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Utility of Radiology, Laser Fluorescence, and Transillumination

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Since the prevalence, site preference, and lesion behavior of caries have changed during the last several decades, carious lesions have become more difficult to diagnose in dental practice [1]. Dental radiographs are recommended primarily for the detection of proximal carious lesions, which are not visible clinically, and as a supplement to the clinical examination of occlusal surfaces for pit and fissure caries. Studies have shown that radiographic examinations improve the diagnostic accuracy for proximal and occlusal carious lesions [2–4].

Overview of radiology in detection of carious lesions

Although radiographs, especially intraoral radiographs, have an important role in caries detection, their limitations need to be taken into account, especially when they are used for the detection of incipient and hidden carious lesions. The carious process results in tooth demineralization. Because of the low attenuation of radiation in the demineralized zone, the typical radiographic appearance of caries is a radiolucent area; however, 40% to 60% of tooth decalcification is required to produce the radiographic image. An initial or incipient lesion may not be seen radiographically. Even if it is visible on the film, the image usually underestimates the actual size or depth of the lesion [5,6]. Some studies [7–9] have suggested that intraoral radiographs have little value in the detection of occlusal enamel lesions. In

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addition, a single radiographic examination alone may not provide sufficient information to determine whether the lesion is active or arrested, although the latter condition will usually show a remineralized zone or band on the radiograph.

Techniques

Intraoral and extraoral radiographs are commonly obtained in dental practice. Because of their higher resolution and greater image details, intraoral radiographs generally are superior to extraoral radiographs for caries detection, especially for incipient and hidden carious lesions. The most useful intraoral radiographic technique for caries detection is the bitewing projection. Periapical radiographs may be equally useful; however, they are primarily prescribed for detecting changes in the periapical region.

Periapical radiographs can be obtained using two techniques—the paralleling and bisecting angle. The former technique is considered superior to the latter because the paralleling technique allows a long source-to-object distance, which results in less magnification and distortion of tooth structures. By using a film holder and a beam-aiming device, the paralleling technique also reduces the number of overlapping contacts and improves interpretation accuracy [10].

Pantomography, with a lower radiation dose than a complete mouth survey, provides broad anatomic coverage on a single film. It is easy to perform, convenient for the patient, and inexpensive. Nevertheless, disadvantages of pantomographs include lower image resolution than on intraoral radiographs, overlapping of the proximal surfaces, especially in the premolar region, and possible distortion. Despite several technological improvements in panoramic machines and subsequent improvements in image quality, the diagnosis of carious lesions by pantomographs has shown lower accuracy than intraoral radiographs [11–13].

Diagnostic accuracy of radiographs

The diagnostic accuracy of an imaging modality should always be validated against a true diagnosis or the gold standard. Because no diagnostic methods for caries in vivo have been accurate enough to be identified as the gold standard [14], most imaging studies have been conducted in in vitro experiments. A recent study [15] suggested that laboratory results for caries detection using a true golden standard could be transferred to the clinical situation. In that study, microscopic examinations were used as the gold standard [15].

The accuracy of a diagnostic method is usually measured according to its sensitivity and specificity. Sensitivity and specificity describe the abilities of a test to diagnose disease correctly when disease is actually present and to rule out the disease correctly when it is truly absent. Diagnostic accuracy can also be evaluated by the receiver operating characteristic (ROC) curve. ROC analysis is based on signal detection theory. It provides an unbiased measurement of discrimination in the paired-comparison or forced-choice situation. An ROC curve is a plot of sensitivity and specificity with several cut-off points.

Using sensitivity and specificity values for a diagnostic test or imaging modality can be ambiguous because dentists exhibit a wide variation in their decision criteria. The ROC analysis gives a measurement of discrimination that is independent of the cut-off points of the decision criterion; therefore, it is unbiased [16,17]. Because of these characteristics, the use of ROC analysis has been recommended to evaluate imaging systems for caries diagnosis [18]. The higher the area (A_z) below the curve, the better the diagnostic accuracy of the method [16,17]. As a general rule, an A_z of 0.5 is the same as a random guess. An ROC area between 0.7 and 0.8 would be considered acceptable, whereas an area between 0.8 and 0.9 would be excellent and an area greater than 0.9 outstanding [19]. Table 1 lists the results of previous studies on the diagnostic accuracy of radiographs for caries detection [20–26]. In general, there are lower sensitivity and specificity values for enamel caries than for dentinal lesions. The ROC area for occlusal enamel caries ranges from 0.51 to 0.61 and for dentinal lesions from 0.72 to 0.81. These data indicate that intraoral radiographs are better for the detection of dentinal caries and have less value for detecting enamel lesions.

Skodje and coworkers [20] specifically evaluated the diagnostic accuracy of bitewing radiographs for enamel and dentinal caries diagnosis at different radiographic densities. For enamel lesions, the quality of the diagnosis (A_z) improved with the density of the images. Higher-density images (darker) had better diagnostic quality (0.61 for high-density radiographs and 0.51 for low-density radiographs). The diagnostic quality for all dentinal lesions was higher (0.80 for high-density radiographs and 0.72 for low-density radiographs) but not statistically significant within different densities. When only small dentinal lesions (outer third of dentin) were considered, the high- and medium-density radiographs showed better diagnostic quality.

Frequency of examination

Radiographic examination should be performed after reviewing the patient history and clinical examination. As a rule, radiographic examination is necessary only when the history and clinical examination have not provided enough information, and when the patient will potentially benefit by the discovery of clinically useful information on the radiograph [27].

Professional judgment should always be used to determine the type, frequency, and extent of each radiographic examination. The nature and extent of the diagnosis required for patient care constitute the only rational

Table 1
Summary of previous studies on diagnostic accuracy of dental radiographs for caries detection

Study [reference]	ROC area (A_z)	Sensitivity	Specificity
Skodje et al, 1998 [20]			
Occlusal enamel lesions	0.51–0.61	—	—
Occlusal dentinal lesions	0.72–0.80	—	—
Nytum et al, 1992 [8]			
Occlusal dentinal lesions	—	0.66	0.50
Rocha et al, 2003 [21]			
Occlusal enamel lesions	—	0.34	0.50
Occlusal dentinal lesions	—	0.96	0.81
Lussi, 1993 [22]			
All lesions (occlusal surface)	—	0.45	0.83
Huysmans et al, 1998 [23]			
All lesions (occlusal surface)	0.73	0.58	0.87
Ashley et al, 1998 [24]			
Occlusal enamel lesions	—	0.19	0.80
Occlusal dentinal lesions	—	0.24	0.89
White and Yoon, 2000 [25]			
Proximal enamel lesions	0.59–0.61	0.40–0.42	0.75–0.78
Proximal dentinal lesions	0.79–0.81	0.61–0.63	0.91–0.92
Ricketts et al, 1997 [6]			
Proximal enamel lesions	—	0.14–0.23	0.97–1.0
Occlusal enamel lesions			
Premolars	—	0.02–0.06	0.80–1.0
Molars	—	0.18–0.30	0.80–1.0
White and Yoon, 1997 [26]			
Proximal enamel lesions	—	0.18–0.28	0.88–0.91

basis for determining the need, type, and frequency of examination. The concept of routine examination should not be used to make these decisions [28].

De Vries and coworkers [4] suggested that, in patients younger than 12 years, the omission of radiographic examination would not result in a substantial loss of information. Above this age, it is advisable to include radiographic examinations for proximal surfaces [4]. Another study concluded [7] that older patients with little previous caries experience would not benefit from bitewing examinations. According to Hintze and Wenzel [7], in patients with little caries experience, bitewing examinations should be restricted to clinically suspicious surfaces.

The frequency of radiographic examination for caries diagnosis must take into account several different factors. The patient's oral hygiene, fluoride exposure, diet, caries history, extent of restorative care, and age should be considered in determining the time interval between radiographic examinations [10]. Healthy patients with good oral hygiene need infrequent radiographic examinations when compared with patients with a high incidence of caries [27]. Detailed guidelines for ordering radiographs have been provided by the US Food and Drug Administration (FDA) [29].

Impact of technique factors on imaging quality and caries detection

Several technical factors can have an impact on radiography quality and caries detection. It is extremely important for the clinician to monitor the quality of the images. Good quality radiographs with proper density and contrast allow higher diagnostic accuracy for dental caries, and correct angulations permit a perfect visualization of tooth surfaces. Improper angulations result in distorted radiographs that compromise the ability to detect caries [30].

Film

Several intraoral radiographic films are commercially available with different sensitivities or speeds. The film sensitivity or speed refers to the amount of radiation required to produce an image of a standard density. The faster the film, the less radiation that is necessary to produce the image. The sensitivity of the film is indicated by a letter designating a particular group [31]. The fastest dental film currently available is F-speed, although D-speed and E-speed films are also commercially available. D-speed films are considered the best with regard to image quality; however, better image quality does not necessarily translate into higher diagnostic accuracy for caries detection [6,32,33]. Although their image quality may be lower, F-speed films are recommended for caries detection because they require less radiation than E- and D-speed films. Recent studies [34–36] have shown that F-speed films reduce exposure time by 20% to 24% when compared with E-group films. There are no differences among F-speed, E-speed, and D-speed films with respect to their diagnostic accuracy for caries detection [32,33].

Density

Radiographic density is the degree of darkening of an exposed film and is mainly influenced by exposure and the thickness and density of the object. Radiographs of good quality are important because under- and over-exposure can have an impact on caries diagnosis [20].

Contrast

Radiographic contrast is the difference in density between light and dark regions on a radiograph and is mainly influenced by the kilovolt peak (kVp). Radiographs need to be dark with good contrast to provide an optimal basis for caries detection. Contrast is considered the most important prerequisite for increasing the accuracy of caries diagnosis [37].

Darkroom processing

Quality radiographs leading to an accurate diagnosis of carious lesions are only achieved under optimal processing conditions. Proper processing conditions optimize image density and contrast and maximize the diagnostic quality of the image [28]. A study [38] evaluated the diagnostic accuracy for caries detection according the age of the processing chemicals. A significantly lower diagnostic accuracy was found after the third week when the chemicals should be replaced. In addition to the regular replacement of chemicals, the manufacturers' recommendation should be followed when selecting safelight filters and the proper temperature of processing solutions and processing times. Moreover, the temperature of automatic processors should be checked periodically to ensure adequate time-temperature processing [28].

Digital imaging and imaging processing for caries detection

Although most dentists in North America are still using films as imaging receptors, digital imaging will be the future of dental radiography. The advantages of digital images over conventional radiographs include lower radiation doses to patients, shorter working times, the absence of darkroom processing, digital enhancement and processing, easy imaging storage, and network communication. Dentists can choose from a variety of multiple well-established digital sensors, including charge-couple device-based sensors (CCD), complementary metal oxide semiconductors (CMOS), and photostimulable phosphor plates (PSP) [37]. In the CCD or CMOS systems, the sensor is connected to a computer with a cable or wireless transmission, and the image is displayed almost immediately on a computer screen. In the PSP, an image plate is exposed to x-rays, and a latent image is created. The information contained in the plate is then released by exposure to a laser scanner [39].

In terms of the diagnostic accuracy of digital imaging for caries detection, most studies have shown that digital imaging is comparable to conventional film [26,40]. Although the resolution (reported as line pairs/millimeter) of digital imaging is lower than that of conventional film, digital imaging is a form of dynamic imaging, and digital enhancement and processing may improve the diagnostic accuracy of caries detection, especially for incipient and hidden carious lesions. Different image processing techniques can be used, such as contrast and brightness adjustment, histogram equalization, noise reduction, pseudocoloring, and others. Some studies have demonstrated that image-processing techniques improve the accuracy of caries detection [5,41], whereas others have not been able to demonstrate any gain [42].

The displayed image size and zooming images may have an impact on the accuracy of caries detection. Haak and coworkers [43] evaluated the diagnostic accuracy of displayed radiographs in a computer monitor at different ratios, 1:1, 1:2, and 1:7, and showed that the latter had lower diagnostic accuracy. Moystad and coworkers [44] evaluated whether different magnification factors affected the accuracy of caries diagnosis. They found that digital image magnification over 18 times decreased the capability in detecting proximal caries.

With increased clinical application of digital photography and radiography, there has been an increase in the size of files; consequently, mandatory image storage and archiving have become a greater challenge. One solution to reduce file size is the use of compression techniques. Pabla and coworkers [45] studied the effect of lossy image compression on caries detection. They found that compressions of 1:16 could be used for proximal caries detection without a significant loss of diagnostic efficacy. Similar results at a ratio of 1:21 were reported by Janhom and coworkers [46]; however, at this compression level, the ability to detect small carious lesions, such as enamel lesions, could be compromised. Wenzel and coworkers [47] suggested a maximum compression rate of 1:12, in which the accuracy and image quality for caries detection would not be affected significantly.

Digital images can be displayed and viewed on the monitor of a desktop computer or on a laptop. Ludlow and Abreu [48] showed that the diagnostic accuracy for proximal surface caries detection was not significantly different between desktop monitor and laptop display. When using an indirect digital system (scanning an existing radiograph into a digital format), a proper resolution is necessary so as not to lose image quality. Usually, a resolution of 300 dpi produces high-quality images without significant loss of information for caries diagnosis [49].

To improve the sensitivity and specificity of caries detection and to avoid the relatively high observer variation, some software programs have been created to allow automated computer caries detection. Studies conducted by Schmidlin and coworkers [50] using densitometric analysis have shown that it is possible to detect small changes in incipient carious lesions; however, others found that automatic systems either lack consistency [51] or are inferior to human eyes [52] with regard to caries detection.

Overview of laser fluorescence: the DIAGNOdent device

A recent study discovered that bacterial metabolites within caries produce fluorescence that can be enhanced by a laser light [53]. Quantitative laser fluorescence (QLF) is a method of measuring the induced tooth fluorescence and quantifying tooth demineralization and lesion severity [54]. The DIAGNOdent is a portable laser diode-based device (Fig. 1) that is a commercial development of QLF and is designed to aid dental practitioners in the detection of carious lesions [54].

Technique

A red laser light (wavelength, 665 nm) emitted by the device via an optical fiber and a probe to the caries area is absorbed by inorganic and organic components within tooth substance (Fig. 2). Altered tooth substance is excited and fluoresced. The fluorescence is passed via the return line in the optical fiber back to a corresponding evaluation logic unit (photocell) and

Fig. 1. DIAGNOdent machine. (Courtesy of KaVo, Biberach, Germany; with permission.)

then displayed and indicated acoustically [55,56]. The unit gives an adjustable sound and a digital numeric readout (0–99) to indicate the amount of fluorescence. This measurement can be used to assist clinicians in deciding whether a tooth should be restored [57].

Diagnostic accuracy

Boston [58] evaluated the potential of the DIAGNOdent device in detecting secondary carious lesions associated with resin composite restoration. The sensitivity was 0.67 and the specificity 0.79 for enamel caries diagnosis at the restoration margin. The measurements showed high reproducibility; however, to improve performance of the DIAGNOdent, Boston suggested that some factors, such as fiberoptic tip design, tooth-cleansing protocols, and threshold values, should be optimized.

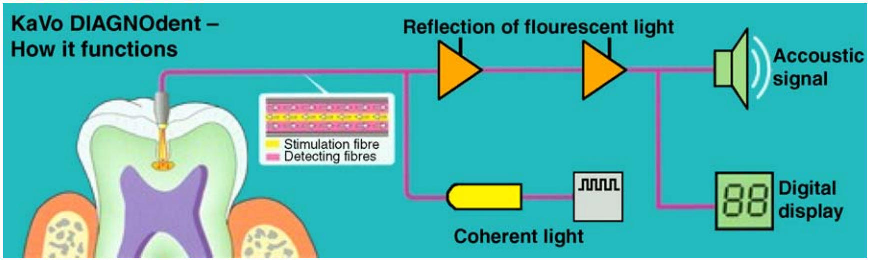

Fig. 2. The DIAGNOdent operates at a wavelength of 655 nm. At this specific wavelength, clean healthy tooth structure exhibits little or no fluorescence, resulting in low scale readings on the display. Carious tooth structure exhibits fluorescence proportionate to the degree of caries, resulting in elevated scale readings on the display. An audio signal allows the operator to hear changes in the scale values. (Courtesy of KaVo, Biberach, Germany; with permission.)

Shi and coworkers [59] compared radiography and the DIAGNOdent for occlusal caries detection. They found higher sensitivity, specificity, and A_z in a comparison with conventional radiographs. In an in vivo study, Lussi and coworkers [60] showed higher sensitivities than bitewing radiographs but lower specificities.

Despite these promising results, the QLF technique has several limitations. QLF can only discern enamel demineralization and cannot differentiate decay, hypoplasia, or unusual anatomic features. QLF also does not discriminate between enamel and dentin lesions. Like other methods, QLF cannot differentiate between an active or inactive lesion [54]. In addition, the instrument is sensitive to the presence of stains, deposits, or calculus, which may be falsely registered as a change in enamel or dentin [59].

Overview of transillumination: the DIFOTI device

Digital imaging fiberoptic transillumination (DIFOTI) (Electro-Optical Sciences, Irvington, New York) was developed as a diagnostic tool for early and reliable detection of caries without the need for ionizing radiation. Images of teeth are obtained using visible light via fiberoptic transillumination (FOTI) [57]. The method has the potential to enable dentists to detect demineralization on all tooth surfaces. It also can be used to inspect the integrity of the tooth for fractures, decalcification, and wear, and as well as the integrity of amalgams, composites, sealants, orthodontic bands, and so forth.

Technique

With DIFOTI, a light propagates from the optical fiber through the tooth to a nonilluminated surface (usually the opposite surface). What makes DIFOTI different from FOTI is that the images are acquired by a digital electronic CCD camera (Figs. 3 and 4); therefore, DIFOTI may eliminate or

Fig. 3. The proximal or occlusal mouthpiece is placed over the tooth in question, allowing light to be shined from one surface, through the tooth, and captured on the opposite side using a CCD camera in the DIFOTI handpiece. (Courtesy of Electro-Optical Sciences, Irvington, New York; with permission.)

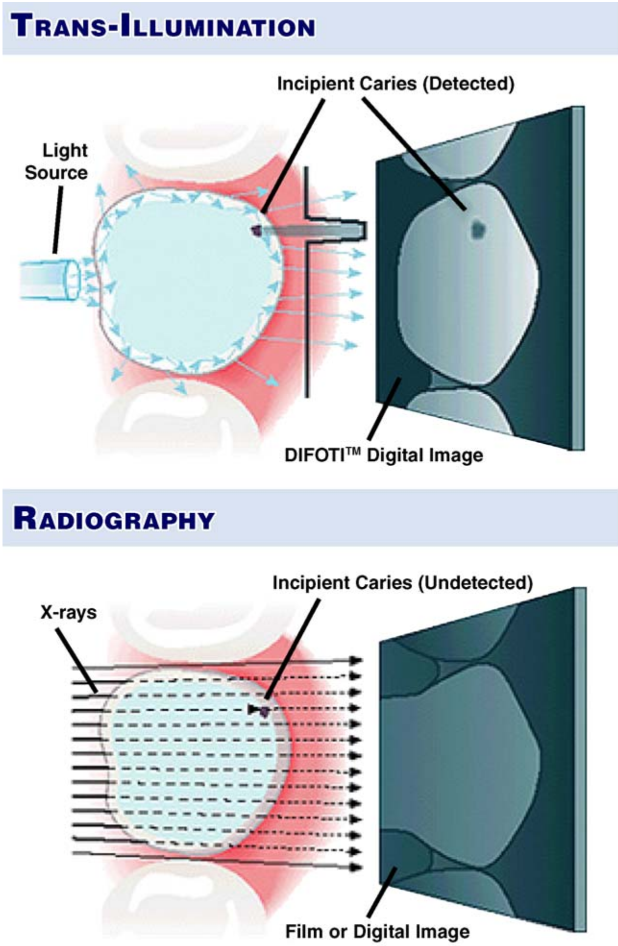

Fig. 4. Comparison of radiographic and DIFOTI projection. Typically, tooth decay scatters and absorbs more light than does surrounding healthy tissue. Decay near the imaged surface appears as a darker area against the more translucent brighter background of surrounding healthy anatomy. (Courtesy of Electro-Optical Sciences, Irvington, New York; with permission.)

reduce intra- and interobserver variation. The acquired data are sent to a computer for analysis, which produces digital images that can be viewed in real time. DIFOTI has the potential not only to detect early lesions but also to monitor the progress of the lesions [57].

Diagnostic accuracy

The diagnostic accuracy of DIFOTI was evaluated by Schneiderman and coworkers [61] for proximal, occlusal, and root surfaces. They found high sensitivities for caries detection but lower sensitivities when compared with radiologic images.

Davies and coworkers [62] performed an evaluation of FOTI as an adjunct tool for proximal caries diagnosis. They found an increase in the number of detected caries; however, another study conducted by Hintze and colleagues [63] found that FOTI was the least reliable when compared with other methods (visual examination and bitewing radiography).

There are several limitations of DIFOTI. The method does not measure lesion depth, and a learning curve is involved in discerning the differences among deep fissures, stain, and actual dentin lesions [57]. Furthermore, overdiagnosis can occur owing to lower specificity when compared with conventional radiographs. Dark areas on the images can be attributed to scatter and the absorption of light as it passes through demineralized enamel and dentin or near the surface [61]; consequently, white spots can be mistaken for cavitations. Further studies are needed to determine how to interpret lesion depth using DIFOTI and whether it can monitor the progress of disease or remineralization [57].

Summary

Dental radiographs have an important role in caries detection; however, many factors, including image techniques and processing conditions, can affect the diagnostic accuracy of carious lesions. Different radiographic techniques, the frequency of radiographic examinations, methods to assess diagnostic accuracy, and factors affecting the diagnostic accuracy of imaging in film and digital receptors have been discussed herein. The DIAGNOdent and DIFOTI devices may be useful in the detection of incipient and hidden carious lesions.

References

[1] Wenzel A. Current trends in radiographic caries imaging. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1995;80(5):527–39.

[2] Creanor SL, Russell JI, Strang DM, et al. The prevalence of clinically undetected occlusal dentine caries in Scottish adolescents. Br Dent J 1990;169(5):126–9.

[3] Kidd EA, Naylor MN, Wilson RF. Prevalence of clinically undetected and untreated molar occlusal dentine caries in adolescents on the Isle of Wight. Caries Res 1992;26(5):397–401.

[4] de Vries HC, Ruiken HM, Konig KG, et al. Radiographic versus clinical diagnosis of approximal carious lesions. Caries Res 1990;24(5):364–70.

[5] Wenzel A, Fejerskov O, Kidd E, et al. Depth of occlusal caries assessed clinically, by conventional film radiographs, and by digitized processed radiographs. Caries Res 1990; 24(5):327–33.

[6] Ricketts DN, Whaites EJ, Kidd EA, et al. An evaluation of the diagnostic yield from bitewing radiographs of small approximal and occlusal carious lesions in a low prevalence sample in vitro using different film types and speeds. Br Dent J 1997;182(2):51–8.

[7] Hintze H, Wenzel A. Clinically undetected dental caries assessed by bitewing screening in children with little caries experience. Dentomaxillofac Radiol 1994;23(1):19–23.

[8] Nytun RB, Raadal M, Espelid I. Diagnosis of dentin involvement in occlusal caries based on visual and radiographic examination of the teeth. Scand J Dent Res 1992;100(3):144–8.
[9] Flaitz CM, Hicks MJ, Silverstone LM. Radiographic, histologic, and electronic comparison of occlusal caries: an in vitro study. Pediatr Dent 1986;8(1):24–8.
[10] Wenzel A. Dental caries. In: White SC, Pharoah MJ, editors. Oral radiology: principles and interpretation. 5th edition. St. Louis (MO): Mosby; 2004. p. 297–313.
[11] Scarfe WC, Langlais RP, Nummikoski P, et al. Clinical comparison of two panoramic modalities and posterior bite-wing radiography in the detection of proximal dental caries. Oral Surg Oral Med Oral Pathol 1994;77(2):195–207.
[12] Douglass CW, Valachovic RW, Wijesinha A, et al. Clinical efficacy of dental radiography in the detection of dental caries and periodontal diseases. Oral Surg Oral Med Oral Pathol 1986;62(3):330–9.
[13] Clifton TL, Tyndall DA, Ludlow JB. Extraoral radiographic imaging of primary caries. Dentomaxillofac Radiol 1998;27(4):193–8.
[14] Wenzel A, Hintze H. Comparison of microscopy and radiography as gold standards in radiographic caries diagnosis. Dentomaxillofac Radiol 1999;28(3):182–5.
[15] Wenzel A, Hintze H. The choice of gold standard for evaluating tests for caries diagnosis. Dentomaxillofac Radiol 1999;28(3):132–6.
[16] Dove SB. Radiographic diagnosis of dental caries. J Dent Educ 2001;65(10):985–90.
[17] Obuchowski NA. Receiver operating characteristic curves and their use in radiology. Radiology 2003;229(1):3–8.
[18] Verdonschot EH, Wenzel A, Bronkhorst EM. Applicability of receiver operating characteristic (ROC) analysis on discrete caries depth ratings. Community Dent Oral Epidemiol 1993;21(5):269–72.
[19] Hosmer DW, Lemeshow S. Applied logistic regression. 2nd edition. New York: John Wiley & Sons; 2000.
[20] Skodje F, Espelid I, Kvile K, et al. The influence of radiographic exposure factors on the diagnosis of occlusal caries. Dentomaxillofac Radiol 1998;27(2):75–9.
[21] Rocha RO, Ardenghi TM, Oliveira LB, et al. In vivo effectiveness of laser fluorescence compared to visual inspection and radiography for the detection of occlusal caries in primary teeth. Caries Res 2003;37(6):437–41.
[22] Lussi A. Comparison of different methods for the diagnosis of fissure caries without cavitation. Caries Res 1993;27(5):409–16.
[23] Huysmans MC, Longbottom C, Pitts N. Electrical methods in occlusal caries diagnosis: an in vitro comparison with visual inspection and bite-wing radiography. Caries Res 1998;32(5): 324–9.
[24] Ashley PF, Blinkhorn AS, Davies RM. Occlusal caries diagnosis: an in vitro histological validation of the electronic caries monitor (ECM) and other methods. J Dent 1998;26(2): 83–8.
[25] White SC, Yoon DC. Comparison of sensitometric and diagnostic performance of two films. Compend Contin Educ Dent 2000;21(6):530–2,4,6 passim.
[26] White SC, Yoon DC. Comparative performance of digital and conventional images for detecting proximal surface caries. Dentomaxillofac Radiol 1997;26(1):32–8.
[27] Atchison KA, Brooks SL. Guidelines for prescribing dental radiographs. In: White SC, Pharoah MJ, editors. Oral radiology: principles and interpretation. 4th edition. St. Louis (MO): Mosby; 2000. p. 241–53.
[28] White SC, Heslop EW, Hollender LG, et al. Parameters of radiologic care: an official report of the American Academy of Oral and Maxillofacial Radiology. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2001;91(5):498–511.
[29] United States Department of Health and Human Sciences. The selection of patients for x-ray examinations: dental radiographic examinations. HHS publication FDA 88–8273. Rockville (MD): National Institutes of Health, Department of Health and Human Services; 1987.

[30] van der Stelt PF, Ruttiman UE, Webber RL, et al. In vitro study into the influence of x-ray beam angulation on the detection of artificial caries defects on bitewing radiographs. Caries Res 1989;23(5):334–41.

[31] White SC, Pharoah MJ. X-ray film, intensifying screens, and grids. In: White S, Pharoah M, editors. Oral radiology: principles and interpretation. 4th edition. St. Louis (MO): Mosby; 2000. p. 68–82.

[32] Ludlow JB, Abreu M Jr, Mol A. Performance of a new F-speed film for caries detection. Dentomaxillofac Radiol 2001;30(2):110–3.

[33] Schulze RK, Nackat D, D'Hoedt B. In vitro carious lesion detection on D-, E-, and F-speed radiographic films. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2004;97(4):529–34.

[34] Geist JR, Brand JW. Sensitometric comparison of speed group E and F dental radiographic films. Dentomaxillofac Radiol 2001;30(3):147–52.

[35] Syriopoulos K, Velders XL, Sanderink GC, et al. Sensitometric and clinical evaluation of a new F-speed dental X-ray film. Dentomaxillofac Radiol 2001;30(1):40–4.

[36] Price C. Sensitometric evaluation of a new F-speed dental radiographic film. Dentomaxillofac Radiol 2001;30(1):29–34.

[37] Wenzel A. Digital imaging for dental caries. Dent Clin North Am 2000;44(2):319–38.

[38] Syriopoulos K, Velders XL, Sanderink GC, et al. The effect of developer age on the detection of approximal caries using three dental films. Dentomaxillofac Radiol 1999;28(4):208–13.

[39] Wenzel A. Digital radiography and caries diagnosis. Dentomaxillofac Radiol 1998;27(1):3–11.

[40] Syriopoulos K, Sanderink GC, Velders XL, et al. Radiographic detection of approximal caries: a comparison of dental films and digital imaging systems. Dentomaxillofac Radiol 2000;29(5):312–8.

[41] Li G, Yoshiura K, Welander U, et al. Detection of approximal caries in digital radiographs before and after correction for attenuation and visual response: an in vitro study. Dentomaxillofac Radiol 2002;31(2):113–6.

[42] Eickholz P, Kolb I, Lenhard M, et al. Digital radiography of interproximal caries: effect of different filters. Caries Res 1999;33(3):234–41.

[43] Haak R, Wicht MJ, Nowak G, et al. Influence of displayed image size on radiographic detection of approximal caries. Dentomaxillofac Radiol 2003;32(4):242–6.

[44] Moystad A, Svanaes DB, Larheim TA, et al. Effect of image magnification of digitized bitewing radiographs on approximal caries detection: an in vitro study. Dentomaxillofac Radiol 1995;24(4):255–9.

[45] Pabla T, Ludlow JB, Tyndall DA, et al. Effect of data compression on proximal caries detection: observer performance with DenOptix photostimulable phosphor images. Dentomaxillofac Radiol 2003;32(1):45–9.

[46] Janhom A, van der Stelt PF, van Ginkel FC. Interaction between noise and file compression and its effect on the recognition of caries in digital imaging. Dentomaxillofac Radiol 2000;29(1):20–7.

[47] Wenzel A, Gotfredsen E, Borg E, et al. Impact of lossy image compression on accuracy of caries detection in digital images taken with a storage phosphor system. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1996;81(3):351–5.

[48] Ludlow JB, Abreu M Jr. Performance of film, desktop monitor and laptop displays in caries detection. Dentomaxillofac Radiol 1999;28(1):26–30.

[49] Janhom A, van Ginkel FC, van Amerongen JP, et al. Scanning resolution and the detection of approximal caries. Dentomaxillofac Radiol 2001;30(3):166–71.

[50] Schmidlin PR, Tepper SA, Scriba H, et al. In vitro assessment of incipient approximal carious lesions using computer-assisted densitometric image analysis. J Dent 2002;30(7–8):305–11.

[51] Wenzel A. Computer-automated caries detection in digital bitewings: consistency of a program and its influence on observer agreement. Caries Res 2001;35(1):12–20.

[52] Wenzel A, Hintze H, Kold LM, et al. Accuracy of computer-automated caries detection in digital radiographs compared with human observers. Eur J Oral Sci 2002;110(3):199–203.
[53] Hibst R, Paulus R. Caries detection by red excited fluorescence: investigations on fluorophores. Caries Res 1999;33:295.
[54] Tam LE, McComb D. Diagnosis of occlusal caries: part II. Recent diagnostic technologies. J Can Dent Assoc 2001;67(8):459–63.
[55] El-Housseiny AA, Jamjoum H. Evaluation of visual, explorer, and a laser device for detection of early occlusal caries. J Clin Pediatr Dent 2001;26(1):41–8.
[56] Kavo. DIAGNOdent. In: KaVo, Biberach, Germany; 2004.
[57] Young DA. New caries detection technologies and modern caries management: merging the strategies. Gen Dent 2002;50(4):320–31.
[58] Boston DW. Initial in vitro evaluation of DIAGNOdent for detecting secondary carious lesions associated with resin composite restorations. Quintessence Int 2003;34(2):109–16.
[59] Shi XQ, Welander U, Angmar-Mansson B. Occlusal caries detection with KaVo DIAGNOdent and radiography: an in vitro comparison. Caries Res 2000;34(2):151–8.
[60] Lussi A, Megert B, Longbottom C, et al. Clinical performance of a laser fluorescence device for detection of occlusal caries lesions. Eur J Oral Sci 2001;109(1):14–9.
[61] Schneiderman A, Elbaum M, Shultz T, et al. Assessment of dental caries with Digital Imaging Fiber-Optic TransIllumination (DIFOTI): in vitro study. Caries Res 1997;31(2):103–10.
[62] Davies GM, Worthington HV, Clarkson JE, et al. The use of fibre-optic transillumination in general dental practice. Br Dent J 2001;191(3):145–7.
[63] Hintze H, Wenzel A, Danielsen B, et al. Reliability of visual examination, fibre-optic transillumination, and bite-wing radiography, and reproducibility of direct visual examination following tooth separation for the identification of cavitated carious lesions in contacting approximal surfaces. Caries Res 1998;32(3):204–9.