A Closer Look at Diagnosis in Clinical Dental Practice: Part 3. Effectiveness of Radiographic Diagnostic Procedures

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Abstract

This article, the third in a series, uses the tools described in the first 2 articles to examine some of the radiographic diagnostic procedures that are employed regularly in dental practice. With a general grounding in the meaning of terms such as sensitivity, specificity, thresholds, kappa coefficients, and predictive values, the reader should now be a more discerning user of the operating characteristic data for dental diagnostic procedures. By re-examining some of these procedures in terms of their effectiveness, accuracy and validity, dental practitioners should be able to use the procedures in a more targeted manner and gain the maximum benefit from their results. With a better understanding of the value of a diagnostic test, the clinician's decision-making process will be far better informed. For example, knowing that a certain radiographic view is associated with a 60% false-positive rate for identifying occlusal caries will preclude blind trust in the results and will help the informed clinician attribute a realistic weight to the radiographic findings. This article considers diagnostic procedures in common use in North American practice, with special emphasis on radiography.

MeSH Key Words: *decision support techniques; predictive value of tests; radiography, dental; risk assessment methods*

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Dentists employ many diverse diagnostic procedures. From radiography to vitality testing, from determination of bleeding on probing to apex locators, the devices and systems available range from the simple to the complex. However, given the huge number of diagnostic procedures in the dental armamentarium, it is of interest to determine how well each of them performs. Is the procedure accurate? Does it add significant value to a basic clinical examination? Does one diagnostic procedure tend to produce a large number of false-positive results, while another produces many false-negatives? Can procedure results be combined to generate the best possible diagnostic evidence before treatment decisions are made? By examining some of today's common procedures and analyzing the literature available, practitioners can become better informed about the value of each procedure they use.

This article and the next one in the series use the tools described in the first 2 articles[1,2] to examine the most common dental diagnostic procedures. Diverse studies serve as useful examples of the applications of these procedures to everyday dental practice, placing them in the context of their operating characteristics. With a general grounding in the concepts used in evaluating diagnostic procedures,[1,2] the reader should now be able to examine these operating characteristics with a more discerning eye. This review is not a structured or systematic evaluation of the literature but rather a collection of recent or landmark papers to illustrate situations familiar to the dental practitioner.

A glossary, with concise definitions of terms, is available for the entire series (see **Appendix 1**, Glossary of epidemiology terms, at http://www.cda-adc.ca/jcda/vol-70/issue-4/251.html).

Background

Brunette[3] elegantly and succinctly summarized the performance of dental diagnostic procedures in terms of 3 operating characteristics: sensitivity, specificity and area under the curve (AUC) (**Table 1**). The range of values for

Table 1 **Sensitivity and specificity of some common diagnostic tests in dentistry[a]**

Test	Sensitivity	Specificity	ROC (AUC)
Caries			
Clinical examination	0.13	0.94	-
Radiography	0.58	0.66	-
Bitewing radiography	0.73	0.97	-
Probe and look	0.58	0.94	-
Radiography of occlusal caries: film	-	-	0.82
Radiography of interproximal caries: film	-	-	0.87
Radiography of occlusal caries: digital	-	-	0.90
Radiography of interproximal caries: digital	-	-	0.87
Caries in primary teeth: intraoral radiography	-	-	0.70
Caries in primary teeth: panoramic radiography	-	-	0.64
Root or dentine caries	-	-	0.81
Periodontics			
Bleeding on probing (1 mm loss)	0.43	0.58	-
Bleeding on probing (2 mm loss)	0.29	0.88	-
Bone loss (subtraction)	0.91	0.96	-
Plaque measurements	0.47	0.65	-
Vertical defects (from radiographs)			> 0.80
Endodontics			
Periapical lesions (from radiographs)	0.70	0.77	-

[a]Data from Brunette[3]
ROC = receiver operating characteristic, AUC = area under the curve

Table 2 **Agreement data for some common dental diagnostic tests[a]**

	Correlation coefficient		Kappa value		% agreement	
Test	**Inter-observer**	**Intra-observer**	**Inter-observer**	**Intra-observer**	**Inter-observer**	**Intra-observer**
Periodontics						
Gingival redness	0.61	-	-	-	-	-
Plaque	0.81	0.32	0.22	-	44	47.5
Bleeding on probing	-	-	-	-	-	64
Lack of bleeding on probing	-	-	-	-	-	78
Probing depth	0.63	0.72	0.26	-	69	81.2
Dental radiography						
Vital or nonvital	-	-	-	-	43	72
Caries	-	-	0.73	0.80	-	-
Periodontal disease	-	-	0.80	0.79	-	-
Bone loss (intraoral)	-	-	-	-	58	-
Bone loss (panoramic)	-	-	-	-	60	-
Interdental bone loss	-	-	-	-	38.3	60.9
Periapical radiolucency	-	-	0.25	0.38	27	76.2
Canal length	-	-	-	-	67	-

[a]Modified from Brunette[3]

each procedure was fairly wide, and, remarkably, many of the procedures were in common use without any appraisal of their performance in terms of these parameters. Brunette[3] further examined the list of parameters offered for diagnostic tests, such as various tools to appraise the level of agreement between and within observers for the same clinical case (**Table 2**). The values again had a wide range, with some of the most commonly used diagnostic procedures performing somewhat poorly (e.g., the kappa coefficients for the identification of periapical radiolucent areas and almost any measure of agreement for identification of dental plaque) (**Table 2**). Rather than casting a negative light over the entire armamentarium of diagnostic procedures available, such objective assessment of diagnostic confidence ascribed to various procedures may be used as a point of departure for revisiting the current state of the art. The following section examines in detail some of the most common dental diagnostic procedures in light of recent scrutiny of their value.

Radiography in Dental Practice

Dentists are among the most prolific prescribers of radiographic imaging. Radiography forms part of most clinical examinations, and many patients will be continually monitored throughout their association with any one dentist. Used to detect a range of diseases and employed

Table 3 **Sensitivity and specificity data for caries detection in a comparison of radiography and visual assessment[a]**

Method, surface and extent	No. of studies	No. of observers		Lesion prevalence (%)		Sensitivity		Specificity	
		Mean	Median	Mean	Median	Mean	Median	Mean	Median
Visual									
Occlusal surfaces									
Cavitated	4	1	1	56	51	63	51	89	89
Dentinal	10	9	4	50	44	37	25	87	91
Enamel	2	2	2	21	21	66	66	69	69
Any	4	12	7	78	75	59	62	72	74
Proximal surfaces									
Cavitated	1	1	-	nr	-	94	-	92	-
Radiographic									
Occlusal surfaces									
Dentinal	26	4	3	54	55	53	54	83	85
Enamel	4	2	2	18	18	30	28	76	76
Any	7	5	4	82	84	39	27	91	95
Proximal surfaces									
Cavitated	7	3	3	13	9	66	66	95	97
Dentinal	8	39	5	27	27	38	40	95	96
Enamel	2	10	10	25	25	41	41	78	78
Any	11	6	3	62	66	50	49	87	88

[a]Modified from Bader[6]
nr = not reported

Table 4 **Receiver operating characteristic analysis (area under the curve [AUC]) for a variety of radiographic systems in the assessment of dental caries[a]**

System	Manufacturer	Occlusal AUC	Interproximal AUC
MPDx	Dental/Medical Diagnostic Systems Inc., Woodland Hills, Calif.	0.83	0.74
Dixi	Planmeca, Helsinki, Finland	0.81	0.82
Sidexis	Sirona, Bensheim, Germany	0.80	0.80
RVG(Old)	Trophy, Paris, France	0.89	0.77
RVG(New)	Trophy, Paris, France	0.90	0.77
Visualix	Gendex, Milan, Italy	0.78	0.76
Ektaspeed Plus[b]	Eastman Kodak, Rochester, N.Y.	0.82	0.87
Insight[b]	Eastman Kodak, Rochester, N.Y.	0.81	0.83

[a]Adapted from Hintze[7]
[b]Film system

before, during and after various restorative, surgical, endodontic and orthodontic procedures, radiography is a well-accepted and fundamental part of diagnostic and management procedures. However, questions about this technology are appropriate. How effectively does radiography meet the goals it was originally intended to fulfill? Are digital radiographs better than conventional films? The operating characteristics of various radiographic methods can be used to answer such questions.

Radiography in the Assessment of Dental Caries

Detection and diagnosis of the carious process are perhaps the most common reasons for dental radiography. However, with changes in the caries profiles within certain segments of the younger age groups[4] and increases in the number of older dentate adults,[5] radiographs are now being obtained for many different reasons for patients in all age groups and at all levels of risk. Bader and others[6] have produced an excellent review of all current systems for detecting dental caries, including radiography. **Table 3** shows the data from the studies summarized by Bader and co-workers[6] for a comparison of radiography and visual assessment. This work is discussed in more detail in article 5 of this series.

Occlusal and Interproximal Caries

Numerous studies have assessed the ability to diagnose occlusal caries from radiographs, both conventional and digital. In a recent study employing a receiver operating characteristics (ROC) analysis, occlusal and approximal surfaces were radiographed with 6 charged coupled device (CCD) sensor systems and 2 film-based systems.[7] Four

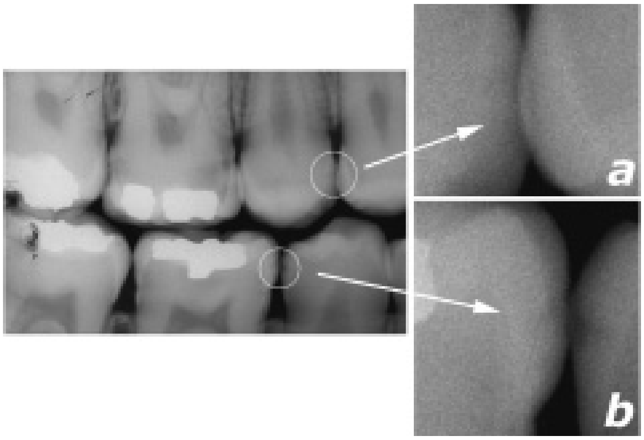

Figure 1: A bitewing radiograph. How sure can a clinician be of a diagnosis of (a) a sound interproximal surface between the premolars and (b) caries interproximally between the second premolar and the first molar? Does this radiographic view alone justify a clinical decision to restore these teeth? Research suggests that the clinician can be very certain of the lack of disease in (a) (specificity of this diagnostic procedure is 97%) but much less certain of the presence of disease in (b) (sensitivity of this procedure is only 54%).

Figure 2: Secondary decay. On clinical examination, the amalgam restoration in this first molar appeared to be failing on the mesial surface. It has been suggested that only 53% of failing restorations will be detected by radiographic examination.

trained observers interpreted the radiographs, and the caries were validated histologically. The systems yielded AUC measurements ranging from 0.74 to 0.90, with the film-based systems scoring generally higher (**Table 4**). Of interest is that using 4 rather than 2 films in bitewing examinations (overlapping films) appeared to add little to the diagnostic value of the exam.[8] In another study, the ability of 276 dental practitioners to detect interproximal demineralization using bitewing radiographs was contrasted with microradiographic assessment (the gold standard).[9] Sensitivity (± standard deviation) was moderate (54% ± 14) and specificity was high (97% ± 5) (AUC of 0.88). Apparently, differences in incidence of caries in different age groups affected radiographic prescribing and the value of ordering such tests: bitewings prescribed for children under 12 years of age added little information to the decision-making process, but for children older than 12 this type of imaging was of value in detecting interproximal lesions.[10] **Figure 1** exemplifies a situation in which an individual clinician may be very certain of the lack of disease in apparently sound interproximal surfaces (97% specificity), but not as certain that disease is indeed present in suspect interproximal surfaces (54% sensitivity).

Secondary Caries

The foremost reason for replacement of restorations is the presence of secondary or recurrent decay. In a study appraising the performance of conventional radiography in detecting recurrent decay, 91% of the noncarious restored teeth were detected, but only 53% of the failed restorations were found.[11] An ROC value of 0.78 was calculated, and the authors suggested that careful clinical assessment of existing restorations was required before a definitive diagnosis of recurrent decay could be made (**Fig. 2**).

The ability to detect recurrent decay from radiographs was examined with Class II amalgam restorations in an in vitro design.[12] Seventy-seven teeth were grouped according to the state of the filling: fillings without failure (controls), fillings with secondary caries and fillings with only marginal defects. The teeth were examined radiographically and clinically. A false-positive rate of 12% and a true-positive rate of 47% were obtained for radiographic examination only. When a clinical examination was added to the diagnostic procedures, the false-positive rate was 3% and the true-positive rate 64%. The authors concluded that for secondary caries, radiographic diagnosis alone was insufficient to attain an acceptable degree of certainty and should always be supplemented by a thorough clinical examination.[12] In a separate study, dentists were asked to examine 77 teeth radiographically, visually and with the aid of a probe and indicate if they would replace the restoration in each tooth.[13] Only 5% of the teeth with no secondary decay were considered as requiring restoration replacement, but 36% of the teeth with small secondary lesions were indicated for replacement. In that study,[13] as in several others involving simulated clinical situations,[14–18] there was a great deal of variation between and within the observers.

Caries in Primary Teeth

One study investigated the ability to detect decay in primary teeth using a variety of imaging methods;[19] the results from intraoral and extraoral film systems are described here. Sixty-four extracted primary teeth with a total of 85 carious lesions were examined; 8 trained observers used a 5-point scale to indicate whether they

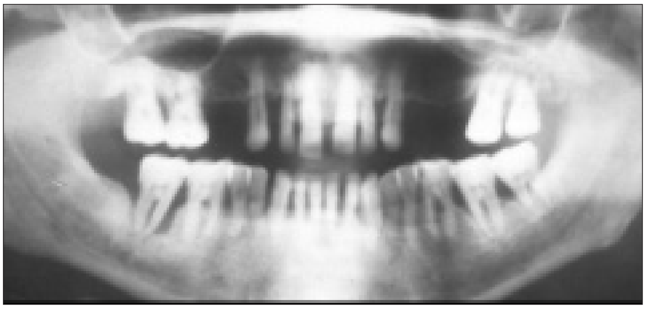

Figure 3a: *Periodontal disease. The diagnosis of periodontal disease from this panoramic radiograph is clear, but how useful are panoramic views in monitoring disease progression over time? Does the reduced radiographic exposure offered by such views affect their diagnostic effectiveness, relative to periapical views (**Figs. 3b** and **3c**)? Diagnostic assessment of such radiographs suggests that agreement between periapical and panoramic views may be as low as 55%.*[26]

Figures 3b and 3c: *Periapical radiograph demonstrating periodontal disease.*

thought caries was present. Using ground sections as the gold standard, the authors employed ROC analysis to determine accuracy of diagnosis. The AUC scores were 0.70 for intraoral film and 0.64 for panoramic views. The authors suggested that intraoral films were better than panoramic images for detecting interproximal lesions, although the difference was less pronounced when occlusal lesions were assessed.[19]

A study investigating the DIAGNODent device (KaVo, Lake Zurich, Ill.) reported kappa values for radiographic detection of decay in primary teeth; intra-observer agreement was 0.58 and inter-observer agreement was 0.56.[20] According to the Landis and Koch[21] scoring system for kappa values, these can be considered to represent moderate agreement; in overall terms, however, they cannot be considered substantially better than the values attained with conventional radiographic imaging (see **Table 2**).

Root Caries

Because adults now retain more teeth as they grow older, the prevalence of root caries has increased.[22] Unfortunately, few tests have proven of value in detecting such lesions. Lesion colour has been used, but it has little validity.[23] Softness of the lesion, as determined by use of an explorer, has been validated with microbiological tests and has shown promise.[23] However, further research is required to develop tests for what will be an area of increasing diagnostic need.

Radiography in the Assessment of Periodontal Disease

Dental radiography is an important procedure for diagnosing and monitoring periodontal disease through appraisal of alveolar bone levels. Both panoramic and periapical radiographs are employed, and a wealth of research has been done in this area. The introduction of subtraction imaging techniques has been especially important in monitoring periodontal disease, and this important innovation is described in greater detail in the next article in this series (part 4).

Correlating panoramic, bitewing and periapical radiographs with probing depths, researchers have found substantial inter-observer variation.[24] Probing depth was the most accurate method (within 5% of the true value), whereas periapical radiography was more accurate than panoramic or bitewing radiography. Panoramic radiography had a lower mean accuracy than bitewing radiography. The underestimation of bone loss ranged from 13% to 32% in panoramic radiographs, 11% to 23% in bitewing radiographs and 9% to 20% in periapical radiographs. A separate study found that periapical radiographs were superior to panoramic views for measuring bone loss in the mandible, although both performed equally well in imaging the maxilla.[25] Molander[26] found inter-observer agreement of 58% for intraoral radiographs and 60% for panoramic systems. On average, agreement between the systems was obtained for 55% of the sites. The conclusion offered was that panoramic views provide an acceptable amount of information for diagnostic purposes but should be supplemented with intraoral views when assessment of disease progression over time is the main purpose of radiographic monitoring at specified periodontal sites. **Figures 3a, 3b** and **3c** depict some sites with obvious periodontal involvement; periapical radiographs supplementing such views may be called for, given that agreement between periapical and panoramic radiographs may not be high. Image enhancement per se may be insufficient to improve the value of the diagnostic procedures. One study[27] compared 3 imaging modalities to assess vertical bony defects — plain bitewing, enhanced bitewing and digital bitewing radiography. A total of 75 dentitions were examined, and the results of2 observers were analyzed with ROC analysis. All 3

Figure 4: *The detection of periapical abnormalities in radiographs is generally accurate. However, 55% of radiographic films with no lesions present were judged by dentists to show evidence of pathosis.[28] In addition, the measurement of periapical lesions is highly variable.[29]*

methods produced ROC AUC values lower than 0.80, and the authors concluded that neither of the enhancement approaches improved detection of the targeted periodontal condition.

Radiography in Endodontic Procedures

Detection of Periapical Lesions

The search for periapical pathosis is typically undertaken by means of periapical radiography for patients with a history of irreversible pulpitis. An important aspect of this application is the effectiveness of radiography in detecting periapical pathosis and measuring lesion size. A change in lesion size remains one of the most important parameters for determining lesion activity and therefore guiding management decisions. The resolution of periapical pathosis may be difficult to confirm if there is substantial variation across observers (**Fig.** 4). Generally speaking, agreement regarding the presence or absence of periapical lesions is greater than agreement on lesion size. In a study of 105 teeth, agreement among 3 observers for the presence and size of periapical radiolucencies was assessed.[29] Agreement regarding the presence or absence of a lesion was high; however, intra-observer and inter-observer agreement levels for lesion size were less consistent, with kappa values ranging from 0.38 to 0.71 for intra-observer comparisons and from 0.25 to 0.48 for inter-observer comparisons.[29] A larger study was undertaken with 80 diseased teeth and 60 normal (control) teeth, each rated by 6 observers.[30] The observers were asked first to determine if periapical abnormality was present and then to provide an indication of their confidence in the decision rendered. The simple measure of accuracy (as a percentage) was 70.2%; specificity (0.78) was higher than sensitivity (0.65). Intra-observer reliability (0.65) was higher than inter-observer reliability (0.54), although both measures of reliability could be considered only marginal.[30]

The identification and assessment of lesion size appears to be influenced by the technology employed. A comparison between digital and conventional radiography (Ektaspeed film [Eastman Kodak, Rochester, N.Y.] and CCD imaging) involved 14 observers measuring 28 lesions. Conventional imaging was consistently the less effective method,[31] although its performance was acceptable for clinical applications. For example, when tomographic imaging (Scanora system, Soredex, Milwaukee, Wis.) was contrasted with conventional periapical radiography, the sensitivity of the latter was 70% and the specificity 77%.[32] Other studies have obtained different values for specificity and sensitivity. In a study targeting the identification of bony lesions, 98 general practitioners examined 32 radiographs to diagnose such lesions.[28] The clinicians correctly identified 81% of all lesions present; they also indicated that 55% of the radiographs had lesions, whereas no lesions were found when the clinicians examined the teeth using the gold standard (i.e., periapical radiographs). These lesions were therefore false-positives. Although no lesions were missed, the false-positive rate was high.

Canal Length and File Length

The use of radiography for most endodontic techniques is well described; however, many assumptions about the accuracy and reproducibility of these procedures remain untested. One group studied the accuracy of root canal measurements obtained with files in cadaver specimens.[33] They asked 9 observers to judge file sizes (10 and 15) in molars and premolars. Inter-observer agreement on the adjustment in file length needed was 68% when adjustments of up to 0.5 mm were needed, 18% when adjustments from 0.5 to 1.0 mm were needed and 14% when adjustments greater than 1.0 mm were needed. Apparently, no correction for chance agreement was undertaken.

Conclusions

This article has examined diagnostic dental radiography in terms of its operating characteristics and has identified the situations in which this procedure is an appropriate diagnostic test, as well as the situations where the diagnostic yield may not justify the use of ionizing radiation. Careful thought should be given to the diagnostic outcome of dental radiographs before prescribing them. The next paper of the series looks at nonradiographic procedures such as standard clinical and visual examinations, root canal treatment, vitality testers and colour shade guides. ✦

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