Detection accuracy of approximal caries by black-and-white and color-coded digital radiographs

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Objective. The objective of this study was to compare detection of approximal caries in vitro by black-and-white and color-coded digital radiographs.
Study design. The material comprised 2 groups of tooth sample. One group consisted of 40 premolars mounted in groups of 3 or 4 and the other group included 90 premolars mounted in groups of 5. Radiographs, respectively exposed with the Dixi and the Digora Optime digital radiographic systems, were color-coded using specially designed software. Seven observers in each of 2 centers subjectively evaluated one series of black-and-white and color-coded radiographs. The teeth were subsequently sectioned for histological determination of the lesions. ROC analyses were performed. Differences between the area under the ROC curves for the digital black-and-white and the color-coded radiographs were analyzed by ANOVA.
Results. There were no significant differences between the black-and-white and the color-coded radiographs in detection of approximal caries.
Conclusion. Color-coded digital radiographs may be used as an alternative to digital black-and-white radiographs.
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Despite the overall decrease in caries prevalence during the past 2 decades[1,2] caries diagnosis remains a major challenge in clinical dentistry. It is generally accepted that fluoride, now widely available in dentifrices and in reticulated water, retards caries progression, and this in turn has led to other changes in the disease pattern. The slower rate of disease progression allows time for remineralization of incipient lesions, and frank cavitation, visible on direct inspection, is no longer a frequent clinical finding. So-called hidden caries, approximal as well as occlusal, may progress beneath a sound enamel surface.[3-5] The methods traditionally taught in dental schools for detection of caries are now of limited application. Current research in this field is directed toward modification of traditional methods, or the development of new methods of caries detection, which reflect more closely the changed pattern of the disease.

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Traditionally, approximal caries has been detected by a combination of bitewing radiographs and visual inspection. Recent rapid progress in the field of digital radiography offers the potential of enhancing visual assessment of radiographs by means of digital image processing. One possible means of enhancing radiographic information is pseudocoloring of dental radiographs. Although a pseudocoloring algorithm according to the rainbow model was proposed by Clarke and Leonard[6] and later on was modified by Lehmann et al.,[7] the algorithm does not correspond to the perception of the gray scale where brightness increased continuously from gray to white.

Recently, Shi et al.[8] suggested a new color scale to replace the conventional black-and-white scale from inherent dark to bright colors by employing dark blue, magenta, red, orange, yellow, and white. Preliminary results, in terms of the perceptibility curve test, indicate that perception is at least as good in color-coded as in black-and-white radiographs.[9]

The present in vitro study, of approximal caries, compared the accuracy of caries detection by black-and-white and color-coded digital radiographs.

MATERIAL AND METHODS

Teeth

The material consisted of 2 groups of tooth samples. One group comprised 40 premolar teeth extracted on orthodontic indications from young adolescents. On visual inspection of the 80 approximal surfaces, 11 were denoted as sound, 5 had cavities, and the remain-

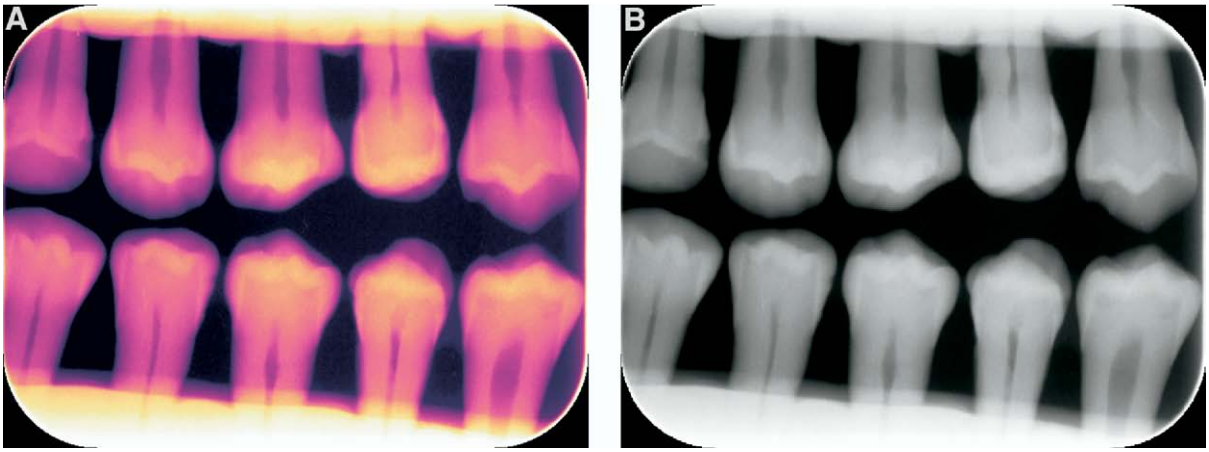

Fig. 1. An example of a color-coded (A) and a black-and-white (B) radiograph employed for viewing.

ing 64 had caries in the form of discolored enamel, but no cavitations. The teeth were mounted in groups of 3 or 4 in plaster blocks, with the most prominent part of the approximal surfaces at the same vertical level, simulating the anatomical position. The 13 tooth blocks were numbered and stored separately in 10% neutral buffered formalin solution.

The other group, which comprised 90 premolars, was arranged in the same way but with the teeth mounted in plaster blocks in groups of 5. Thus, a total of 18 plaster blocks of teeth were constructed.[10]

Test radiographs

Black-and-white radiographs. Radiographs of the 13-block sample group were exposed with the Dixi digital intraoral radiographic system (Planmeca Oy, Helsinki, Finland) using a Prostyle Intra dental unit (Planmeca, Helsinki, Finland) with an exposure time of 0.20 seconds. The nominal tube potential was 63.0 kVp and tube current 8.0 mA. When the radiographs were taken, a 15.0-mm thick soft tissue equivalent plastic compound was placed in front of the blocks. The Dixi digital system has a CCD (charge-coupled device) sensor with a pixel size of 38 $\times$ 38 μm.

Radiographs of the 18-block sample group were exposed with the digital intraoral radiographic system Digora Optime (Soredex, Helsinki, Finland) using a Heliodent MD (Siemens GmbH, Bensheim, Germany) DC x-ray unit. The exposure settings were 60.0 kVcp, 7.0 mA, and 1.0 second. To mimic a bitewing radiograph, 2 tooth blocks in occlusion were exposed along with a 2.0-cm thick water phantom to simulate soft tissue. Since the Digora Optime employs a storage phosphor plate (SPP) to record an image, the SPPs were further scanned with the Digora Optime scanner employing the proprietary software DfW V.2.5 at the high-resolution setting (7.8 lp/mm) immediately after exposure.

To ensure reproducible radiographs, both groups of plaster blocks were placed in a specially designed holder mounted on the x-ray tube, allowing standardized projection geometry during exposure.[10]

Color-coded radiographs. The black-and-white radiographs were transformed by specially designed software into color-coded radiographs with the color scale that preserves the light intensity of original black-and-white radiographs taking into account the response of the human visual system.[8]

Viewing. Viewing was performed at the Department of Oral Radiology, Institute of Odontology, Karolinska Institutet, Stockholm, Sweden, and the Department of Oral and Maxillofacial Radiology, Peking University School of Stomatology, Beijing, China, respectively. In Karolinska Institutet, each of the 7 participating dentists received a brief introduction to the color-coded radiographs before the viewing. The observers then viewed the radiographs independently: first the 13 black-and-white radiographs and then the 13 color-coded radiographs. A specially designed computer program was used for viewing, displaying each set of radiographs in random order. Viewing results were entered via the keyboard and data automatically stored for subsequent evaluation. The radiographs were displayed on a PC monitor using SVGA graphics. Contrast and brightness controls were preset to be consistent for all observers.

Similar viewing procedure was performed by 7 observers in Peking University School of Stomatology, except that the observers were not given a brief introduction to the color-coded radiographs and only the right proximal surface of each tooth coronal to the

cemento-enamel-junction (CEJ) was included, which gave a total of 72 observed surfaces.

Examples of a color-coded and a black-and-white radiograph are shown in Fig. 1. For all observers in both Karolinska Institutet and Peking University School of Stomatology, viewing took place under standardized conditions: subdued lighting and a viewing distance of about 50.0 cm. The observers had no prior information about the number of carious lesions.

Using the following scale, the observers were instructed to rate their level of confidence about the presence or absence of carious lesions on the approximal surfaces of the teeth: 1 = definitely no caries; 2 = probably no caries; 3 = questionable; 4 = probably caries; 5 = definitely caries.

Histological analysis

To isolate each approximal site on a separate specimen, each tooth was embedded in methylmethacrylate and hemi-sectioned with a diamond saw, perpendicular to the occlusal and buccal surfaces. Each half of the tooth crown was then reembedded in methylmethacrylate and 300-mm thick slices were sawn perpendicular to the enamel surface. The tooth slices were examined under a microscope at ×16 magnification. The lesions were defined by the extension of a whitish decalcified zone or a brown zone in a pulpal direction.

The following 5-point scale was used for histopathological stratification of the sites: 0 = sound; 1 = enamel caries limited to the outer half of the enamel; 2 = caries limited to the inner half of the enamel but not extending to the enamel- dentinal junction (EDJ); 3 = caries penetrating the EDJ and limited to the outer half of the dentine; 4 = caries extending to the inner half of the dentine.

A similar procedure was applied to the tooth samples for the SPP radiographs.[10]

ROC analysis

Using the histopathological examination as the gold standard, the radiograph readings were analyzed by receiver operating characteristic curves (ROC) with the program ROCKIT 0.9B, Beta version (University of Chicago, Chicago, IL) for all carious lesions and for the subtypes, enamel and dentine caries, respectively. For each observer, the areas under the ROC curves (A_z) were calculated for the black-and-white and the color-coded radiographs.

Statistical analysis

Radiographic detection of approximal caries was expressed as the values of A_z for both the black-and-white and the color-coded radiographs. One-way analysis of variance (ANOVA) was employed to analyze the differences. A statistically significant difference was considered present when $P < .05$.

Table I. Histopathological validation: number of enamel and dentinal caries lesions and caries prevalence.

	Tooth sample for Dixi		*Tooth sample for Digora*	
	No. of tooth surfaces	*%*	*No. of tooth surfaces*	*%*
Sound	12	16.2	12	16.7
Enamel caries	43	58.1	24	33.3
Dentine caries	19	25.7	36	50.0
Total	74	100	72	100

RESULTS

Histological examination

Table I illustrates the true status of the tooth approximal surfaces. Six specimens were lost during the preparation of tooth slices.

Black-and-white and color-coded radiographs

Table II demonstrates the A_z values for different types of lesions from both groups of radiographs. *P* values are listed in the right column. Analysis disclosed no statistically significant differences between the color-coded and the conventional black-and-white radiographs for any types of caries and any type of radiographs.

DISCUSSION

In theory, the human visual system is more sensitive to differences in color than to differences in gray levels.[11] This is because the number of perceptible colors varying in hue, saturation, and brightness far exceeds the number of perceptible shades of gray, which in fact is no more than 100 for an observer with normal vision.[8] This implies that diagnostic information should be more perceptible in a color-coded than in a black-and-white radiograph, and that a color-coding method used to replace the gray scale should be favorable.

The present study, however, indicates that no statistically significant difference between color-coded and black-and-white radiographs with respect to detection of approximal caries. This agrees with the previous in vivo study that significant difference was not found when measuring marginal bone levels of patients with chronic periodontitis between black-and-white and color-coded radiographs.[12]

Although 1 CCD-based digital sensor system and 1 SPP digital imaging system were employed to record test radiographs in the present study, there were no

Table II. No significant difference was found between black-and-white and color-coded radiographs for any types of lesion regarding the areas under the ROC curves.

		Observers								
	All caries	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*Mean*	*P*
Dixi	Black-and-white	0.53	0.66	0.52	0.68	0.63	0.56	0.66	0.61	.58
	Color-coded	0.67	0.57	0.59	0.6	0.78	0.63	0.58	0.63	
Digora	Black-and-white	0.67	0.73	0.65	0.62	0.58	0.75	0.66	0.67	.56
	Color-coded	0.55	0.73	0.69	0.78	0.71	0.7	0.68	0.69	
	Dentine caries									
Dixi	Black-and-white	0.9	0.79	0.78	0.83	0.9	0.7	0.84	0.82	.23
	Color-coded	0.88	0.7	0.7	0.83	0.94	0.7	0.82	0.80	
Digora	Black-and-white	0.79	0.89	0.84	0.81	0.8	0.89	0.79	0.83	.78
	Color-coded	0.59	0.86	0.85	0.91	0.87	0.85	0.77	0.82	
	Enamel caries									
Dixi	Black-and-white	0.46	0.6	0.43	0.68	0.57	0.51	0.59	0.55	.44
	Color-coded	0.65	0.5	0.54	0.61	0.74	0.6	0.48	0.59	
Digora	Black-and-white	0.48	0.5	0.48	0.31	0.26	0.54	0.46	0.43	.27
	Color-coded	0.51	0.53	0.48	0.58	0.41	0.45	0.54	0.50	

statistical differences between the black-and-white and color-coded radiographs. This may indicate that the color-coding algorithm presented in the study did not have any interaction with digital imaging systems.

In the present study, one group of observers was given a brief introduction for the color coded radiographs while the other group was not. The results, however, showed no differences. This may designate that one observer who is familiar with color-coded radiographs or not does not have any effect on detection accuracy of approximal caries. Since the results in both groups were so similar, only 1 series of radiographs were viewed in 1 place.

Although the prevalence of enamel caries and dentine caries in both sample groups was not the same, even doubled for dentine caries, the detection accuracy as defined by $A_z$values of all caries, enamel caries, and dentine caries was not very different, especially for dentine caries: 0.82 and 0.80 for the Dixi system and 0.82 and 0.83 for the Digora system, respectively. This may lead to an assumption that detection accuracy of dentine caries was independent of observer employed, digital system used, and tooth sample collected.

In conclusion, the presented color-coding algorithm does not improve detection accuracy of approximal caries for any type of lesions in images recorded with any type of digital intraoral radiographic systems. Considering that the presented color-coding algorithm did not end in loss of image diagnostic information and that viewers felt more comfortable when viewing color-coded radiographs, the presently employed color-coding algorithm may be used as an alternative to the conventional gray scale in digital radiographs.

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