. Pitts NB, Renson CE (1986) Further development of a computer-aided image analysis method of quantifying radiolucencies in approximal enamel. Caries Res 20:361–370
9. Pitts NB (1987) Detection of approximal radiolucencies in enamel: a preliminary comparison between experienced clinicians and an image analysis method. J Dent 15:191–197
10 Heaven TJ, Firestone AR, Feagin FF (1992) Computer-based image analysis of natural approximal caries on radiographic films. J Dent Res 71:846–849 Spec No
11. Zubery Y, Dove SB, Ebersole J (1993) An in vitro study of the characteristics of a computer-aided radiographic evaluation (CARE) system for longitudinal assessment of density changes. J Periodontal Res 28:233–240
12. Sund T, Møystad A (2006) Sliding window adaptive histogram equalization of intraoral radiographs: effect on image quality. Dento-Maxillo-Facial Radiol 35:133–138
13. Maggio JJ, Hausmann EM, Allen K, Potts TV (1990) A model for dentinal caries progression by digital subtraction radiography. J Prosthet Dent 64:727–732
14. Heaven TJ, Weems RA, Firestone AR (1994) The use of a computer-based image analysis program for the diagnosis of approximal caries from bitewing radiographs. Caries Res 28:55–58
15. Duncan RC, Heaven T, Weems RA, Firestone AR, Greer DF, Patel JR (1995) Using computers to diagnose and plan treatment of approximal caries. Detected in radiographs. J Am Dent Assoc 126:873–882
16. Gakenheimer DC (2002) The efficacy of a computerized caries detector in intraoral digital radiography. J Am Dent Assoc 133:883–890
17. Schmidlin PR, Tepper SA, Scriba H, Lutz F (2002) In vitro assessment of incipient approximal carious lesions using computer-assisted densitometric image analysis. J Dent 30:305–311
18. Li S, Fevens T, Krzyzak A, Jin C, Li S (2005) Toward automatic computer aided dental X-ray analysis using level set method. Med Image Comput Comput Assist Interv 8:670–678
19. Kositbowornchai S, Siriteptawee S, Plermkamon S, Bureerat S, Chetchotsak D (2006) An artificial neural network for detection of simulated dental caries. Int J CARS 1:91–96
20. Yoon DC, Wilensky GD, Neuhaus JA, Manukian N and Gakenheimer DC (1998) Quantitative dental caries detection system and method. US patent number5742700, Apr 21
21. Wenzel A, Hintze H, Kold LM, Kold S (2002) Accuracy of computer-automated caries detection in digital radiographs compared with human observers. Eur J Oral Sci 110:199–203
22. Navarro FL, Llena Puy MC, Godoy GF (2008) Diagnostic performance of radiovisiography in combination with a diagnosis assisting program versus conventional radiography and radiovisiography in basic mode and with magnification. Med Oral Patol Oral Cir Bucal 13:E261–E265
23. U.S. Food and Drug Administration, Center for Devices and Radiological Health. Summary of Safety and Effectiveness data: Logicon Caries Detector (1998) PMA No.980025, Sept.1998. www.fda.gov/cdrh/pma/pmasep98.html.A
24. Wenzel A (2001) Computer-Automated Caries Detection in Digital Bitewings: Consistency of a Program and Its Influence on Observer Agreement. Oper Dent 35:12–20
25. Harase Y, Araki K, Okano T (2006) Accuracy of extraoral tuned aperture computed tomography (TACT) for proximal caries detection. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 101:791–796
26. Tsuchida R, Araki K, Okano T (2007) Evaluation of a limited cone-beam volumetric imaging system: comparison with film radiography in detecting incipient proximal caries. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 104:412–416
27. Hahn SK, Kim JW, Lee SH, Kim CC, Hahn SH, Jang KT (2004) Microcomputed tomographic assessment of chemomechanical caries removal. Caries Res 38:75–78
28. Lee HS, Berg JH, Garcia-Godoy F, Jang KT (2008) Long-term evaluation of the remineralization of interproximal caries-like lesions adjacent to glass-ionomer restorations: a micro-CT study. Am J Dent 21:129–132
29. Khan EA, Tyndall DA, Ludlow JB, Caplan D (2005) Proximal caries detection: Sirona Sidexis versus Kodak Ektaspeed Plus. Gen Dent 53:43–48
30. Moystad A, Svanaes DB, Risnes S, Larheim TA, Grondahl HG (1996) Detection of approximal caries with a storage phosphor system. A comparison of enhanced digital images with dental X-ray film. Dento-Maxillo-Fac Radiol 25:202–206
31. Naitoh M, Yuasa H, Toyama M, Shiojima M, Nakamura M, Ushida M et al (1998) Observer agreement in the detection of proximal caries with direct digital intraoral radiography. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 85:107–112
32. Syriopoulos K, Sanderink GC, Velders XL, van der Stelt PF (2000) Radiographic detection of approximal caries: a comparison of dental films and digital imaging systems. Dento-Maxillo-Fac Radiol 29:312–318
33. Tyndall DA, Ludlow JB, Platin E, Nair M (1998) A comparison of Kodak Ektaspeed Plus film and the Siemens Sidexis digital imaging system for caries detection using receiver operating characteristic analysis. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 85:113–118
34 Wenzel A (2004) Bitewing and digital bitewing radiography for detection of caries lesions. J Dent Res 83:C72–C75 Spec No C
35. Pitts NB (2004) Are we ready to move from operative to non-operative/preventive treatment of dental caries in clinical practice? Caries Res 38:294–304
36 Pitts NB (2004) Modern concepts of caries measurement. J Dent Res 83:C43–C47 Spec No C
37. Selwitz RH, Ismail AI, Pitts NB (2007) Dental caries. Lancet 369:51–59
38. Faculty of GDP (1998) Selection criteria for dental radiography. Faculty of General Dental Practitioners The Royal college of Surgeons of England, London
39. Wenzel A, Haiter-Neto F, Gotfredsen E (2007) Risk factors for a false positive test outcome in diagnosis of caries in approximal surfaces: impact of radiographic modality and observer characteristics. Caries Res 41:170–176
40. Mileman PA, van den Hout WB (2002) Comparing the accuracy of Dutch dentists and dental students in the radiographic diagnosis of dentinal caries. Dento-Maxillo-Facial Radiol 31:7–14
41. Schulze RK, Nackat D, D'hoedt B (2004) In vitro carious lesion detection on D-, E-, and F-speed radiographic films. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 97:529–534